1 Proposed GSSP for the base of Cambrian Stage 10 at the lowest
2 occurrence of *Eoconodontus notchpeakensis* in the House Range, Utah,
3 USA

4 *Proposition de la première apparition de Eoconodontus notchpeakensis*
5 *dans le House Range, Utah, USA, comme Point Stratotypique Mondial*
6 *de la base de l'Etage 10 du Cambrien.*

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24 ABSTRACT

25 The lowest occurrence of the conodont *Eoconodontus notchpeakensis* (Miller, 1969) has been proposed as
26 the base of Cambrian Stage 10. The horizon is recognized in three sections in the House Range, western Utah, USA
27 in the lower part of the Red Tops Member of the Notch Peak Formation. This horizon fits within a tightly integrated
28 framework that includes conodont, trilobite, and brachiopod biozonations, as well as carbon-isotope stratigraphy and
29 sequence stratigraphy. The proposed horizon is the base of the *Eoconodontus* conodont Zone. This horizon is in the
30 lower part of the *Saukiella junia* Subzone of the *Saukia* trilobite Zone and is near the top of the *Billingsella*
31 brachiopod Zone. The HERB Event is a high-amplitude, negative carbon-isotope excursion that has been identified
32 in Laurentia, Australia, China, and Argentina. The start of the excursion is at a negative carbon-isotope peak that is
33 less than half a metre above the base of the *E. notchpeakensis* Subzone, and the highest-amplitude peak of the
34 HERB Event is near the middle of that relatively thin subzone. The HERB Event has been identified in strata with
35 minimal faunal data, providing the possibility of identifying the base of Stage 10 in nearly unfossiliferous strata. The
36 Notch Peak Formation has been divided into a detailed sequence-stratigraphic framework within a lithostratigraphic
37 context, and some of the sequence boundaries have been identified in Australia and China.

38 Conodonts diagnostic of the *Eoconodontus* Zone have been identified at 54 localities around the world,
39 including in a succession of Cambrian deep-ocean radiolarian cherts. The Utah conodont zonation has been
40 identified across Laurentia and in other parts of the world in facies ranging from continental slope to nearshore
41 sandstone deposits. The variety of correlation tools and the integration of diverse data produce a superior framework
42 for correlation of the proposed base of Stage 10 and for correlation of many horizons within Stage 10.

43 *Keywords:* Cambrian Stage 10, conodonts, trilobites, brachiopods, carbon isotopes

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45 RÉSUMÉ

46

47 La première apparition du conodonte *Eoconodontus notchpeakensis* (Miller, 1969) a été proposée comme
48 base de l'Étage 10 du Cambrien. Cet horizon est reconnu dans trois sections du House Range, dans l'ouest de
49 l'Utah, aux États-Unis, dans la partie inférieure du Membre Red Tops de la Formation du Notch Peak. Cet horizon
50 est intégré avec précision dans un cadre qui comprend des biozonations à conodontes, trilobites, et brachiopodes,
51 ainsi que de la stratigraphie isotopique du carbone. L'horizon proposé est la base de la sous-zone à *Eoconodontus*
52 *notchpeakensis* de la zone à conodontes *Eoconodontus*. Cet horizon se trouve dans la partie inférieure de la sous-
53 zone à *Saukiella junia* de la zone à trilobites *Saukia*, et se situe près de la limite supérieure de la zone à brachiopodes
54 *Billingsella*. L'événement HERB est une excursion négative des isotopes du carbone de grande amplitude qui a été
55 identifiée en Laurentia, en Australie, en Chine, et en Argentine. La base de l'excursion correspond à un pic négatif
56 des isotopes du carbone qui se situe moins d'un demi-mètre au-dessus de la base de la sous-zone à *E.*
57 *notchpeakensis*, et le pic d'amplitude maximale de l'événement HERB est enregistré au milieu de cette sous-zone
58 relativement peu épaisse. L'événement HERB a été identifié dans des strates pauvres en faune, ce qui offre la
59 possibilité d'identifier la base de l'Étage 10 dans des strates quasi non fossilifères. La Formation du Notch Peak a
60 été divisée selon un cadre stratigraphique séquentiel détaillé dont certaines limites de séquence sont identifiées en
61 Australie et en Chine. Des conodontes indicatifs de la Zone à *Eoconodontus* ont été identifiés dans 54 localités du
62 monde entier, y compris dans une série de cherts à radiolarite cambriens déposés en domaine océanique profond. La
63 zonation à conodontes de l'Utah a été identifiée à travers le Laurentia ainsi que dans d'autres parties du monde dans
64 des faciès variés, allant des dépôts de talus continental à des grès de plateforme interne. La variété d'outils de
65 corrélation et l'intégration de données diverses fournissent un cadre de corrélation remarquable de la base proposée
66 de l'Étage 10 ainsi que de plusieurs horizons de l'Étage 10.

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68 *Mots clés:* Étage 10 du Cambrien, conodontes, trilobites, brachiopodes, isotopes du carbone

1. Introduction

The various subcommissions of the International Commission on Stratigraphy have finished subdividing and defining boundaries between Eras and Systems of the Geological Time Scale. Recently, these subcommissions have shifted their work to dividing the various Systems into international series and stages. The International Subcommission on Cambrian Stratigraphy has divided the Cambrian System into four series and ten stages. The lower two series each have two stages, and the upper two series each have three stages. Stage 10 will be the highest stage of the highest Cambrian Furongian Series.

Two horizons have been proposed for the base of Stage 10. The lower horizon is at the First Appearance Datum (FAD) of the agnostoid arthropod *Lotagnostus americanus* (Billings, 1860). Peng et al. (2014) proposed placing the Global Boundary Stratigraphic Section and Point (GSSP) in the Wa'ergang section in Hunan, South China. Lazarenko et al. (2011) proposed a GSSP at the same level in the Khos-Nelege section in northern Siberia, Russia. Miller et al. (2011) and Landing et al. (2011) proposed placing the GSSP at a somewhat higher stratigraphic level, at the FAD of the euconodont *Eoconodontus notchpeakensis* (Miller, 1969) in the House Range in western Utah, USA.

The HERB Event is a distinctive negative carbon-isotope excursion that has been identified in several continents (Ripperdan et al., 1992; Ripperdan et al., 1995; Jing et al., 2008; Kouchinsky et al., 2008; Sial et al., 2008). The base of the HERB Event is less than half a metre above the proposed GSSP, and the peak of the excursion is within the relatively thin *E. notchpeakensis* Subzone. The base of the HERB Event and the negative excursion peak would be useful for identifying and correlating a GSSP based on the conodont horizon. Miller et al. (2011, 2014) identified three sections in western Utah that might serve as a GSSP and presented data on trilobites, brachiopods, carbon isotopes, and sequence stratigraphy that would further characterize the proposed conodont horizon and increase the potential for its correlation. Each of these correlation tools will be discussed in separate sections of this paper.

2. *Eoconodontus notchpeakensis* horizon in Utah

Miller et al. (2003) presented detailed range charts for conodonts, trilobites, and brachiopods and also defined sequence stratigraphic units in several sections in western Utah. That paper also included detailed descriptions of 17 measured sections that are distributed across an area that is approximately 110 km from south to north, from Lawson Cove in the northern Wah Wah Mountains to the northern Drum Mountains in the north (Fig. 1B). Seven of these 17

sections include strata in which the FAD of *E. notchpeakensis* has been identified. The seven sections are located on Figure 1B; among these, the Steamboat Pass, Lava Dam Five East, and Sneakover Pass sections are the best because of diversity and abundance of data, exposure, and access. Several additional sections are also located on Figure 1B. Miller et al. (2011) presented range charts for conodonts and trilobites and other data for the Steamboat Pass and Lava Dam Five East sections. New diagrams herein present data from the Sneakover Pass section, which is located more precisely in Figure 2. This paper is an expanded version of a short paper by Miller et al. (2014), and it has new conodont, trilobite, brachiopod, and carbon-isotope data that were not included in that paper nor in Miller et al. (2011).

3. Stratigraphy and lithology

Miller et al. (2012a) discussed and illustrated Cambrian and Ordovician strata in western Utah, which were deposited on a rapidly subsiding, tropical, passive-margin carbonate platform. Cambrian strata in the House Range are ~3870 m thick, of which ~850 m is assigned to the upper Cambrian Furongian Series. Relevant strata are assigned to the Notch Peak Formation and the House Limestone and include the Hellnmaria, Red Tops, Lava Dam, and Barn Canyon Members (Fig. 3). The proposed base of Cambrian Stage 10 is in the lower part of the Red Tops

Member. Stage 10 would continue upward to the base of the *Iapetognathus* Zone, in the middle of the Barn Canyon Member of the House Limestone (Fig. 3).

The Notch Peak Formation is entirely limestone in the Sneakover Pass area, and exposures there comprise the type sections of its three members. The Hellnmaria Member is primarily shallow subtidal lime mudstone with many stromatolitic and thrombolitic intervals. This member is 367 m thick in the area, but only the top 34 m is documented in this paper (Fig. 4). The Red Tops Member (Fig. 5) comprises 44 m of high-energy lime grainstone with a few thin intervals of lime mudstone, all deposited during a sea-level lowstand (Red Tops Lowstand on Fig. 3). The Lava Dam Member is 110 m thick and can be divided into three parts. The lower ~40 m is subtidal, thick-bedded, cherty lime mudstone. The middle part comprises ~12.5 m of high-energy lowstand deposits (Lange Ranch Lowstand on Fig. 3) that include lime mudstone, skeletal and ooid grainstone, and a bed of stromatolitic boundstone. A major extinction of conodonts, trilobites, and brachiopods occurs at the base of this middle part of the Lava Dam Member, at 121.3 m on Figure 6. The upper ~56 m of the member comprises a massive stromatolitic reef. The lower 4 m of the House Limestone at the Sneakover Pass section is lime mudstone with abundant brown to light gray chert.

4. General aspects of conodont faunas

Conodonts are usually common to abundant in strata that would comprise Stage 10. Some of the oldest known species of euconodonts occur in the Hellnmaria Member of the Notch Peak Formation and are part of the *Proconodontus* Evolutionary Lineage (Miller, 1980), which includes *Proconodontus tenuiserratus* Miller, 1980, *P. posterocostatus* Miller, 1980, *P. muelleri* Miller, 1969, *Eoconodontus notchpeakensis* (Miller, 1969), species of *Cambrooistodus* Miller, 1980, and species of *Cordylodus* Pander, 1856. These taxa comprise the first major evolutionary diversification among euconodonts, and species of this evolving lineage are used to define the zones and one subzone in Figure 6. Taxa of this lineage are identified on Figure 6 by a thin white line in the middle of the wide black line that shows the range of the species. The conodont species used for biozonation are distributed globally and are abundant in most marine depositional settings.

Vertical range lines shown on Figure 6 have small horizontal marks that indicate levels at which the species was found. The number following the name of the species is the total number of conodont elements (specimens) of that species found within the range shown on the figure. In 137 m of strata illustrated in Figure 6, 118 samples yielded 27 taxa and 13,084 identified conodont elements.

5. Conodont biostratigraphy

The proposed Stage 10 would include nine conodont subzones distributed among four zones (Fig. 3). The zones and subzones are interval zones, and the bases of zones are at the FAD of a specific species in the evolving *Proconodontus* Lineage. If the base of Stage 10 were placed at the base of the *Eoconodontus* Zone, then the upper part of the Jiangshanian Stage would include the *Proconodontus tenuiserratus*, *P. posterocostatus*, and *P. muelleri* Zones. Faunas diagnostic of those zones occur in the upper part of the Hellnmaria Member (Figs. 3, 6). The *P. tenuiserratus* Zone has not been identified at Sneakover Pass because sampling for conodonts has not extended far enough down section. Miller et al. (2003) identified that zone in northern Tule Valley, east of the Chalk Knolls South section (Fig. 1). The upper part of the *P. posterocostatus* Zone is in the lowermost few metres studied at Sneakover Pass (Fig. 6), but most of the strata likely assigned to the zone are thrombolitic and yielded no conodonts. The *P. muelleri* Zone includes the highest strata of the Hellnmaria Member and the lowest few metres of the Red Tops Member. *Proconodontus muelleri* is the most common and characteristic species of this zone and comprises 16% of all conodont elements documented in Figure 6. Additional taxa appear in lime grainstone beds near the base of the Red Tops Member, but these taxa are a protoconodont and several paraconodonts that are not useful for correlation.

The base of the *Eoconodontus* Zone is at the lowest occurrence of *E. notchpeakensis*, which comprises 49.8% of all of the conodonts documented in Figure 6. The appearance of that species notably does not coincide with a lithofacies shift at the Hellnmaria–Red Tops boundary but is 4.1 m higher (Fig. 4). Strata just below and above this horizon have been sampled at very

168 closely spaced intervals at Steamboat Pass, Lava Dam Five East, and Sneakover Pass. The evolutionary
169 transition from *Proconodontus muelleri* to *E. notchpeakensis* (Miller, 1969, 1980) is subtle but is marked by
170 narrowing of the elements, by a slight shortening of the basal cavity, and by the appearance of a short cusp made of
171 white matter in *E. notchpeakensis* (Miller et al. 2006, fig. 7). The basal cavities become shorter and the cusps
172 become longer in the next few metres of strata. Most taxa that occur in the underlying *P. muelleri* Zone occur
173 throughout the *E. notchpeakensis* Zone. *Cambrooistodus cambricus* (Miller, 1969) occurs in nearly all of the
174 *Eoconodontus* Zone, and several uncommon taxa also occur in the zone (Fig. 6). *Cambrooistodus* has a geniculate
175 element, which is lacking in *Proconodontus* and *Eoconodontus*.

176 Dong et al. (2004) recognized an *Eoconodontus* Zone in Hunan, South China. Although *E. notchpeakensis*
177 occurs in the section they studied, Chen et al. (1988) did not recognize an *Eoconodontus* Zone in Jilin, North China
178 but instead identified a *Cambrooistodus* Zone. The FAD of *Cambrooistodus cambricus* is 1.0 m above the FAD of
179 *E. notchpeakensis* at Sneakover Pass (Fig. 6) and less than half a metre at the Lava Dam section (Miller et al., 2011,
180 fig. 6), so the *Eoconodontus* and *Cambrooistodus* Zones recognized in different parts of China appear to comprise
181 almost identical stratigraphic intervals and are nearly identical for practical correlation. The lowest occurrences of *E.*
182 *notchpeakensis* and *C. cambricus* are so close together that both species characterize the proposed base of Stage 10.
183 However, *C. cambricus* is a rather rare species and comprises only 0.9% of the conodont elements documented in
184 Figure 6.

185 The *Eoconodontus* Zone is divided into *E. notchpeakensis* and *Cambrooistodus minutus* Subzones. The
186 base of the upper subzone is at the FAD of *C. minutus* (Miller, 1969), which comprises 10.1% of the conodont
187 elements documented in Figure 6. This species apparently evolved from *C. cambricus*, but *C. minutus* is a smaller
188 species with a shallower basal cavity (Miller et al., 2011, fig. 7). *C. minutus* occurs throughout the subzone, as does
189 the uncommon species *Proconodontus serratus* Miller, 1969, which typically occurs also in the upper part of the *E.*
190 *notchpeakensis* Subzone. The top of the *C. minutus* Subzone is at a mass extinction where species of *Proconodontus*
191 and *Cambrooistodus* disappear.

192 *Eoconodontus notchpeakensis* has a rather long range that extends to the top of the proposed Stage 10, but
193 it always occurs with other species. *Proconodontus* and *Cambrooistodus* occur with *E. notchpeakensis* in the

Eoconodontus Zone, but they disappear at the top of the zone. Taxa occurring with *E. notchpeakensis* in the overlying *Cordylodus proavus* Zone comprise a very different fauna that includes species of *Cordylodus*, *Fryxellodontus* Miller, 1969, *Teridontus* Miller, 1980, and younger genera not shown on Figure 6. Thus, it is quite easy to assign a sample containing *E. notchpeakensis* to either the *Eoconodontus* Zone or the *Cordylodus proavus* Zone.

The ranges of conodonts known from the upper part of the Sneakover Pass section are not shown on Figure 6 due to space limitation. Detailed ranges of conodonts extend upward through the upper strata of the Notch Peak Formation, which are assigned to the three subzones of the *Cordylodus proavus* Zone, and through the lowest 4 m of the House Limestone, which are assigned to the *Hirsutodontus simplex* Subzone of the *Cordylodus intermedius* Zone (Fig. 3).

6. Distribution and utility of conodont faunas

Conodont species used to construct this zonal framework have global distribution, and consequently the zones and subzones are recognized globally and are used for detailed correlation. In some countries the classification of zones and subzones differs from what is illustrated in Figure 3, but correlation is still possible because the same species are so widely distributed. Miller et al. (2014, fig. 2) shows the global distribution of conodonts that are diagnostic of the *Eoconodontus* Zone; 55 localities are shown on their map. The most common example of a diagnostic fauna is a joint occurrence of *Eoconodontus notchpeakensis* with *Proconodontus muelleri* or *P. serratus* or *Cambrooistodus cambricus* or *C. minutus* or any mix of those species. An individual occurrence of any of the latter three species is also diagnostic of the *Eoconodontus* Zone. These occurrences are in North and South America, Europe, Asia, and Australia in depositional environments including open-ocean radiolarian chert, continental slope deposits, passive-margin platform carbonates, cratonic carbonates, aulacogen carbonates, mixed siliciclastic and carbonate facies, and nearshore sandstone and dolomite facies. Miller et al. (2011) cited references for these widespread occurrences.

Although these faunas are widely distributed, more detailed work on these faunas and their biostratigraphy has been done in the western half of the United States than anywhere else. Figure 1A identifies states where conodont faunas and zones have been documented in detail. Studies done in states with black dots are especially important for reasons discussed below. The conodont faunas and zonation discussed above have been used for 25 years to solve a variety of sedimentological, paleotectonic, and biostratigraphic problems, and the conodont zonation has been integrated with trilobite and brachiopod zonations, as well as with a detailed carbon-isotope stratigraphy. What follows is a summary of some of the areas where these faunas have been studied in detail in Laurentia. The purpose of the discussion is to demonstrate the variety of facies in which these faunas are distributed and have been used for detailed biostratigraphy. Locations on other continents where these faunas are known include similar depositional settings.

Cook et al. (1989) studied continental slope strata at Tybo Canyon in south-central Nevada, and Taylor et al. (1989) studied coeval carbonate platform strata farther east at Sawmill Canyon, Nevada. Trilobites in slope deposits at Tybo Canyon are mostly deep-water taxa but also include trilobites in redeposited clasts derived from shallower platform strata, similar to those at Sawmill Canyon. The two sections yielded many of the same conodonts, so it is easy to correlate the different lithofacies in the two areas. One result of these conodont correlations was realizing that rapid fluctuations in sea level during the Lange Ranch Lowstand (Fig. 3) caused repeated collapse of the margin of the carbonate platform. Those collapses resulted in deposition at Tybo Canyon of thick slump deposits, debris-slide breccias, and turbidites that caused rapid progradation of the margin of the carbonate platform across the continental slope (Miller, 1992).

Miller et al. (2003) documented ranges of tens of thousands of conodonts in 17 sections in western Utah; some of the sections are identified in Figure 1B. Conodont faunas in those sections permitted detailed correlation of strata from Lawson Cove to the Drum Mountains (Fig. 1), a region ~110 km from south to north. They defined the sequences and packages shown in Figure 3, traced them across the area, and used changes in facies and sediment thickness to delineate three regional paleotectonic features that influenced deposition during the Cambrian. These tectonic features are the Wah Wah Arch (~southern one-third of Fig. 1B), the down-faulted House Range Embayment (~central one-third of Fig. 1B), and the Tooele Arch (~northern one third of Fig. 1B). Miller et al.

(2012a) used these tectonic features as a central organizing theme to explain Cambrian lithofacies and sediment thickness patterns across the region.

Myrow et al. (2003) studied Cambrian and Ordovician strata in central to western Colorado. Their figure 6 identified nine sections across an area extending 265 km east to west. Strata included dolomite, limestone, shale, and sandstone deposited across a southwestern extension of the Laurentian craton known as the Transcontinental Arch. Conodont and trilobite faunas provided biostratigraphic control for correlation of these sections, and most of the conodont zonal units discussed herein were documented in seven of the nine sections, including the *Eoconodontus* Zone. The result of the study was revision of the regional lithostratigraphy and a revised interpretation of regional sedimentary basins active during the Cambrian.

Sections in central Texas and southwest Oklahoma (Fig. 1A) have been especially important in determining relationships among the trilobite, conodont, and brachiopod zones shown on Figure 3. Central Texas is a cratonic dome, and much of the Cambrian comprises skeletal, ooid–peloid, and intraclast grainstone. Winston and Nicholls (1967) and Longacre (1970) established a trilobite zonation in these strata, and Miller et al. (1982) documented a conodont zonation and showed its relationship to the trilobite zonal units. Miller et al. (2012b) updated the Texas trilobite and conodont zonal frameworks. Work on brachiopod biostratigraphy is in progress (Freeman and Miller, 2011c).

The Oklahoma section comprises fine- and coarse-grained limestone deposited in a rapidly subsiding aulacogen. Stitt (1977) established a trilobite zonation there that was similar to the Texas zonation but had some refinements. Miller et al. (1982) showed relationships between conodont and trilobite zones in Oklahoma. Derby et al. (1991) discussed how the conodont zonation was useful for petroleum exploration in Oklahoma. Freeman and Stitt (1996) established calcitic brachiopod zones in these Oklahoma strata (Fig. 3).

Runkel et al. (2007) studied Cambrian and Lower Ordovician strata in northern Iowa and southern Minnesota (Fig. 1A) and constructed two detailed cross sections that together were ~800 km long. These cross-sections illustrated complex lateral facies changes and sequence-stratigraphic units. Control points for the cross sections were 38 exposures and drill cores, of which 34 had trilobite faunas and 17 yielded conodont faunas. The

zonal frameworks for these two fossil groups are so well integrated (Fig. 3) that detailed correlations were possible along these cross sections. These strata comprise sandstone, shale, and dolomite that were deposited near the Cambrian shoreline of the Canadian Shield, which was slightly east, north, and west of their study area. Samples processed for conodont faunas were from surface exposures and drill core provided by the Minnesota Geological Survey. Most of the samples were sandstone; some were dolomite. Miller processed samples using standard acid and heavy-liquid techniques, and enough conodont elements were recovered to provide good biostratigraphic control. The interval from which conodonts were recovered included all of the zonal units shown on Figure 3, but faunas diagnostic of the *Proconodontus muelleri*, *Eoconodontus*, and *Cordylodus proavus* Zones were the most common. The study by Runkel et al. (2007) demonstrates that the same conodont zonation that is recognized in slope facies in Nevada and in a variety of carbonate facies across the western United States (Fig. 1) can be extended into nearshore siliciclastic facies in the continental interior.

7. Trilobite faunas and biostratigraphy

Miller et al. (2011) reported that the base of the *Eoconodontus* conodont Zone lies within a part of the *Saukia* trilobite Zone that is characterized by rapid turnover of species in numerous upper Cambrian trilobite families, among them the Dikelocephalidae, Entomaspidae, Eurekaidae, Illaenuridae, Plethopeltidae, and Ptychaspidae. Study of collections recovered from sections in Utah and central Texas over the past two years confirms that species from more than fifteen trilobite genera are useful for determining the approximate position of the base of the *Eoconodontus* Zone in Laurentian platform successions. Updated range data composited from two of the most completely sampled sections in the Ibex area of Utah, the Steamboat Pass and Sneakover Pass sections (Fig. 1B), are provided in Figure 7. The new range data from Utah and

Texas further confirm that the proposed base of Stage 10 is within the upper part of the *Illaeonurus* Zone of western North America and in the lower part of the *Saukiella junia* Subzone of the *Saukia* Zone east of the Rocky Mountain region (Fig. 3).

A number of widespread species, such as *Proricephalus scapane* (Longacre, 1970), *Prosaugia pyrene* (Walcott, 1914), *Saukiella pepinensis* (Owen, 1852), and *Eurekia granulosa* Walcott, 1924, range upward almost to the proposed boundary level in Texas. Other species, such as *Meniscocoryphe platycephala* (Kobayashi, 1935) and *Stenopilus latus* Ulrich in Bridge, 1931, appear slightly above the base of the *Eoconodontus* Zone in many places. Perhaps most useful, however, are species such as *Illaenurus montanensis* Kobayashi, 1935, *Glaberaspis vescula* (Stitt, 1971), and (in particular) *Cherrycreekia benjii* Adrain and Westrop, 2004, which have relatively short ranges that span the base of the *Eoconodontus* Zone, making them good indicators of proximity to the proposed stage boundary (Fig. 7).

Full utilization of species in other important genera throughout this interval, such as *Euptychaspis* Ulrich in Bridge, 1931, *Idiomesus* Raymond, 1924, *Bowmania* Walcott, 1925, *Eurekia* Walcott, 1924, and *Bayfieldia* Clark, 1924, awaits completion of ongoing taxonomic refinement of species concepts within those and other broadly defined taxa that were described in earlier studies. The need for more taxonomic study is also reflected in extensive use of open nomenclature in the range chart presented in Figure 7. The narrowed species concepts that will emerge from such taxonomic study will significantly increase the number of trilobite taxa whose ranges can be used to constrain the position of the proposed stage boundary, particularly when integrated with data provided by other taxonomic groups (brachiopods, conodonts) and non-paleontological methods of chronocorrelation, such as carbon-isotope stratigraphy and sequence stratigraphy (see discussions in Taylor, 2009 and Taylor et al., 2012).

Figure 7 shows the ranges of trilobite species near the proposed stage boundary. Figure 3 shows a summary of older and younger trilobite zones that are well established in many parts of the USA. Strata assigned to the Notch Peak Formation are quite thick, and many sections have been measured (Miller et al., 2003). There has been little collecting of trilobites from strata below those shown in Figure 7. However, Miller et al. (2003, 2011) showed ranges of trilobites from younger strata, up to the top of the proposed Stage 10 and higher. Trilobite faunas from these younger strata are well known and are similar in Utah, Texas (Miller et al., 2012b), and Oklahoma (Stitt, 1977), where many of the uppermost Cambrian trilobite zones were established.

8. Brachiopod faunas and biostratigraphy

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322 Although calcitic-shelled brachiopods are quite rare in the Hellnmaria and Red Tops Members, the
323 zonation of Freeman and Stitt (1996) can be applied to these strata (Fig. 3). The proposed stage boundary is near the
324 base of the *Finkelburgia* Zone as defined in Oklahoma (Freeman and Stitt, 1996), and this genus has been reported
325 previously from western Utah (Miller et al., 2003; Miller et al., 2011). The base of the *Nanorthis* brachiopod Zone
326 (Freeman and Stitt, 1996) is based on the appearance of *Nanorthis hamburgensis* (Walcott, 1884), a species that is
327 not common but has been reported from the Lava Dam Five section (Miller et al., 2003; see Fig. 1B). This zone can
328 also be recognized in central Texas based on the occurrence of that species in the same stratigraphic interval
329 (Winston and Nicholls, 1967).

330 Phosphatic-shelled brachiopods are more useful for biostratigraphy than calcitic-shelled taxa in these strata
331 because many samples processed for conodonts yield moderately abundant linguliform brachiopods (Fig. 6).
332 Although the proposed stage boundary does not coincide with any defined linguliform brachiopod zone, the interval
333 is characterized by species of *Quadrisonia* Rowell and Henderson, 1978, *Zhanatella* Koneva, 1986, *Wahwahlingula*
334 Popov, Holmer, and Miller, 2002, and *Stittia* Freeman and Miller, 2011. Although all of the species appear to be
335 endemic to Laurentia, the first three genera are cosmopolitan. The base of the *Cordylodus proavus* conodont Zone
336 coincides with the extinction of species of the acrotretid genus *Quadrisonia*, which is followed by the appearance of
337 another similar acrotretid genus, *Eurytreta* Rowell, 1966 . This pattern of extinction and replacement has been well
338 documented in western Utah (Popov et al., 2002; Freeman and Miller, 2011 a, b) and has been extended to
339 Oklahoma and Texas (Freeman and Miller, 2011c and unpublished data). This turnover of genera occurs slightly
340 lower in the Malyi Karatau region of Kazakhstan, where the lowest species of the genus, *Eurytreta discors* Popov,
341 1988, appears in the *Eoconodontus allisonae* conodont Zone. This species has been documented only tentatively in
342 slope facies at the Tybo Canyon section, Nevada (Freeman and Miller, 2011a). *Eurytreta sublata* Popov, 1988
343 appears higher, in the *Cordylodus proavus* Zone, in both Laurentia and Kazakhstan and in the Shirgesht Formation
344 in Iran (Popov et al., 2009). Thus, the base of the *C. proavus* Zone can be identified based on the appearance of *E.*
345 *sublata*, or somewhat less precisely on the extinction of *Quadrisonia* followed by the appearance of *Eurytreta*.

346

9. Carbon-isotope stratigraphy

Carbon-isotope stratigraphy is a method of correlation that is independent of other methods, but when it is used with conodont, trilobite, and brachiopod biostratigraphy, the combination produces a very powerful framework for global correlation. Strata of the Notch Peak Formation contain a good record of variation in carbon isotopes preserved in marine carbonates. The most easily recognized feature of the carbon-isotope record is the *Hellnmaria*–*Red Tops* Boundary (HERB) Event, a prominent $\delta^{13}\text{C}$ excursion that begins slightly above the boundary between the *Hellnmaria* and *Red Tops* Members and continues into the Lava Dam Member (Fig. 8). The pattern of $\delta^{13}\text{C}$ variation within the HERB Event is remarkably consistent despite marked regional variability in the absolute magnitude of the excursion, and the event provides an important constraint for recognition and correlation of the base of the proposed Stage 10, including in barren or sparsely fossiliferous carbonate successions.

The HERB Event has been identified in a number of regions and appears to have global significance. Ripperdan et al. (1992) first identified a rapidly changing and roughly symmetrical negative excursion of $\sim 4\text{‰}$ in $\delta^{13}\text{C}$ values within the uppermost Chatsworth Limestone at Black Mountain (western Queensland, Australia). Ripperdan and Miller (1995) reported a coeval negative excursion of $\sim 2\text{‰}$ slightly above the boundary between the *Hellnmaria* and *Red Tops* Members of the Notch Peak Formation (Fig. 8A) at Lawson Cove (northern Wah Wah Mountains, western Utah, USA). Cooper et al. (2001) indirectly referred to an $\sim 5\text{‰}$ negative excursion in the Martin Point Member of the Green Point Formation, Cow Head Group, at Green Point (western Newfoundland, Canada), which later was reported in Ripperdan (2002). Miller et al. (2011, fig. 14) illustrated carbon-isotope profiles from several of these sections. Sial et al. (2008) found a negative excursion of $>4\text{‰}$ in the Flecha Formation at Quebrada de la Flecha (eastern Precordillera, Argentina) and correlated it to the negative excursions at Black Mountain and Lawson Cove. Others have suggested that the HERB Event is identifiable in the Tarim Basin and in Jilin Province, China (Jing et al., 2008; Zhang et al., 2000), and in the Kulyumbe River section in northwestern Siberia, Russia (Kouchinsky et al., 2008). Landing et al. (2011) summarized some of these previous studies in their discussion of the HERB Event as a marker for the base of the proposed Cambrian Stage 10. However, their conclusion that the HERB Event is different from the TOCE Event of Zhu et al. (2006) is almost certainly in error. The TOCE Event is

poorly defined, and none of our carbon-isotope profiles has documented a high-amplitude negative excursion in upper Cambrian strata that differs from the HERB Event.

Subsequent investigations have identified the HERB Event in other locales. In western Utah and southern Nevada (USA), at least six sections have coeval negative excursions of 1–2‰. An ~2‰ excursion was found in the coeval Shoshone Canyon section on the flank of the Bighorn Mountains (Cody, Wyoming, USA), and an ~1‰ excursion was found at the Threadgill Creek section in the Llano Uplift (central Texas, USA). A limited data set from Batyrbai Ravine (Malyi Karatau, Kazakhstan) suggests that part of the HERB Event may be present, but it is attenuated by a disconformity (Ripperdan, unpublished data).

A comparison of $\delta^{13}\text{C}$ profiles from coeval upper Cambrian strata reveals a complex set of features that are present in most or all of the sections for which we have detailed carbon-isotope profiles. A slow lowering of $\delta^{13}\text{C}$ values is preserved in the upper *Proconodontus posterocostatus* Zone (Fig. 8B, point 1). In sections where the *P. muelleri* Zone is relatively thick, the slow lowering is evident as a brief, asymmetrical ~1.5‰ negative excursion (Fig. 8B, points 1–2), followed by a positive peak in the upper *Proconodontus muelleri* Zone (Figs. 8B, D, point 3). The slow rate of lowering in $\delta^{13}\text{C}$ values was punctuated by an ~1.5‰ negative excursion that essentially coincides with the FAD of *Eoconodontus notchpeakensis* (Fig. 8D, point 4)). That excursion is confined to a very thin stratigraphic interval that is either covered (Fig. 8B, point 4) or inadequately sampled (Fig. 8C, point 4) in other Utah sections. This prominent excursion appears to be very useful for characterizing the proposed base of Stage 10 because it is so close to the FAD of *E. notchpeakensis*. Strata in that interval in other sections need further sampling for carbon isotopes to document the geometry of that part of the $\delta^{13}\text{C}$ profile.

The rate of lowering in $\delta^{13}\text{C}$ values accelerates somewhat above the FAD of *E. notchpeakensis* (Figs. 8B, C, D, point 5). The $\delta^{13}\text{C}$ values reach a minimum value near the middle of the thin *E. notchpeakensis* Subzone (Fig. 8, point 6, the negative peak of the HERB Event) and eventually return to pre-HERB $\delta^{13}\text{C}$ values at the base of the *Fryxellodontus inornatus* Subzone (Fig. 8A). Above the negative peak of the HERB Event (Fig. 8, point 6), $\delta^{13}\text{C}$ values increase in the upper part of the *E. notchpeakensis* Subzone. Most sections preserve a minor (~0.5‰) positive excursion away from the overall trend of rising values, slightly below the base of the *Cambrooistodus minutus* Subzone (Fig. 8, point 7). Slightly higher is another minor negative excursion that coincides with the base of the *C.*

minutus Subzone (Fig. 8, point 8). A minor negative excursion at that stratigraphic position is present in carbon-isotope profiles from several other areas (Miller et al., 2011, fig. 14).

The rising $\delta^{13}\text{C}$ values end with an $\sim 1\text{‰}$ decrease in values slightly below the base of the *Hirsutodontus hirsutus* Subzone (Fig. 8A, point 9). That feature is not readily identified in all sections and appears to be controlled in part by regional differences in depositional rate. This $\sim 1\text{‰}$ drop in $\delta^{13}\text{C}$ values ends virtually coincident with the base of the *H. hirsutus* Subzone and marks the level separating the top of the HERB Event (Fig. 8A, point 9) from a trio of $\sim 1\text{‰}$ oscillations within the middle to upper part of the proposed Stage 10 (Fig. 8A, points 10–16).

Ripperdan et al. (1992) and Ripperdan and Miller (1995) described the three $\sim 1\text{‰}$ oscillations noted above. They are increases in $\delta^{13}\text{C}$ values from points 10 to 11, 12 to 13, and 14 to 15 on Figure 8A. These features are useful for correlation within the upper part of the proposed Stage 10. The positive peak at Figure 8A, point 15 is only 10 cm below the base of the *Iapetognathus* Zone. The $\sim 2.5\text{‰}$ drop in $\delta^{13}\text{C}$ values from point 15 to 16 is a characteristic feature of the lowest part of the Ordovician.

In sections such as Black Mountain, Australia the full magnitude of change during the HERB Event yields a pattern of $\delta^{13}\text{C}$ variation that is unique through the interval from the Jiangshanian SPICE Event to the top of the Tremadocian Series. However, significant differences exist in the absolute magnitude of $\delta^{13}\text{C}$ variation at the minimum peak value of the HERB Event. At Black Mountain, Quebrada de la Flecha, Argentina, and Green Point, Newfoundland, the lowest $\delta^{13}\text{C}$ value is $\sim 4\text{‰}$ lower than $\delta^{13}\text{C}$ values found in pre-HERB strata. The maximum change in $\delta^{13}\text{C}$ values in western Utah, at Shoshone Canyon in northern Wyoming, and in central Texas is $\sim 1.5\text{‰}$. However, these differences in absolute magnitude do not appear to be related to the timing of $\delta^{13}\text{C}$ variation, which seem to be remarkably consistent between sections with well-resolved conodont biostratigraphy.

The series of negative and positive peaks present within the $\delta^{13}\text{C}$ profiles of the HERB Event has the potential to provide a highly resolved chronostratigraphic framework for the proposed Cambrian Stage 10. At Green Point, $\delta^{13}\text{C}$ values provide a reliable indicator for the *Eoconodontus*, *Cordylodus proavus*, and *Cordylodus intermedius* Zones despite the absence of fossils from the lower 90 m of section. At Quebrada de la Flecha, the

distinctive low point of $\delta^{13}\text{C}$ values establishes the age of the Flecha Formation and provides an opportunity for metre-scale intercontinental correlation despite the near absence of fossils.

The cause of major carbon-cycle perturbation evidenced by the HERB Event is not well understood. Strong regional differences exist in the absolute magnitude of the HERB Event excursion, but the role of paleogeography (if any) is unknown. Furthermore, there is no straightforward relationship between depositional environment and absolute magnitude of $\delta^{13}\text{C}$ change; the most striking $\delta^{13}\text{C}$ records are from successions deposited in very shallow (Black Mountain, Quebrada de la Flecha) and very deep (Green Point) environments.

10. Sequence stratigraphy

Miller et al. (2003) divided the Notch Peak Formation and the House Limestone into thirteen sequences, many of which were subdivided into smaller sequence units that were identified as packages (Fig. 3). Several of these sequences comprise predominantly high-energy strata that are interpreted as sea-level lowstand deposits, which are named and marked by shading on Figure 3; unshaded intervals are highstand deposits. The rates of subsidence and sediment deposition in western Utah were so rapid that unconformities are absent in most of the Cambrian, and relatively thick lowstand strata are well preserved. Miller et al. (2003) identified their sequence units using multiple criteria, including lithology, superpositional changes in lithofacies, and variations in insoluble residues (fine quartz sand) from conodont samples. High amounts of quartz sand are interpreted as indicating low sea level and increased sand influx from exposed source areas, whereas low amounts of quartz sand suggest highstands of sea level when some source areas were flooded and others were distant (Miller et al., 2003). Sequence 3 is characterized by very low abundance of quartz sand. Sequence 4 has higher concentrations of quartz sand, and the part of Sequence 5 assigned to the Red Tops Member has the highest concentrations of quartz sand, which is consistent with its deposition during lowstand conditions.

Sequences 1–4 are within the Hellnmaria Member, but Sequences 1–3 are not well understood except that they comprise a prolonged interval of rising sea level that is identified as the Hellnmaria Highstand on Figure 3. Detailed relationships among strata, conodont zones, trilobite zones, and sequences are shown in Figures 6–8. The top of Sequence 3 is an 11-m thrombolite unit at Sneakover Pass, which is interpreted as indicating peritidal

conditions at the top of Sequence 3. A thinner thrombolite unit occurs at the top of Sequence 3 at the Threadgill Creek section in central Texas (Miller et al., 2003, fig. 30). Sequence 4 is a thin interval that records filling of accommodation at the end of the Hellnmaria Highstand, and at Sneakover Pass it comprises mostly subtidal strata that shallow upward to 1.5 m of cross-stratified ooid–peloid grainstone and an overlying stromatolite bed 0.9 m thick at the top of Sequence 4. A thin stromatolite bed occurs also at the top of the Hellnmaria Member at the Lawson Cove, Notch Peak, Chalk Knolls South, and Drum Mountains sections (see lithologic descriptions in Miller et al., 2003).

Miller et al. (2003) divided Sequence 5 into three packages, with 5A and 5B comprising the Red Tops Member and the Red Tops Lowstand. Package 5C was the lower part of the Lava Dam Member and was interpreted as the highstand part of Sequence 5. Further study of the Red Tops Member indicates that it consists of three, rather than two, depositional packages, and it is revised here. To avoid confusion with the earlier lettered packages (5A–C), the new divisions are identified as Packages 5-1 through 5-4 (Fig. 3). Packages 5-1 through 5-3 are divisions of the Red Tops Member, and Package 5-4 is the lower part of the Lava Dam Member (Fig. 8).

Thin stromatolite beds occur within the Red Tops Lowstand in some sections and are used to subdivide Sequence 5 into shallowing-upward packages. A thin stromatolite bed occurs a little above the FAD of *E. notchpeakensis* at Lawson Cove, Notch Peak, and Chalk Knolls South (Fig. 1). Lithofacies changes in other sections also suggest shallowing at the same levels as the stromatolite beds. At Sneakover Pass the lower Red Tops Member includes a 2-m sequence with flat-pebble conglomerate at the base, overlain by ooid grainstone that records a shallow peritidal environment, overlain by a tidal-flat lime mudstone with large linguloid brachiopods, and then deepening to a second ooid grainstone. A thin lime mudstone with large linguloids occurs at the same level at the Lava Dam Five East section. These distinctive, shallow peritidal lithologies mark the top of Package 5-1 in the Red Tops Member (Figs. 6–8). The lower part of Package 5-1 is assigned to the *P. muelleri* Zone and the upper part to the *E. notchpeakensis* Subzone, so the FAD of *E. notchpeakensis* is not coincident with the boundaries of Package 5-1.

Similar evidence of shallowing occurs at the same levels in distant areas. The Clinetop Stromatolite Bed in central Colorado is at the same level as the stromatolite beds at the top of Package 5-1 (Myrow et al., 2007). Upward

476 shallowing at the same level is recorded at the Black Mountain section in Queensland, Australia in the Lily Creek
477 Sandstone Member of the Chatsworth Limestone (Shergold et al., 1991); this sandstone occurs in a very thick
478 carbonate succession. In all of these sections the apparent peak of the shallowing-upward succession is a little above
479 the FAD of *Eoconodontus notchpeakensis*, the level proposed to characterize the base of Cambrian Stage 10. The
480 widespread distribution of stromatolite beds or a tidal flat or a sandstone at the equivalent level suggests that
481 shallowing at that level is not due to just a local or regional change of sea level but suggests that Package 5-1 may be
482 useful for global correlation.

483 Package 5-2 is thicker than Package 5-1 and extends from the tidal-flat deposit just discussed up to another
484 indicator of especially shallow marine conditions in the upper Red Tops Member. Stromatolite mounds occur in the
485 upper Red Tops Member at Steamboat Pass, Sevier Lake Corral, and Chalk Knolls South, and they are interpreted as
486 indicating shallowing upward to peritidal conditions. All of these key beds occur just below or at the FAD of
487 *Cambroostodus minutus* (Fig. 6). Thin intervals of cherty lime mudstone occur at equivalent stratigraphic levels at
488 the Sneakover Pass and Notch Peak sections, and these lithologies also are interpreted as indicating peritidal to tidal-
489 flat conditions (see section descriptions in Miller et al., 2003). The top of Package 5-2 is placed at the bases of the
490 stromatolite beds and at the base of the coeval cherty lime mudstone bed at Sneakover Pass.

491 Package 5-3 extends up to the base of the Lava Dam Member, which comprises lime mudstones deposited
492 under deeper marine conditions than the Red Tops Member. Package 5-3 is 10.2 m thick at Sneakover Pass, and all
493 but the lowest 1.4 m is assigned to the *Cambroostodus minutus* Subzone.

494 Package 5-4 is the lower part of the Lava Dam Member, from the base of the member up to a thin interval
495 of high-energy lowstand deposits at the base of Sequence 6. Miller et al. (2003) identified this horizon at Lawson
496 Cove at 31.7 m above the base of the Lava Dam Member. Strata near the base of Sequence 6 have a relatively high
497 content of quartz sand (Miller et al., 2003, table 13) and typically weather to produce a poorly exposed interval. The
498 boundary between Sequences 5 and 6 at Sneakover Pass probably is in a covered interval from 22.6–26.5 m above
499 the base of the Lava Dam Member, and a conodont sample at 102.7 m has a high concentration of quartz sand,
500 typical of lowstand deposits. Miller et al. (2003) discussed younger sequences that would be included in the
501 proposed Stage 10.

11. Summary

The relationships among trilobite, conodont, and brachiopod zonal units and sequence stratigraphic units established in Texas, Oklahoma, and Utah are shown in Figure 3. These different correlation tools form a tightly integrated framework that has been used for decades to produce very detailed correlations among upper Cambrian strata in other areas, such as in the other states identified in Figure 1A, and elsewhere in Laurentia. These correlation tools are also integrated with carbon-isotope stratigraphy. The conodont biostratigraphy and carbon-isotope stratigraphy can be correlated around the world in a great variety of depositional settings and lithologies. Accordingly, establishing a GSSP for the base of Cambrian Stage in Utah would provide an unparalleled basis for global correlation. The three sections at Sneakover Pass, Lava Dam Five, and Steamboat Pass have similar sets of data and would provide an unusually large data set for a stratotype section and two informal accessory sections.

Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.

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670 **FIGURE CAPTIONS**

671

672 **Fig. 1.** Location map. A, United States of America. *Eoconodontus notchpeakensis* Subzone has been identified in
673 states that are named. States with black dots are discussed in text. B, Location of sections in western Utah. (LC)
674 Lawson Cove, (SP) Steamboat Pass, (LD5E) Lava Dam Five East, (LDN) Lava Dam North, (A) section A, (NP)
675 Notch Peak section, (SNP) Sneakover Pass, (CKS) Chalk Knolls South, (DM) Drum Mountains.

676 *Carte A, États-Unis d'Amérique. La sous-zone à Eoconodontus notchpeakensis a été identifiée dans les états*
677 *nommés. Nous discutons dans le texte les états indiqués avec un point noir. B, localisation des sections dans l'ouest*
678 *de l'Utah. (LC), Lawson Cove, (SP), Steamboat Pass, (LD5E), Lava Dam Five East, (LDN), Lava Dam North, (A),*
679 *section A, (NP), Notch Peak section, (SNP), Sneakover Pass, (CKS), Chalk Knolls South, (DM), Drum Mountains.*

680

Fig. 2. Part of Skull Rock Pass topographic map with location of Sneakover Pass section. (H), location of Hellnmaria Member (R), location of Red Tops Member (L), location of Lava Dam Member. Universal Transverse Mercator coordinates are shown, in UTM Zone 12.

Extrait de la carte topographique du Skull Rock Pass avec localisation de la section du Sneakover Pass. (H), localisation du Membre de Hellnmaria, (R), localisation du Membre des Red Tops, (L), localisation du Membre du Lava Dam. Nous utilisons les coordonnées transverses universelles de Mercator (UTM), dans la Zone UTM 12.

Fig. 3. Summary of stratigraphic units discussed in text. Modified from Miller et al. (2011, Fig. 8).

Résumé des unités stratigraphiques discutées dans le texte. Modifié d'après Miller et al. (2011, fig. 8).

Fig. 4. Photograph of lower part of Sneakover Pass section, showing where Hellnmaria Member was measured. View is toward the south; compare with Figure 2. All of Red Tops Member and lower part of Lava Dam Member are also exposed.

Une photographie de la partie inférieure de la section du Sneakover Pass qui montre le lieu où le Membre de Hellnmaria a été mesuré. La vue est orientée vers le sud; veuillez comparer avec la Figure 2. La totalité du Membre des Red Tops et la partie inférieure du Membre du Lava Dam affleurent également.

Fig. 5. Photograph of middle part of Sneakover Pass section, where Red Tops Member was measured. Measured section of Lava Dam Member is to the left of the photo. View is toward the southwest; compare with Figure 2. FAD and arrow indicate position of lowest occurrence of *Eoconodontus notchpeakensis*.

702 Une photographie de la partie médiane de la section du Sneakover Pass où le Membre des Red Tops a été mesuré.
703 La section mesurée du Membre du Lava Dam se trouve à la gauche de la photo. La vue est orientée vers le sud-
704 ouest; veuillez comparer avec Figure 2. FAS et la flèche indiquent la position de l'apparition la plus basse de
705 *Eoconodontus notchpeakensis*.

706

707 **Fig. 6.** Stratigraphic ranges of brachiopods and conodonts in the Sneakover Pass section, House Range, Utah, USA.
708 Wide black lines with a white line in the middle are parts of the *Proconodontus* Evolutionary Lineage. Small
709 horizontal lines along wide black lines show occurrences of species. Numbers are numbers of specimens for each
710 species. Sequence-stratigraphic units 3–8 are also shown; compare with Figure 3.

711 *Intervalles stratigraphiques des brachiopodes et conodontes de la section du Sneakover Pass, dans le House Range,*
712 *États-Unis. Les lignes noires larges avec une ligne blanche au milieu font partie de la Lignée Evolutive de*
713 *Proconodontus . De petites lignes horizontales le long des lignes noires grasses montrent la présence des espèces.*
714 *Les numéros sont les nombres de spécimens pour chaque espèce. Les unités stratigraphiques séquentielles 3 à 8 sont*
715 *également illustrées ; cf. Figure 3.*

716

717 **Fig. 7.** Composite stratigraphic ranges of trilobites in the Steamboat Pass and Sneakover Pass sections, House
718 Range, Utah, USA. White circles indicate collections from Steamboat Pass section, black circles indicate collections
719 from Sneakover Pass section. See Figure 1B for locations of sections. *Illiaenurus* Zone is an alternative trilobite zone
720 that can be recognized in this section, although most of the species shown are characteristic of the *Saukia* Zone.

721 *Zones stratigraphiques composites de trilobites dans les sections des Steamboat Pass et Sneakover Pass, House*
722 *Range, Utah, États-Unis. Les cercles blancs indiquent les collections de la section du Steamboat Pass, les cercles*
723 *noirs indiquent les collections de la section Sneakover Pass. Voir la localisation des sections en Figure 1B . La zone*
724 *à Illaenurus est une zone à trilobites alternative qui peut être reconnue dans cette section, bien que la plupart des*
725 *espèces ici soient typiques de la zone Saukia.*

726

727 **Fig. 8.** Carbon-isotope profile of four sections in Utah. See Figure 1B for locations of sections. Sequence
728 stratigraphy is also shown; compare with Fig. 4. Points 1–16 are positions along the profiles that can be correlated to
729 carbon-isotope profiles from other sections; see text for discussion.

730 *Profil des isotopes du carbone de quatre sections en Utah. Voir la Figure 1B pour la localisation des sections. Le*
731 *cadre stratigraphique séquentiel est également illustré; veuillez comparer avec la Fig. 4. Les points 1 à 17 le long*
732 *du profil peuvent être corrélés aux profils des isotopes du carbone des autres sections; voir le texte pour plus de*
733 *détails.*

734

Figure 1

Figure 2

CAMBRIAN SYSTEM				ORDOVICIAN	SEQUENCE STRATIGRAPHY		
Furongian Series				Lower			
proposed Stage 10				Tremacocian			
HOUSE LIMESTONE		HOUSE LIMESTONE					
Barn Canyon Member	75.6 m	CONODONT ZONATION		TRILOBITE ZONATION		CALCITIC BRACHIOPOD ZONATION	
		Cordylodus angulatus Zone		Symphysurina Zone	Symphysurina "bulbosa" Subzone		
		Iapetognathus Zone					
		Cordylodus lindstromi sensu lato Zone	Upper				Lower
Lava Dam Member	76.5 m	Cordylodus intermedius Zone	Clavohamulus hintzei Subzone	Symphysurina brevispicata Subzone	Apheoorthis Zone	Zone	
			Hirsutodontus simplex Subzone				
			Cordylodus proavus Zone				Clavohamulus elongatus Subzone
		Fryxellodontus inornatus Subzone					
Red Tops Member	26.5 m	Eoconodontus Zone	Hirsutodontus hirsutus Subzone	Tangshanaspis depressa	Nanorthis Zone	Zone	
Hellnmaria Member	318 m		Eoconodontus Zone	Cambrooistodus minutus Subzone	Eurekia apopsis Zone		Finkelburgia Zone
				Proconodontus muelleri Zone	Saukia Zone		
		Proconodontus posterocostatus Zone		Saukiella junia Subzone			
		Proconodontus tenuiserratus Zone				Billingsella Zone	

Figure 4

Figure 5

Figure 6

Figure 7