CAMBRIAN STRATIGRAPHY AND PALEONTOLOGY OF NORTHERN ARIZONA AND SOUTHERN NEVADA

THE 16TH FIELD CONFERENCE OF THE CAMBRIAN STAGE SUBDIVISION WORKING GROUP INTERNATIONAL SUBCOMMISSION ON CAMBRIAN STRATIGRAPHY FLAGSTAFF, ARIZONA, AND SOUTHERN NEVADA, UNITED STATES

ISCS Field Conference
Southwest U.S., 2011

Edited by
J. Stewart Hollingsworth
Frederick A. Sundberg
John R. Foster

Museum of Northern Arizona Bulletin 67
Flagstaff, Arizona 2011

Museum of Northern Arizona

CAMBRIAN STRATIGRAPHY AND PALEONTOLOGY

OF NORTHERN ARIZONA AND SOUTHERN NEVADA

THE 16TH FIELD CONFERENCE OF

THE CAMBRIAN STAGE SUBDIVISION WORKING GROUP

INTERNATIONAL SUBCOMMISSION ON CAMBRIAN STRATIGRAPHY

FLAGSTAFF, ARIZONA, AND SOUTHERN NEVADA, UNITED STATES

Edited by

J. Stewart Hollingsworth

Frederick A. Sundberg

John R. Foster

Museum of Northern Arizona Bulletin
No. 67
Flagstaff, Arizona 2011

Museum of Northern Arizona

Citation Information

This volume, and articles in it, should be cited as:

Hollingsworth, J. S., Sundberg, F. A., and Foster, J. R., (editors), 2011, Cambrian Stratigraphy and Paleontology of Northern Arizona and Southern Nevada: Museum of Northern Arizona Bulletin 67, 321 p.

the next depositional sequence would be of Delamaran age (DMS 1 as defined by McCollum and McCollum, this volume, Article 8). However, exposure is very poor above the top of the measured section, and there is little biostratigraphic constraint on the position of the Dyeran-Delamaran boundary at Frenchman Mountain. Indeed, only two biostratigraphically informative fossil collections have been documented from strata higher than the sandstone at the top of the measured section: Pack and Gayle (1971, p. 894) refer to an "*Albertella* faunule" recovered from within their Unit 24, the base of which is approximately 43.9 m above the top of their Unit 16; and a specimen of *Albertella schenki* Resser in McKee and Resser, 1945 was recovered from approximately 63.4 m above the section-topping sandstone in a (now inaccessible) section just south of that studied herein (L. B. McCollum, personal communication, 1998). This latter species is indicative of the *Albertella highlandensis* Subzone of the *Mexicella mexicana* Zone (Eddy and McCollum, 1998; McCollum and Sundberg, 2007). The intervening poorly sampled and/or barren interval thus comprises strata equivalent to the lower Delamaran *Eokochaspis nodosa*, *Amecephalus arrojosensis*, *Poliella denticulata*, and lower *Mexicella mexicana* Zones (McCollum and Sundberg, 2007).

ACKNOWLEDGMENTS

L. B. and M. B. McCollum introduced the author to the Frenchman Mountain section and donated their collections from Frenchman Mountain to UCR. F. A. Sundberg generously transferred material originally collected by Pack and Gayle to UCR. G. Dechman and C. Stephenson braved the June heat to assist in making the new collections. A. Tomasovych found the stratigraphically highest olenelloid fossil. Comments by F. A. Sundberg and formal reviews by S. M. Rowland and R. R. Gaines helped improve this manuscript.

STOPS 5A, 5B, AND 6A

LITHO- AND BIOSTRATIGRAPHY OF THE DYERAN-DELAMARAN BOUNDARY INTERVAL IN THE PIOCHE-CALIENTE REGION, NEVADA

MARK WEBSTER

Department of the Geophysical Sciences, University of Chicago, 5374 South Ellis Avenue, Chicago, Illinois 60637 <mwebster@geosci.uchicago.edu>

INTRODUCTION

ON DAYS 5 and 6 of the field conference we will examine exposures of upper Dyeran through Delamaran Stage strata of the Pioche Formation in the mountain ranges adjacent to the towns of Pioche and Caliente in Lincoln County, east-central Nevada (Fig. 1). The Pioche Formation in this (its type) region was deposited on the inner shelf (Webster, Article 7, this volume), and differs markedly from the essentially cratonic strata mapped as the Pioche Formation at Frenchman Mountain (Webster, this volume, Stop 4B). Most strikingly, the upper Dyeran part of the Pioche Formation in Lincoln County is a mixed succession of siliciclastics and carbonates; limestones are absent from the Dyeran of the cratonic sections of Nevada and Arizona.

Economic mining of the Pioche Formation has been in decline for almost 140 years (Merriam, 1964), but paleontological exploitation of the unit is currently at its peak. Recent fieldwork has unveiled a wealth of Dyeran and Delamaran trilobites (Sundberg and McCollum, 1997, 2000, 2002, 2003a; Eddy and McCollum, 1998; Palmer, 1998a; Webster, 2007a, 2007b, 2009a, 2009b, 2011; Webster et al., 2008; Hopkins and Webster, 2008, 2009) and other invertebrates (Lieberman, 2003). The abundance and high preservational quality of trilobites from many intervals within the Pioche Formation has provided insight into issues of phylogeny (Sundberg and McCollum, 1997, 2000; Webster et al., 2001; Sundberg, 2004; Paterson and Edgecombe, 2006; Webster, 2007a, 2009a, 2011), paleobiology (Palmer, 1998a; Webster et al., 2001; Webster and Zelditch, 2005, 2011, in press; Webster, 2007a, 2011), and taphonomy (Webster and Hughes, 1999; Webster et al., 2008), and has contributed towards an improved resolution of Dyeran and Delamaran biostratigraphy (Eddy and McCollum, 1998; Sundberg and McCollum, 2000; Webster, Article 7, this volume) and intercontinental correlation (McCollum and Sundberg, 2007; Webster, 2009b). The Pioche Formation of this region is also at the center of a debate regarding the conformity (or lack thereof) of the Dyeran-Delamaran boundary that has important implications for our understanding of the tempo and mode of the extinction of olenelloid trilobites (McCollum, 1994; McCollum and McCollum, 1994; Palmer, 1998a; Montañez et al., 2002; McCollum et al., this volume, Stops 5A-D, 6A; Webster, Article 7, this volume).

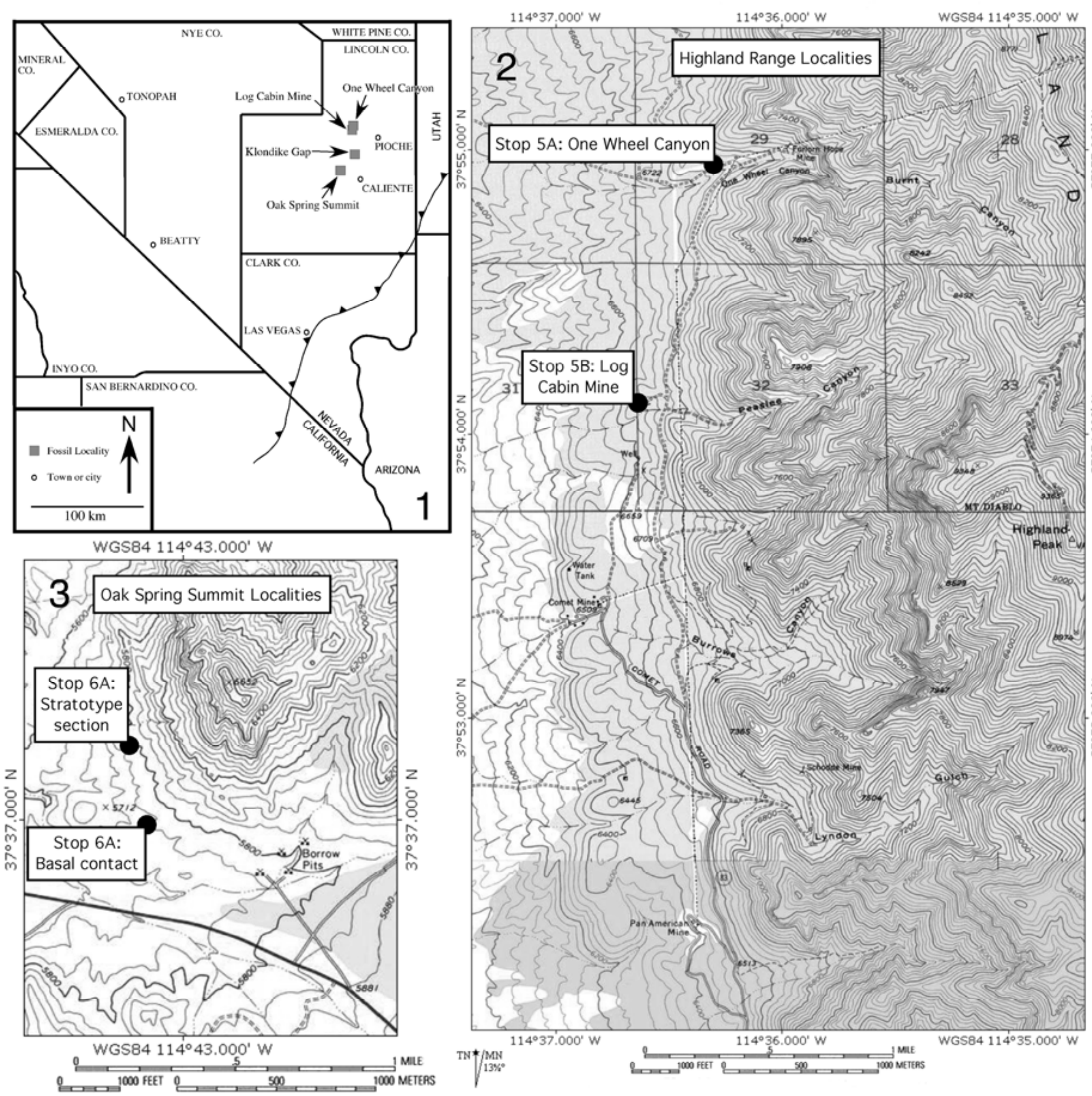

FIGURE *1*.—*1*, Map of the southern Great Basin showing location of upper Dyeran sections mentioned in this paper. *2*, Map of the western Highland Range, showing the location of the One Wheel Canyon and at Log Cabin Mine sections. *3*, Map of the Oak Spring Summit localities, northern Delamar Mountains, showing the location of the two sites described herein. The road to the south is Highway 93. Maps in 2 and 3 created with TOPO! software (© National Geographic, 2002).

We will examine the Pioche Formation at several localities in the Highland Range (Stops 5A-D) and the Delamar Mountains (Stop 6A). The present paper includes an introduction to the upper Dyeran part of the Pioche Formation, and provides details of the sections at the One Wheel Canyon and Log Cabin Mine localities in the Highland Range (Stops 5A and 5B, respectively; Fig. 1.2) and at the Oak Spring Summit locality in the Delamar Mountains (Stop 6A; Fig. 1.3). The important debate surrounding the nature of the Dyeran-Delamaran boundary in this region is only briefly mentioned herein; for more comprehensive discussions see Webster (Article 7, this volume) and McCollum et al. (Stops 5A-D, 6A, this volume).

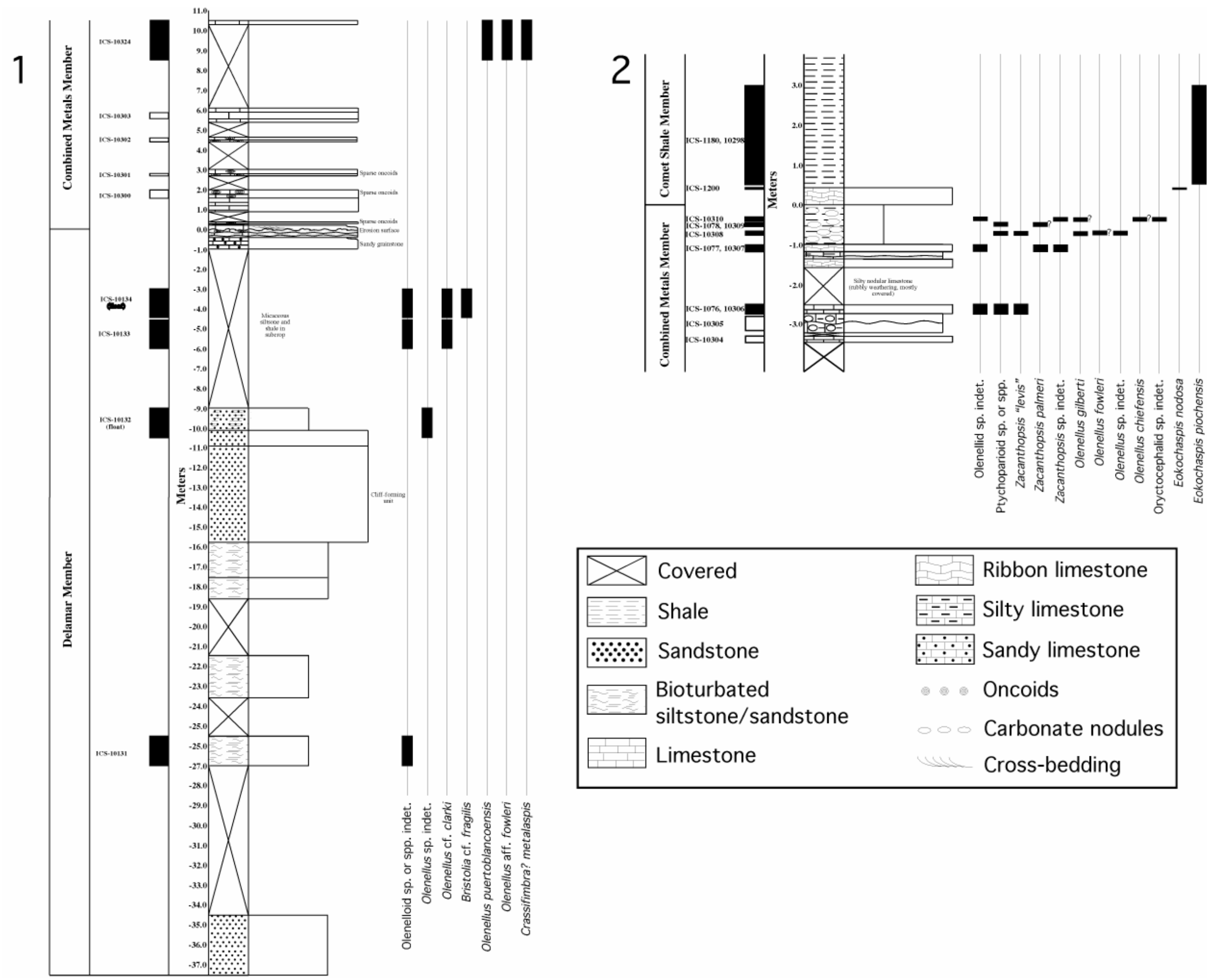

FIGURE *2*.—Biostratigraphic range charts for the measured section at One Wheel Canyon (Stop 5A, Highland Range). *1*, Main measured section. *2*, Boundary exposure. Black bars to the left of the meter scale indicate provenance of stratigraphically constrained trilobite-bearing collections housed in the Institute for Cambrian Studies, University of Chicago (ICS); empty bars indicate levels of failed searches for trilobites (although many of these collections contain other fossils). A question mark next to a black bar indicates a tentative identification due to poor or incomplete preservation.

REGIONAL SETTING AND GENERAL STRATIGRAPHY

The Pioche Formation in its type area was deposited on the western Laurentian shelf during the late Dyeran and early Delamaran, inboard of the coevally deposited Carrara Formation to the west (Webster, Article 7, this volume). The Dyeran part of the Pioche Formation in the Pioche-Caliente region contains intervals dominated by carbonate deposition. Such limestones are absent from coeval strata mapped as the Pioche Formation in the cratonic section at Frenchman Mountain (Webster, Stop 4B, this volume), which may have accumulated closer to the continental source of clastic input or were deposited in a fundamentally different environmental regime (Rose, 2006; Rose, Article 5, this volume).

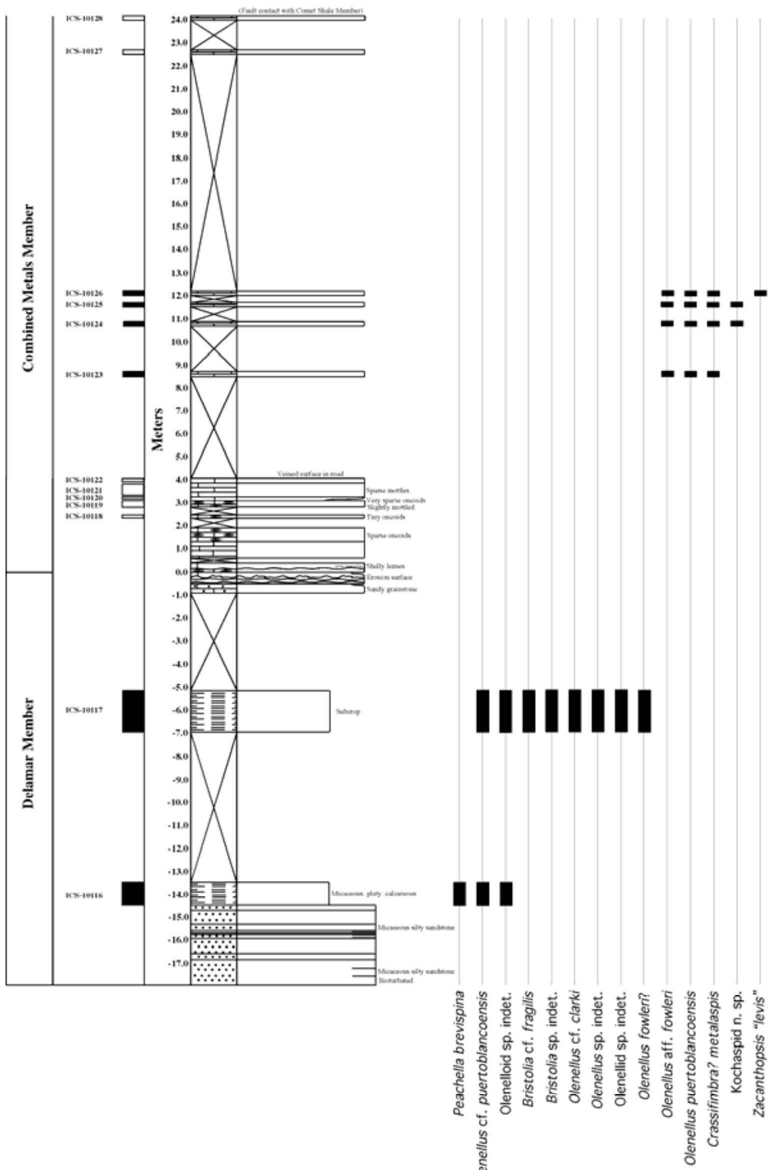

FIGURE 3.—Biostratigraphic range chart for the measured section at Log Cabin Mine (Stop 5B, Highland Range). See Figure 2 for explanation

In the Pioche-Caliente region, the Pioche Formation conformably overlies the Zabriskie Quartzite (formerly mapped here as the Prospect Mountain Quartzite, but see Stewart [1974]) and is in turn overlain by the cliff-forming Lyndon Limestone, the recessive Chisholm Shale, and the massive carbonates of the Highland Peak Formation (Webster, Article 7, this volume, fig. 3). Six members were formally recognized within the Pioche Formation by Eddy and McCollum (1998) and Sundberg and McCollum (2000), replacing the informal mining subdivisions of the unit in previous usage (Merriam, 1964; Palmer, 1998a). This paper focuses on the lower members of the Pioche Formation (the Delamar, Combined

Metals, and basal Comet Shale members) that record the complex environmental changes and evolutionary events around the Dyeran-Delamaran boundary. Litho- and biostratigraphic details of the higher Delamaran units in the Pioche Formation (Comet Shale, Susan Duster Limestone, Log Cabin, and Grassy Spring members) can be found elsewhere (McCollum et al., Stops 5A-D, 6A, this volume; see also Eddy and McCollum, 1998; Sundberg and McCollum, 1997, 2000, 2002, 2003a).

A composite measured section and biostratigraphic range chart through the entire Delamar Member has been constructed at Klondike Gap in the Chief Range (Fig. 1.1; Webster, Article 7, this volume, fig. 4.2; Webster, 2007b). Sections through the upper part of this member have been measured at several other localities in the Delamar Mountains, Chief Range, Burnt Springs Range, and Highland Range (below; Webster, Article 7, this volume; also unpublished data held at the Institute for Cambrian Studies [ICS], University of Chicago). All sections exhibit the same general litho- and biostratigraphic pattern. The Delamar Member is a relatively thick (~103 m at Klondike Gap) heterolithic sequence dominated by fine sandstones and bioturbated siltstones, with minor fissile shale intervals and thin sandy carbonate interbeds (Webster, Article 7, this volume, fig. 4.2; Webster, 2007b). The sediments were deposited during a general relative deepening-to-shallowing cycle that is recorded in correlative strata across the southwestern United States (upper Dyeran Depositional Sequence I as defined by Webster, Article 7, this volume; see also Sundberg and McCollum, 2000; Webster, 2007b).

The initial deposits of the Delamar Member overlie the coarse siliciclastics of the Zabriskie Quartzite and consist of hackly, bioturbated siltstones with centimeter- to decimeter-scale interbedded sandstones that sometimes exhibit cross-bedding. Flat-pebble conglomerates and other thin, fining-up conglomerates occur in the lower third of the member. An approximately 1.3 m interval of mudstone interrupted only by millimeter- to centimeter-thick micaceous siltstone stringers occurs at approximately two-thirds of the distance from the base to the top of the Delamar Member (Webster, Article 7, this volume, fig. 4.2). Regional correlation and facies interpretation suggest that this interval approximates the time of maximal flooding (Webster, Article 7, this volume). *Bristolia insolens* (Resser, 1928), characteristic of the *Bristolia insolens* Zone (Webster, Article 7, this volume), is confined to this interval.

The upper third of the Delamar Member is a crudely coarsening-up succession of bioturbated siltstones, sandstones, thin shales, and thin carbonate interbeds. *Peachella iddingsi* (Walcott, 1884), characteristic of the *Peachella iddingsi* Zone (Webster, Article 7, this volume), occurs in this interval (Webster, 2007b, 2009a). The upper 20 m of the Delamar Member are dominated by extensively burrowed, hackly siltstones and fine sandstones with centimeter-scale sandy carbonates. *Bristolia fragilis* Palmer in Palmer and Halley, 1979 has been recovered from this interval at Klondike Gap and in the Highland Range (Figs. 2.1, 3; Webster, 2007b), and poorly preserved specimens tentatively identified as *Bolbolenellus euryparia* (Palmer in Palmer and Halley, 1979) have been recovered from 7.5 m below the top of the Delamar Member at Klondike Gap (Webster, 2007b). This last species is characteristic of the *Bolbolenellus euryparia* Zone (Webster, Article 7, this volume). The Delamar Member terminates in a 3 m thick succession of calcareous sandstones capped by a sandy grainstone. This grainstone is truncated by a regionally developed erosion surface with centimeter- to decimeter-scale relief (Fig. 4) that has been interpreted as a paleokarst (Sundberg and McCollum, 2000), and that marks the sequence boundary between Depositional Sequences I and II (as defined by Webster, Article 7, this volume). The basal oncolitic carbonate ledge of the Combined Metals Member overlies this erosion surface.

The Combined Metals Member is typically 25 to 30 m thick and comprises a lower cliff-forming part and an upper part of more recessive strata. The member exhibits markedly changes from south to north in the Pioche-Caliente region (Webster, Article 7, this volume). In sections south of the Highland Range, the lower part of the member consists of two oncolitic limestones separated by a sandy interval (Fig. 5; Webster, 2007b; Webster, Article 7, this volume). The lower oncolitic limestone and sandy interval represent upper Dyeran Depositional Sequence II, and the upper oncolitic limestone represents the lowest local deposit of Depositional Sequence III (Webster, Article 7, this volume). Above the second horizon of oncolitic strata, the upper part of the Combined Metals Member is dominated by rubbly-weathering, nodular carbonates with thin limestone interbeds, which pass upward into shale. The shale forms a southward-thickening wedge of siliciclastics between the rubbly-weathering, nodular carbonates of the Combined Metals Member and a ribbon limestone marking the base of the Delamaran (Webster, Article 7, this volume; McCollum et al., Stops 5A-D, 6A, this volume; see also Palmer, 1998a; Webster, 2007b; Webster et al., 2008; Hopkins and Webster, 2009). A ribbon limestone also occurs within the uppermost Dyeran shale, 0.5 m to 2 m below the basal Delamaran ribbon limestone. The base of this uppermost Dyeran ribbon limestone represents the sequence boundary between Depositional Sequences III and IV (Webster, Article 7, this volume).

In sections within the Highland Range, the sandy interval appears to be absent from the lower part of the Combined Metals Member (Figs. 2.1, 3), and the uppermost Dyeran siliciclastic wedge is represented by a rubbly-weathering, carbonate nodule-rich shale (Fig. 2.2; Webster, Article 7, this volume). There is ambiguity as to where the sequence boundary at the base of Depositional Sequence III lies within these northern sections, but Depositional Sequence IV has been identified (discussed in Webster, Article 7, this volume).

The carbonates of the lower part of the Combined Metals Member often contain a rich fauna of inarticulate brachiopods, pelagiellids, chancelloriids, hyolithids, and various spines and small shelly fossils (unpublished data; collections held in the ICS). Limestone ledges and carbonate nodules in the upper part of the member often contain rich and exquisitely preserved silicified trilobite faunas that have been and continue to be extensively studied (Fig. 6; Palmer, 1957, 1958; Smith, 1998a, b; Webster et al., 2001; Webster and Zelditch, 2005, 2011, in press; Webster, 2007a, 2011; Hopkins and Webster, 2008, 2009). Trilobites of the *Nephrolenellus multinodus* Zone, including the eponymous species, are common within the upper part of the Combined Metals Member (Fig. 7; Palmer, 1998a; Webster, 2007a, b, 2009a, b). A ribbon limestone containing the ptychoparioid *Eokochaspis nodosa* Sundberg and McCollum, 2000 marks the base of the overlying Comet Shale Member (Sundberg and McCollum, 2000) and represents the lowest local deposit of Delamaran sequence DMS 1 (McCollum and McCollum, this volume, Article 8). This coincides with the Dyeran-Delamaran stage boundary (Palmer, 1998b).

STOP 5A: ONE WHEEL CANYON, HIGHLAND RANGE

The One Wheel Canyon locality represents the northernmost exposure studied in the Highland Range (Fig. 1.2). The locality is here described using two non-overlapping measured sections (Fig. 2); the stratigraphic separation between the lower (“main”) section and the upper (“boundary”) section is unclear (discussed below).

The main measured section (Fig. 2.1) covers the upper part of the Delamar Member and the Combined Metals Member of the Pioche Formation. The 0 m datum is set at the base of the Combined Metals Member. The section extends 37.5 m below this contact, to the top surface of a prominent sandstone ledge that crosses the mining road just north of the prominent northward bend in the road. The Delamar Member is mostly covered, although sandstones and bioturbated siltstones are exposed in places. A sandstone ~16.5 to 10 m below the base of the Combined Metals Member forms a prominent cliff. Poorly preserved olenelloid cephala resembling *Olenellus clarki* (Resser, 1928) and *Bristolia fragilis* have been recovered from float just above this cliff. These strata likely belong to the lowermost part of the *Bolbolenellus euryparia* Zone (Webster, Article 7, this volume).

The erosion surface marking the base of the Combined Metals Member is developed on a sandy grainstone, and is successively overlain by a 0.14 m thick, oncolitic limestone and a 0.21 m thick, non-oncolitic, cross-bedded grainstone. Limestone ledges then sporadically outcrop up to 10.5 m above the base of the Combined Metals Member; those in the lower 4.5 m contain sparse oncoids. Residues of the limestones from the basal 6 m of the Combined Metals Member contain abundant brachiopods and pelagiellids but no trilobites. A dark blue, micritic limestone bed outcropping at approximately 10.5 m above the base of the section (henceforth referred to as the “10.5 m limestone”) yields an exquisitely silicified trilobite fauna comprising *Olenellus puertoblancoensis* (Lochman in Cooper et al., 1952), *Olenellus* aff. *fowleri* (see appendix in Webster, Article 7, this volume), and *Crassifimbra*? *metalaspis* (Sundberg and McCollum, 2000), and is presumably the source of the material from One Wheel Canyon described by Palmer (1957, 1958; USGS locality 1400-CO). Above this horizon the main section is covered by talus and vegetation.

The contact between the Combined Metals Member and the Comet Shale Member (the Dyeran-Delamaran boundary) is exposed uphill, in an outcrop in the northern bank of the road just west of the hairpin bend in the road as it crosses One Wheel Canyon. Accurate measurement of the stratigraphic distance of this boundary exposure (Fig. 2.2) above the main measured section (Fig. 2.1) is rendered difficult by topography and cover by vegetation and talus. However, at another locality just to the south (between One Wheel Canyon and Log Cabin Mine), limestone beds roughly correlative with the "10.5 m limestone" occur 8 to 10 m below the basal Delamaran ribbon carbonate (unpublished data), suggesting a thickness of the Combined Metals Member there of roughly 20 m. This value is close to the typical thickness of the unit in the exposures within the Chief Range, Burnt Springs Range, and Delamar Mountains (Webster, Article 7, this volume, fig. 7).

Within the boundary section, silicified specimens of *Eokochaspis nodosa* have been extracted from the ribbon limestone, the base of which defines the 0 m datum (Fig. 2.2). This basal Delamaran bed rests upon a meter-thick interval of nodular shale from which olenellid, zacanthoidid, ptychoparioid, and oryctocephalid trilobites have been recovered. The olenellids recovered from this interval are typical but not unambiguously diagnostic of uppermost Dyeran faunas elsewhere (e.g., Fig. 5; Webster et al., Stop 6B, this volume). The occurrence of *Zacanthopsis palmeri* Hopkins and Webster, 2009 (Fig. 2.2) indicates that the uppermost meter of Dyeran strata represents Depositional Sequence IV (Webster, Article 7, this volume).

FIGURE *4*.—Photograph of the erosion surface (paleokarst?) developed at the base of the Combined Metals Member at the Log Cabin Mine section, Highland Range (Stop 5B). A sandy grainstone at the top of the Delamar Member (lowest ledge) is truncated by a regionally developed erosion surface with centimeter-scale relief (arrow). Above this surface is a bioturbated rubbly packstone, overlain by the lowest oncolitic limestone bed of the Combined Metals Member (to the right of the notebook). This is in turn overlain by a non-oncolitic grainstone with small-scale cross-bedding and shelly lenses (topmost ledge).

Intriguingly, a biostratigraphic range chart presented by Sundberg and McCollum (2000, fig. 2) shows an occurrence of "*Nephrolenellus multinodus*? (Palmer in Palmer and Halley" (question mark in the original) from immediately below the basal Delamaran limestone bed in the Highland Range (see also McCollum et al., this volume, Stop 5A). Elsewhere this species is characteristic of the lower part of the *Nephrolenellus multinodus* Zone, and has not been found in association with *Zacanthopsis palmeri* or in strata representing Depositional Sequence IV (Webster, Article 7, this volume; Webster, 2007a). Unfortunately, the original collection appears to have been lost, and extensive fieldwork and examination of many previously existing collections by the author has failed to verify the presence of *Nephrolenellus* *multinodus* so close to the base of the Delamaran (unpublished data). This identification therefore remains equivocal.

It is conceivable that more pronounced northward erosion and/or condensation of strata below the bases of upper Dyeran Depositional Sequence IV and of basal Delamaran sequence DMS 1 brings the range of *Nephrolenellus multinodus* into closer proximity to the basal Delamaran ribbon limestone in the Highland Range relative to sections further south (discussed by Webster, Article 7, this volume). The prevalence of carbonate nodules within Depositional Sequence IV is consistent with this interpretation, because sediment starvation or winnowing encourages growth of such diagenetic nodules below a static sediment surface (Brett et al., 2006; Peters, 2007; Webster et al., 2008). Carbon isotope excursions from other sections in the southern Great Basin also suggest the presence of stratigraphic hiatuses of sub-biostratigraphic resolution around the Dyeran-Delamaran boundary (Montañez et al., 2002).

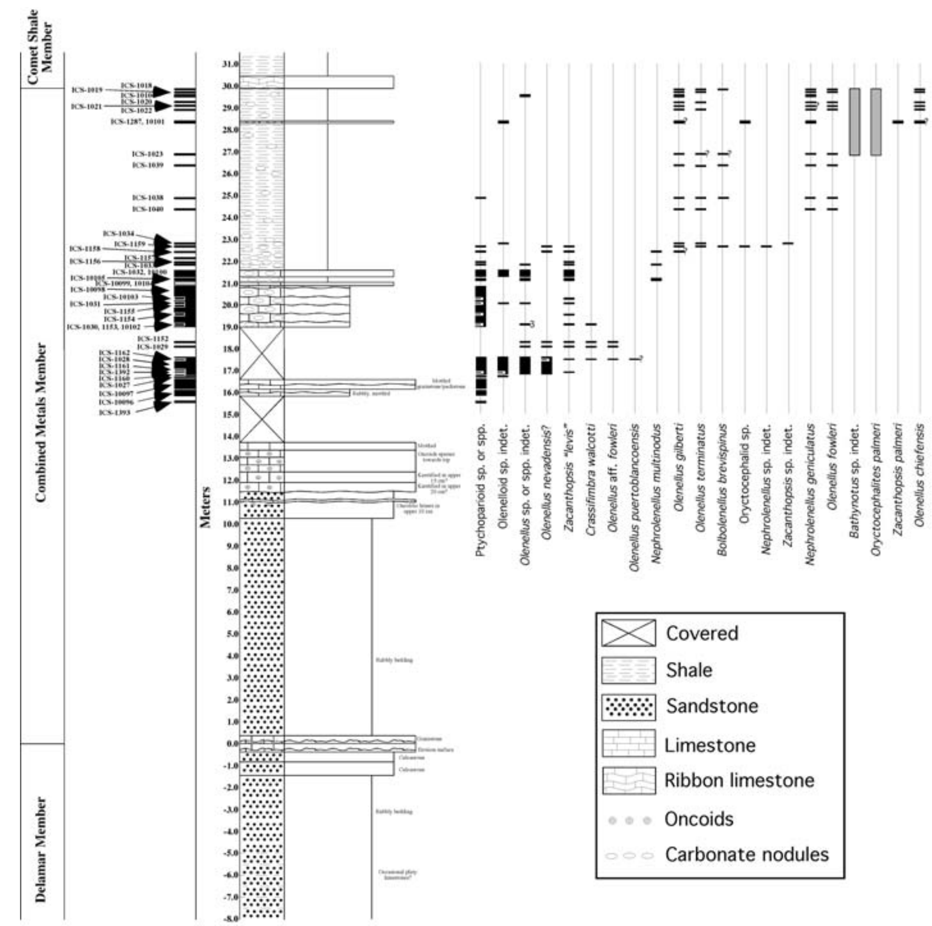

FIGURE 5.—Biostratigraphic range chart for the stratotype section of Oak Spring Summit (Stop 6A). Black bars to the left of the meter scale indicate provenance of stratigraphically constrained trilobite-bearing collections housed in the ICS; gray boxes indicate less well constrained fossil collections in the ICS; empty bars indicate levels of failed searches for trilobites (although many of these collections contain other fossils). A question mark next to a black bar indicates a tentative identification due to poor or incomplete preservation. Bars representing collections that show partial or entire stratigraphic overlap are shown offset from each other and with different widths. The number "3" next to an occurrence of *Olenellus* sp. indet. indicates that at least three unidentified species are represented in that collection.

STOP 5B: LOG CABIN MINE, HIGHLAND RANGE

At this locality we will examine a measured section incorporating 42 m of strata and spanning the upper Delamar Member and Combined Metals Member. The Log Cabin Mine section is very similar to that at One Wheel Canyon to the north (Fig. 1.2), and bed-to-bed lithological correlation is possible (compare Figs. 2.1, 3). The base of the Log Cabin Mine section (Fig. 3) is the foot of a prominent sandstone cliff adjacent to the abandoned and collapsed mining sheds, 18 m below the base of the Combined Metals Member (defining the 0 m datum); this is equivalent to the cliff ~16.5 to 10 m below the equivalent 0 m datum at One Wheel Canyon (above; Fig. 2.1). *Peachella brevispina* Palmer in Palmer and Halley, 1979 and an olenellid resembling *Olenellus puertoblancoensis* have been recovered from the micaeous, platy siltstone immediately overlying this cliff. (Note that a poorly preserved specimen of *Peachella brevispina* from this horizon was misidentified as *Peachella iddingsi* in Webster [2009a, p. 207].) An olenelloid trilobite fauna including poorly preserved specimens resembling *Olenellus clarki*, *Olenellus fowleri* Palmer, 1998a s.s., and *Bristolia fragilis* occurs approximately 7 to 5 m below the base of the Combined Metals Member, closely matching that recovered from the equivalent stratigraphic horizon at One Wheel Canyon. The succession of limestone beds between -1 m and 4 m at Log Cabin Mine (including the erosion surface marking the base of the Combined Metals Member; Figs. 3, 4) corresponds to that between -1 m and 6 m at One Wheel Canyon (Fig. 2.1) and contains a similar fauna. A series of dark blue-gray, micritic limestone beds yielding exquisitely silicified specimens of *Olenellus puertoblancoensis*, *Olenellus* aff. *fowleri*, *Crassifimbra*? *metalaspis*, and a new species of kochaspid trilobite (Fig. 6) outcrop between 8.5 m and 12.2 m above the base of the section; this interval is equivalent to that around the "10.5 m limestone" bed at One Wheel Canyon. The specimens of *Crassifimbra*? *metalaspis* recently studied by Webster (2011) and Webster and Zelditch (2011, in press) were extracted from the bed 10.75 m above the base of the Combined Metals Member.

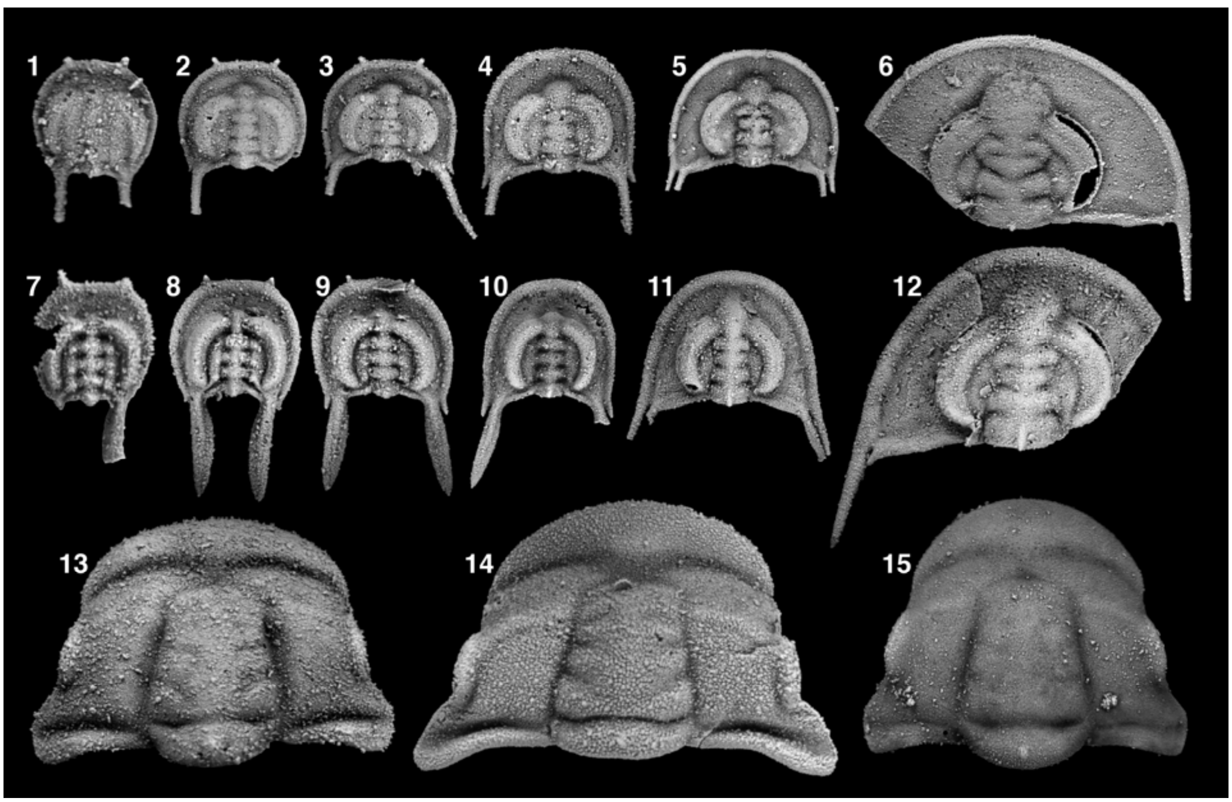

FIGURE *6*.—Representative silicified trilobites from the Combined Metals Member, Pioche Formation. *1-6*, Sequence of specimens showing ontogenetic development of the cephalon of *Olenellus puertoblancoensis* (x19, x10, x9, x8, x6, and x4, respectively). *7-12*, Sequence of specimens showing ontogenetic development of the cephalon of *Olenellus* aff. *fowleri* (x17, x11, x10, x7, x5, and x6, respectively). *13*, Cranidium of *Crassifimbra*? *metalaspis*, x9. *14*, Cranidium of kochaspid n. sp., x8. *15*, Cranidium of *Crassifimbra walcotti*, x11. 1-14 from collection ICS-10124, Log Cabin Mine section (Stop 5B, Highland

Range); 15 from collection ICS-1029, Oak Spring Summit stratotype section (Stop 6A, Delamar Mountains).

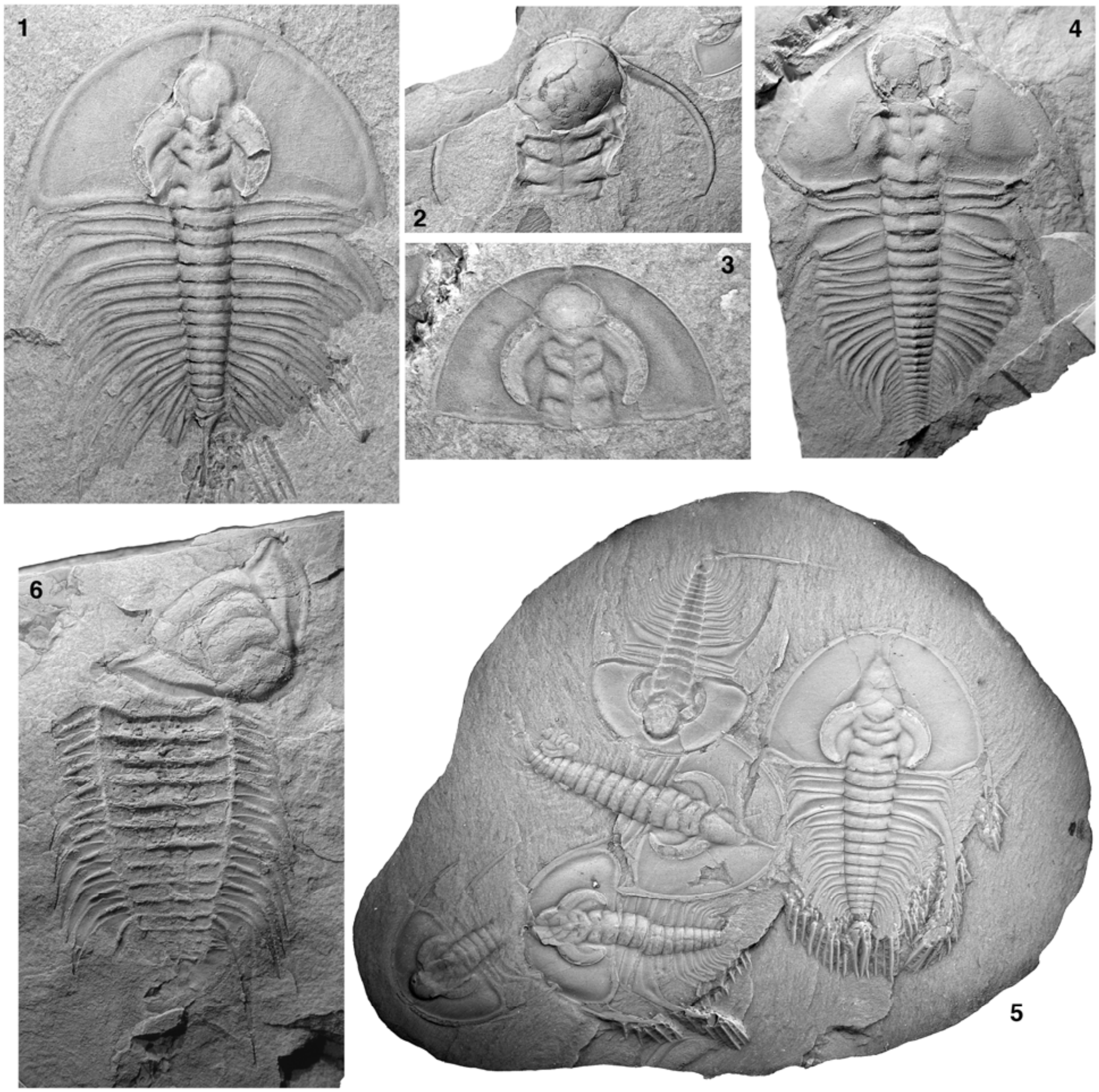

FIGURE 7.—Representative trilobites from the uppermost Dyeran shale of the Combined Metals Member, Pioche Formation. *1*, Articulated dorsal exoskeleton of *Olenellus fowleri*, internal mold, collection ICS-1044, x3. *2*, Cephalon of *Bolbolenellus brevispinus* showing the non-mineralized extraocular area and posterior margin that characterizes this species, internal mold, CMCP 2324b, x1.5. *3*, Cephalon of *Olenellus terminatus*, internal mold, collection ICS-1044, x3. *4*, Articulated dorsal exoskeleton of *Nephrolenellus genciulatus*, internal mold, FMNH PE57943, x2.5. *5*, A slab showing articulated exoskeletons of *Olenellus gilberti* (top, lower center, and lower left) and *Olenellus chiefensis* (center and right), latex cast of internal and external molds, collection ICS-1044, x2. *6*, Articulated dorsal exoskeleton of *Bathynotus granulatus*,

internal mold, FMNH PE58120, x1.5. 1-5 from the Ruin Wash locality (Chief Range), 6 from collection ICS-10255, Oak Spring Summit (Delamar Mountains), all in Lincoln County, Nevada.

The section is covered above 12.2 m except for two thin limestone beds outcropping ~22.6 m and 24 m above the base of the section (Fig. 3). Residues of these limestones contain abundant brachiopods, pelagiellids, hyolithids, and other small shelly fossils, but no trilobites, and are similar to the limestones at the base of the boundary exposure at One Wheel Canyon (Fig. 2.2). Above the highest ledge, the Combined Metals Member appears to be faulted against the Comet Shale Member; the boundary interval itself is not observed at Log Cabin Mine. However, in an adjacent section just to the north, limestones containing a silicified trilobite fauna identical to (and presumably roughly correlative with) the beds 8.5 to 12.2 m above the base of the Log Cabin Mine section occur 8 to 10 m below the basal Delamaran ribbon limestone (unpublished data), suggesting that the top of the measured section at Log Cabin Mine is close to the Dyeran-Delamaran boundary.

STOP 6A: OAK SPRING SUMMIT, DELAMAR MOUNTAINS

The Oak Spring Summit locality is an important section of well-exposed Cambrian strata spanning the Dyeran-Delamaran stage boundary. The section is found on the western flank of the Delamar Mountains just north of Highway 93, ~20 km (12 miles) west of Caliente and 1.6 km (1 mile) northwest of Oak Spring (Fig. 1.3). It is named for the nearby Oak Spring Summit pass on Highway 93, ~4 km southeast of the locality. The land is managed by the Bureau of Land Management, which has constructed a "Trilobite Trail" for the public. Parking is available at the end of the gravel road near the borrow pits (Fig. 1.3); the first of the outcrops to be examined is located a short hike (~600 m) west. The first stop (Fig. 1.3) permits examination of the basal contact of the Pioche Formation (Delamar Member) with the underlying Zabriskie Quartzite. The Delamar Member is poorly exposed at Oak Spring Summit, and is suspected to contain much small-scale faulting. Nevertheless, this locality was chosen as the stratotype for the Delamar Member (Sundberg and McCollum, 2000, p. 604). No detailed measured section through the member has been made at Oak Spring Summit. The meterages above the base of the Delamar Member for the following occurrences are therefore estimates, but their rank stratigraphic order is considered robust based on field observations and on biostratigraphic comparison with other localities. The entire Delamar Member at Oak Spring Summit has been estimated to be ~130 m thick (A. R. Palmer, unpublished data, 9/22/91) or 85 to 90 m thick (Sundberg and McCollum, 2000); these figures are in reasonable agreement with the 103 m thickness of this member at Klondike Gap 20 km to the northeast (Webster, 2007b; Webster, Article 7, this volume, fig. 4.2).

The fossil content of the Delamar Member at Oak Spring Summit has not been well sampled. However, the succession of faunas that have been collected is consistent with that at the better-sampled Klondike Gap locality (Webster, 2007b) and with the newly revised regional biostratigraphic zonation of the upper Dyeran (Webster, Article 7, this volume). *Bristolia harringtoni* Lieberman, 1999 has been recovered from approximately 30 m above the base of the unit; this species consistently occurs stratigraphically immediately above *Bristolia mohavensis* (Crickmay in Hazzard, 1933) in localities elsewhere in the southern Great Basin (Webster, Article 7, this volume; Webster et al., 2003; unpublished data). *Bristolia insolens* occurs with typical elements of the "*Insolens* Beds" (Webster, 2007b) ~52 m above the base of the unit, and *Peachella iddingsi* occurs in thin limestones in the upper third of the unit (Webster, 2009a). The Delamar Member at Oak Spring Summit is therefore interpreted to minimally span the *Bristolia mohavensis* through *Peachella iddingsi* zones (Webster, Article 7, this volume). At Klondike Gap and in the Highland Range the uppermost part of the member likely falls within the *Bolbolenellus euryparia* Zone (see above; Webster, 2007b). Other notable trilobites recovered from the Delamar Member at Oak Spring Summit include the long-ranging taxa *Mesonacis fremonti* (Walcott, 1910), *Olenellus clarki*, and *Olenellus nevadensis* (Walcott, 1910), the shorter-ranging taxa *Bristolia bristolensis* (Resser, 1928), *Paranephrolenellus klondikensis* Webster, 2007b, and *Eopeachella angustispina* Webster, 2009a, and a new species of *Olenellus* Hall, 1862.

The second stop at the Oak Spring Summit locality is a short hike (~350 m) north of the first (Fig. 1.3), and is of particular importance because it has been designated as the stratotype section for the Dyeran-Delamaran stage boundary (Palmer, 1998b). The uppermost Delamar Member through Comet Shale Member is well exposed at this site. The litho- and biostratigraphic range chart presented herein (Fig. 5) was compiled from fieldwork by A. R. Palmer (1991, 1992, 1995, 1999, 2000) and by the author (1997, 2000, 2001, 2005); all trilobite identifications were made by the author. A sequence stratigraphic interpretation of this section is provided by Webster (this volume, Article 7, figs. 6, 7.3).

The base of the Combined Metals Member is taken to be the base of the lowermost oncolitic limestone bed, which immediately overlies the regional erosion surface (paleokarst?; Sundberg and McCollum, 2000; Webster, 2007b). This is the 0 m datum in the measured section (Fig. 5). The base of the ribbon limestone containing *Eokochaspis nodosa* (coinciding with the base of the Comet Shale Member and with the Dyeran-Delamaran stage boundary) occurs 29.88 m above the base of the Combined Metals Member. The lowermost 13.73 m of the Combined Metals Member is cliff- and ledge-forming; the upper 16.15 m is comprised of more recessive strata (7.87 m of rubbly-weathering, nodular carbonate with a grainstone/packstone ledge 2.87 m from its base, overlain by 8.28 m of shale). The recessive part of the Combined Metals Member has been well sampled (Fig. 5; see also Palmer, 1998a). The carbonates frequently contain exquisitely preserved silicified faunas, which are currently under study (see also Webster, 2007a, 2011; Webster and Zelditch, in press).

Trilobite diversity in the Combined Metals Member at this locality (Fig. 5) is higher than that from the Highland Range (Figs. 2, 3) and on a par with that from correlative strata in the northern Groom Range (Webster et al., Stop 6B, this volume). *Olenellus puertoblancoensis* and *Olenellus* aff. *fowleri* co-occur within the recessive, rubbly limestone interval of the Combined Metals Member at Oak Spring Summit, in association with *Zacanthopsis "levis"* (Walcott, 1886) (a wastebasket taxon currently under revision; Hopkins and Webster, 2008, 2009), *Crassifimbra walcotti* (Resser, 1937) (Fig. 6.15), and a species tentatively identified as *Olenellus nevadensis*. This interval therefore appears to correlate with the limestones containing the exquisitely preserved silicified trilobites in the Highland Range (where *Crassifimbra walcotti* is replaced by *Crassifimbra*? *metalaspis*; Fig. 6.13), and with the nodular limestone and basal 12 m of shale intervals of the Combined Metals Member in the northern Groom Range (Webster et al., Stop 6B, this volume).

Nephrolenellus multinodus ranges from at least as low as 21.06 m (defining the local base of the *Nephrolenellus multinodus* Zone) to at least as high as 22.40 m above the base of the Combined Metals Member (Fig. 5). An indeterminate specimen of *Nephrolenellus* Palmer and Repina, 1993 was found at 22.70 m. *Nephrolenellus geniculatus* Palmer, 1998a, characteristic of the upper part of the *Nephrolenellus multinodus* Zone (Webster, Article 7, this volume), occurs at least as low as 24.38 m above the base of the Combined Metals Member, and ranges to the top of the unit. Other typical elements of the "terminal Dyeran" olenelloid assemblage described by Palmer (1998a) include *Olenellus gilberti* Meek in White, 1874, *Olenellus terminatus* Palmer, 1998a, *Olenellus chiefensis* Palmer, 1998a, *Olenellus fowleri* s.s., and *Bolbolenellus brevispinus* Palmer, 1998a (Fig. 7). Like *Nephrolenellus geniculatus*, all these species make their first appearances in the upper 8 m of the Combined Metals Member at Oak Spring Summit and persist to the top of the member, crossing the sequence boundary between Depositional Sequences III and IV (marked by a ribbon limestone) less than 2 m below the base of the Delamaran. *Bathynotus* sp. indet. and *Oryctocephalites palmeri* Sundberg and McCollum, 1997 also occur in the upper 3 m of the Combined Metals Member at the stratotype section. An articulated specimen of *Bathynotus granulatus* Lermontova, 1940 has been recovered from shale from the uppermost Combined Metals Member at a site ~600 m SSE of the main section (Fig. 7.6; Webster, 2009b). This species is also known from the Amgan(?) of the Altay-Sayan Foldbelt of Siberia and from the upper Duyunian (*Ovatoryctocara granulata-Bathynotus holopygus* Zone) of the Kaili Formation of eastern Guizhou Province, South China, and thus plays an important role in intercontinental correlation (Webster, 2009b).

The coincident nature of the last appearances of the "terminal Dyeran" olenelloid species in the Pioche-Caliente region was interpreted by Palmer (1998a) as evidence for an abrupt extinction event. However, an alternative hypothesis has been proposed, in which the extinction was protracted over a longer interval of time and the apparent coincident disappearance of all taxa in the Pioche-Caliente region results from non-deposition and/or minor erosion of uppermost Dyeran strata (McCollum, 1994; McCollum and McCollum, 1994; Montañez et al., 2002; McCollum et al., this volume, Stops 5A-D, 6A). For a thorough review and new interpretation of this important issue, see Webster (Article y, this volume).

ACKNOWLEDGMENTS

Assistance in the field at the sections documented herein was generously provided by R. R. Gaines, M. Hoerner, M. J. Hopkins, N. C. Hughes, L. B. McCollum, M. B. McCollum, S. Miller, and E. Sperling. Several of the collections studied herein were made by A. R. Palmer. Comments by L. B. McCollum and formal reviews by A. R. Palmer and P. Ahlberg helped improve this manuscript.