

# High-resolution stratigraphy and correlation of Cambrian strata using carbon isotopes: an example from the southern Appalachians, USA

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**Abstract** This study presents an example of using well-constrained stratigraphic trends in carbon isotope composition of marine carbonate deposits as a tool for high-resolution correlation of successions that lack prominent biomarkers. A large, positive carbon isotope excursion is recorded within the Steptoean (Furongian, Upper Cambrian) strata of the southern Appalachians in Tennessee. A coeval excursion (also known as SPICE) has been reported for the western United States (the Great Basin area), China, Kazakhstan, and Australia, indicating that this is a global phenomenon. The anatomy of this excursion was determined through extensive sampling of homogeneous micrite and dolomicrite from strata at the Thorn Hill locality in northeastern Tennessee. The  $\delta^{13}\text{C}$  values show an increase from the upper Nolichucky Shale into the overlying Maynardville Formation (Conasauga Group). The most positive  $\delta^{13}\text{C}$  values (+4 to +5 ‰ VPDB) correspond to the transition between the Maynardville and the Copper Ridge Dolomite (Knox Group). The  $\delta^{13}\text{C}$  values decline in the lower part of the Copper Ridge. This characteristic carbon isotope record is compared with the  $\delta^{13}\text{C}$  record from the Lee Valley locality, which is about 30 km away and contains a coeval succession of strata that represent similar carbonate platform depositional environments. A comparison of the  $\delta^{13}\text{C}$  records shows a remarkable similarity and provides the means for detailed correlation of these two stratigraphic successions. Next the results are compared with those from the Tazewell locality, which is in the northwesternmost outcrop belt of lower Paleozoic rocks in Tennessee. This section is separated

from the Thorn Hill and Lee Valley sections by three thrust faults and is truncated at the base by a thrust fault. The strata at the Tazewell locality differ from those at Thorn Hill and Lee Valley in that they were deposited more closely to the carbonate platform margin. Despite these differences, carbon isotope records proved very useful for correlation among the three successions. The results of this study encourage application of similar approaches in correlation of Steptoean strata at more widely spaced outcrops within and beyond the Appalachian basin.

**Keywords** Cambrian · Carbon isotopes · Steptoean · Maynardville · Southern Appalachians · SPICE

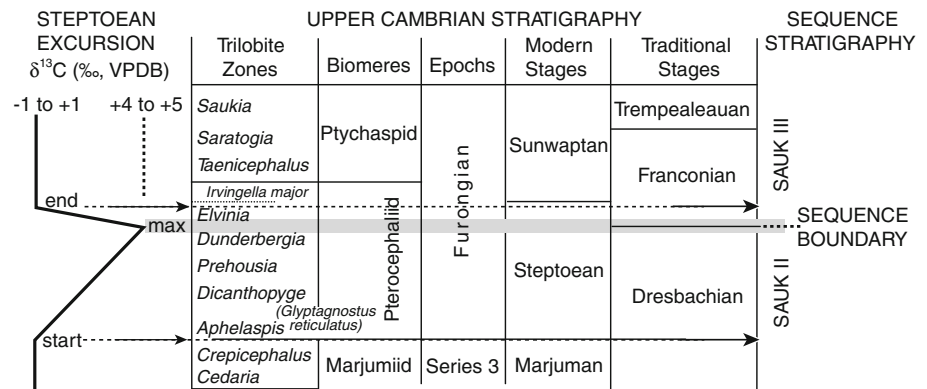
## Introduction

Carbon isotope stratigraphy is a very important and widely used stratigraphic tool (e.g., reviews by Immenhauser et al. 2008; Weissert et al. 2008). This tool can be especially powerful for high-resolution stratigraphy and correlation of sedimentary successions that lack prominent biostratigraphic markers. Stratigraphic correlation of Cambrian strata in the eastern United States is further complicated by structural deformation, extensive dolomitization, thick soil and vegetation cover, and by the presence of poorly exposed and geographically isolated and widely spaced outcrops.

A large positive carbon isotope excursion has been recorded in Steptoean (Furongian, Upper Cambrian) strata at numerous localities throughout the world (Fig. 1). This excursion has been named SPICE and the timing of the onset, the maximum, and the end of the excursion was determined by investigation of fossiliferous successions in the western United States (the Great Basin area), China, Kazakhstan and Australia (Brasier 1993; Saltzman et al.

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**Fig. 1** The global Steptoean positive carbon isotope excursion (SPICE) is defined as an increase in  $\delta^{13}\text{C}$  values of marine carbonate above their background value of  $-1$  to  $+1$  ‰ VPDB to a maximum of  $+4$  to  $+5$  ‰. The timing of the onset, the maximum (shaded interval), and the end of the excursion was determined by Brasier (1993) and Saltzman et al. (1998, 2000)



1998, 2000; Cowan et al. 2005; Kouchinsky et al. 2008). The beginning of the excursion is represented by an increase in  $\delta^{13}\text{C}$  values of marine carbonate above a background range of  $-1$  to  $+1$  ‰ VPDB (Fig. 1). This increase is coincident with the first occurrence of the trilobite *Glyptagnostus reticulatus*, which corresponds to the base of the Pterocephaliid biomere, the Steptoean stage, and the *Aphelaspis* zone (Fig. 1). Maximum  $\delta^{13}\text{C}$  values ( $+4$  to  $+5$  ‰ VPDB) span the late *Dunderbergia* to early *Elvinia* trilobite biozones within the Pterocephaliid biomere and also correspond to the late Steptoean or Dresbachian–Franconian boundary interval, which in Laurentia is commonly represented by a craton-wide hiatus separating the Sauk II and Sauk III sequences (Fig. 1). The return to background  $\delta^{13}\text{C}$  values marks the end of the excursion prior to the end of the Pterocephaliid biomere and during the *Elvinia* zone (Fig. 1).

The documented consistent relationship between the Steptoean carbon isotope excursion record and biostratigraphic markers on different continents suggests that carbon isotopes can be applied to stratigraphic studies of successions for which biostratigraphic determinations cannot be made. Carbon isotope stratigraphy can be applied with caution to even diagenetically altered and dolomitized carbonate strata because massive alteration of their primary carbon isotope values is usually hindered by relatively small concentrations of carbon in diagenetic fluids relative to host carbonate rocks (i.e., rock buffering). In addition, the Steptoean carbon isotope excursion is a particularly useful stratigraphic marker because of its great magnitude (up to 5 ‰ VPDB). Positive excursions of such magnitude are sufficiently uncommon in the geological record to be readily recognized and utilized in stratigraphic studies (Saltzman et al. 2000).

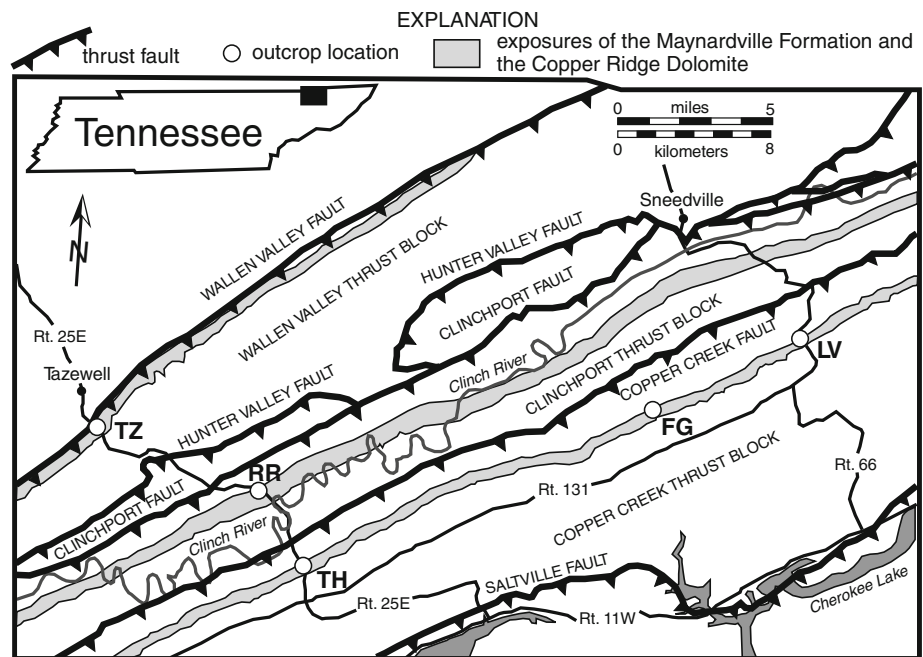
These characteristics allowed carbon isotope stratigraphy to be successfully applied to a succession of poorly fossiliferous and partially dolomitized Cambrian strata from the northeastern Tennessee Appalachians (Glumac and Walker 1998). The current work, on the other hand, evaluates the potential of using well constrained stratigraphic trends in

carbon isotopes as a tool for high-resolution stratigraphy and correlation of strata exposed at: (1) relatively closely spaced outcrops within the same thrust block with similar lithological successions representing similar depositional environments; and (2) outcrops separated by several thrust faults and exposing strata deposited within different environments. The application of this stratigraphic correlation tool allows recognition and correlation of coeval strata deposited during a time interval in the later Cambrian, which was characterized by sea-level fluctuations and by large perturbations in the global cycling of carbon, which may be related to changes in ocean stratification patterns, climate, rates of sediment accumulation, and organic productivity.

### Geological setting of the study area

Within the Valley and Ridge physiographic province of the northeastern Tennessee Appalachians, the Furoingian (Upper Cambrian) strata dip to the southeast and crop out within several imbricated, northeast-southwest trending thrust blocks (Fig. 2). These strata were deposited on a large carbonate platform along the passive margin of eastern Laurentia (Fig. 3). This carbonate platform faced the Iapetus Ocean to the east and the Conasauga intrashelf shale basin to the west (Fig. 3). Five outcrops of the upper Nolichucky Shale and the Maynardville Formation (Conasauga Group) and the lower Copper Ridge Dolomite (Knox Group) were examined to develop the stratigraphic framework for deposition and diagenesis of this later Cambrian interval (Figs. 2, 3; Glumac and Walker 2000, 2002). These strata were deposited along the western margin of the carbonate platform and the adjacent platform interior (Fig. 3). This study focuses on the Thorn Hill and Lee Valley outcrops from the Copper Creek thrust block and on the Tazewell locality from the Wallen Valley thrust block (Fig. 2). The Thorn Hill and Lee Valley outcrops are about 30 km apart and are separated by three thrust faults from the Tazewell locality, which is in the northwestward outcrop belt of Cambrian strata in Tennessee (Fig. 2).

**Fig. 2** Map of the study area in northeastern Tennessee Appalachians. Five outcrops of Cambrian strata have been examined to develop their depositional, diagenetic and sequence stratigraphic framework (Glumac 1997; Glumac and Walker 2000, 2002). The current study focuses on three of these outcrops: Thorn Hill (TH), Lee Valley (LV), and Tazewell (TZ). Note the location of the Thorn Hill and Lee Valley outcrops within the Copper Creek thrust block. The Tazewell outcrop is in the northwesternmost outcrop belt of Lower Paleozoic strata in Tennessee and is separated from the Thorn Hill outcrop by three thrust faults



### Summary of lithofacies and depositional environments

Detailed lithofacies descriptions and interpretations of depositional environments and diagenesis of the Maynardville Formation in northeastern Tennessee are included in Glumac (1997) and Glumac and Walker (2000, 2002). The following sections contain only brief summaries of the most pertinent information.

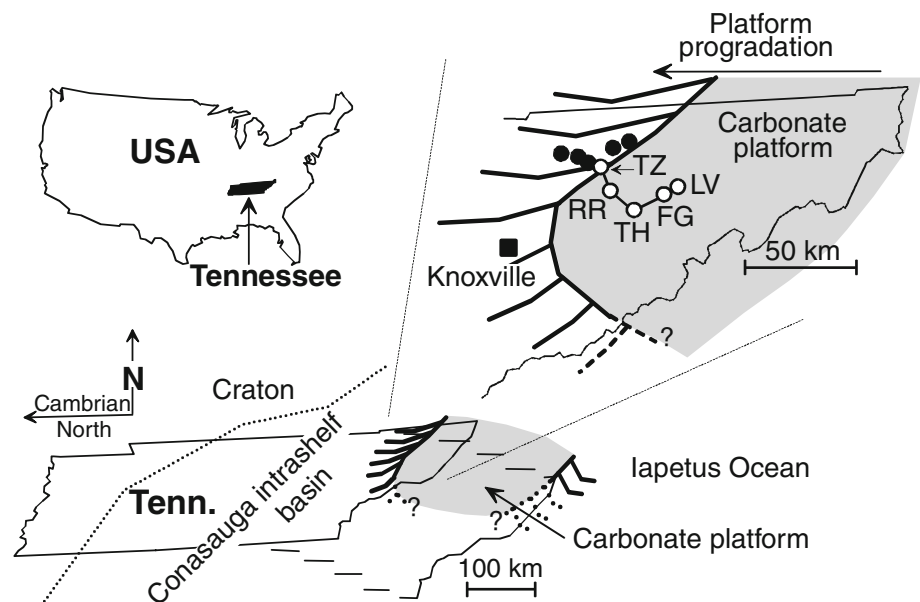
#### Lithofacies descriptions

The Maynardville Formation consists of: (1) a lower subtidal facies succession conformably underlain by the Nolichucky Shale; and (2) an upper peritidal facies succession, which is conformably overlain by similar peritidal deposits of the Copper Ridge Dolomite (Knox Group; Fig. 4). The base of the Maynardville is placed at the base of the lowest thick limestone unit above the Nolichucky Shale. The uppermost Nolichucky in the study area consists of calcareous and silty shale interbedded with carbonate layers, which are similar in composition to carbonate deposits from the lower Maynardville Formation (Fig. 4). These deposits are part of the subtidal facies association and are dominated by ribbon rocks, which contain centimeter-scale layers and lenses of limestone alternating with argillaceous dolostone, siltstone and shale (Fig. 4). Limestone layers are composed of normally graded skeletal packstone/grainstone, burrow-mottled mudstone, and peloidal packstone. Interbedded with the ribbon rocks are thrombolitic bioherms, coarse-grained intraclastic packstone/grainstone, and shale layers (Fig. 4). The subtidal

succession at the most basinward Tazewell outcrop also contains ooid grainstone, intraclastic-ooid grainstone, fossiliferous-peloidal packstone/grainstone, and more common thrombolitic bioherms (Fig. 4).

The vertical transition from the subtidal to the peritidal depositional succession is reflected in a change from ribbon rocks to microbial laminites or stratiform stromatolites (Fig. 4). At the Tazewell outcrop, the subtidal to peritidal transition is marked by the first occurrence of microbial laminites overlain by thrombolites and ribbon rocks (Fig. 4). Overlying this interval at Tazewell, and the microbial laminites at other localities, is a variety of peritidal lithofacies, most of which are substantially dolomitized (Fig. 4). Fining-upward centimeter-scale couplets or mechanical laminites are the predominant peritidal lithofacies (Fig. 4). Coarse-grained couplets contain intraclasts along sharp, scoured bases. Peloid-rich, medium-grained couplets display wavy and lenticular bedding and current and wave ripple cross-stratification. Upper parts of couplets are composed of horizontally laminated or massive dolomicrite. Couplets are interbedded with dolomitized mudstone and a variety of microbial carbonate deposits, including thrombolites, digitate stromatolites, columnar and domal stromatolites, and microbial laminites (Fig. 4). The vertical succession of the peritidal lithofacies is complex. Meter-scale shallowing-upward cycles with oolitic or thrombolitic bases, overlain by stromatolites and/or couplets, and capped by dolomitized mudstones and microbial laminites are present in the succession. Some of these cycles are also capped with subaerial exposure surfaces (Fig. 4). Peritidal deposits of the upper Maynardville Formation are

**Fig. 3** Schematic paleogeographic reconstruction of eastern Tennessee in the Middle to early later Cambrian showing a large carbonate platform (*shaded*) facing the Iapetus Ocean to the east and being separated from the exposed craton to the west by the Conasauga intrashelf shale basin. Palinspastic reconstruction is after Roeder and Witherspoon (1978). Enlargement of the western carbonate platform margin shows present-day location of outcrops (*solid circles*) and their palinspastically reconstructed location (*open circles*). This study focused on the Thorn Hill (TH), Lee Valley (LV) and Tazewell (TZ) outcrops (see also Fig. 2)



conformably overlain by similar peritidal carbonates of the Copper Ridge Dolomite (Knox Group). The Maynardville—Copper Ridge boundary is within a conformable interval that is 10–15 m thick and characterized by the occurrence of quartz and feldspar sand grains (Fig. 4).

#### Depositional environments

Deposition of shale and subtidal carbonate took place in deep-ramp (Nolichucky) to shallow-ramp, subtidal-shoal and lagoonal environments (lower Maynardville). The carbonate ramp was westward sloping toward the Conasauga intrashelf shale basin (Fig. 2). Microbial buildups, along with oolites and fossiliferous-peloidal grainstone deposits are most common at the most basinward Tazewell outcrop (Figs. 2, 3). These deposits formed on low-relief subtidal shoals. These shoals never developed into a prominent, continuous platform margin because the characteristic platform margin deposits are not abundant (Fig. 3). However, the shoals likely played an important role in the periodic establishment of subtidal, restricted, lagoonal-type sedimentation in more eastward localities. Thus, the subtidal succession of the Maynardville was deposited on a shallow ramp and in locally developed shoals and lagoonal settings. To the east the ramp was linked to a broad, semiarid carbonate tidal flat with a variety of peritidal environments (upper Maynardville and Copper Ridge). The Maynardville is a shallowing-upward succession that formed by carbonate platform aggradation and basinward progradation. The transition between the Maynardville and the Copper Ridge Dolomite is within a conformable peritidal carbonate succession that contains common sand-size siliciclastic detritus (Fig. 4). This

interval is interpreted as a sequence boundary zone correlative with the craton-wide late Steptoean (Dresbachian–Franconian or Sauk II–Sauk III) unconformity (Kozar et al. 1990; Osleger and Read 1993; Glumac and Walker 2000).

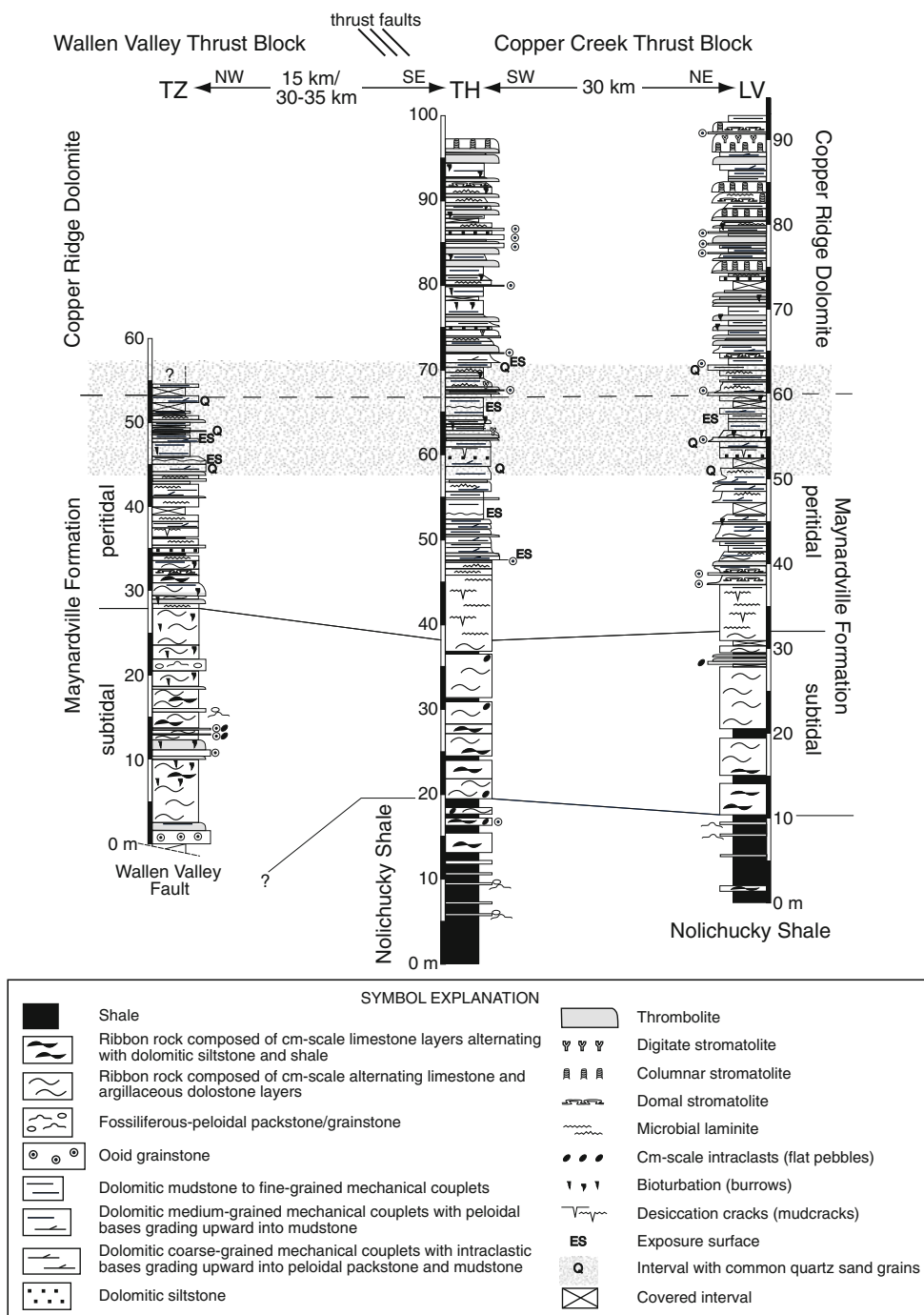
#### Carbon isotope stratigraphy

##### Methods

Following standard petrographic and cathodoluminescent microscopy, samples for isotope analysis were collected by drilling 2–10 mg of individual carbonate components from polished thin-section billets using a microscope-mounted microdrill. In the absence of abundant marine cements, this study relied on the use of fine-grained carbonate matrix composed of homogeneous calcimicrite or dolomicrite without visible cements and skeletal fragments, and with nonluminescent to dark cathodoluminescence patterns. The micritic layers of the ribbon rocks provided most of the calcimicritic matrix samples from the Nolichucky Shale and the subtidal package of the Maynardville. The transitional interval between the subtidal and peritidal depositional successions of the Maynardville Formation is represented by calcimicrite samples from microbial laminites or stratiform stromatolites. The peritidal package of the Maynardville and the Copper Ridge Dolomite was primarily sampled for dolomicritic matrix from mudstone, couplet and microbial deposits.

The powdered samples were roasted at 380°C for 1 h to remove volatile organic matter, and all samples were reacted with 100% H<sub>3</sub>PO<sub>4</sub>. Samples for isotope analysis from the Thorn Hill section were reacted off-line at 25°C

**Fig. 4** Lithostratigraphic comparison and correlation of the successions exposed at the Thorn Hill (TH), Lee Valley (LV) and Tazewell (TZ) localities. The columns are hung on the first occurrence of sandy siliciclastic detritus (*stippled area*). Note the distance and lithologic similarity between the Thorn Hill and Lee Valley sections from the same thrust block. These sections are separated from the Tazewell outcrop by three thrust faults, and their present-day (15 km) versus palinspastically reconstructed distance (30–35 km) is indicated. The Tazewell section is along a carbonate platform margin located to the west of a vast platform interior represented by the Thorn Hill and Lee Valley sections (see also Fig. 3)



for 24 h (calcite) or 48 h (dolomite) and analyzed on a VG-903 isotope ratio mass spectrometer. Samples from the Lee Valley section were reacted off-line overnight (calcite at 25°C and dolomite at 75°C) and analyzed on a Finnigan Delta Plus mass spectrometer. Samples from the Tazewell section were reacted at 70°C for 5 min and analyzed using an on-line automated carbonate preparation system (Kiel III) linked to a Finnigan-MAT Delta Plus XL mass spectrometer. Standard isobaric and phosphoric acid fractionation corrections were applied to all results, and analytical

precision was monitored through daily analysis of a variety of carbonate standards.

**Results for the Thorn Hill succession**

The anatomy of the Steptoean positive carbon isotope excursion in the southern Appalachians was first documented at Thorn Hill by Glumac and Walker (1998). The  $\delta^{13}\text{C}$  values show an increase from the upper Nolichucky Shale into the Maynardville Formation and a decline in the

lower part of the Copper Ridge (Fig. 5). The most positive  $\delta^{13}\text{C}$  values (+4 to +5 ‰ VPDB) correspond to the transition between the Maynardville and the Copper Ridge, which is characterized by common sandy siliciclastic detritus (Fig. 5).

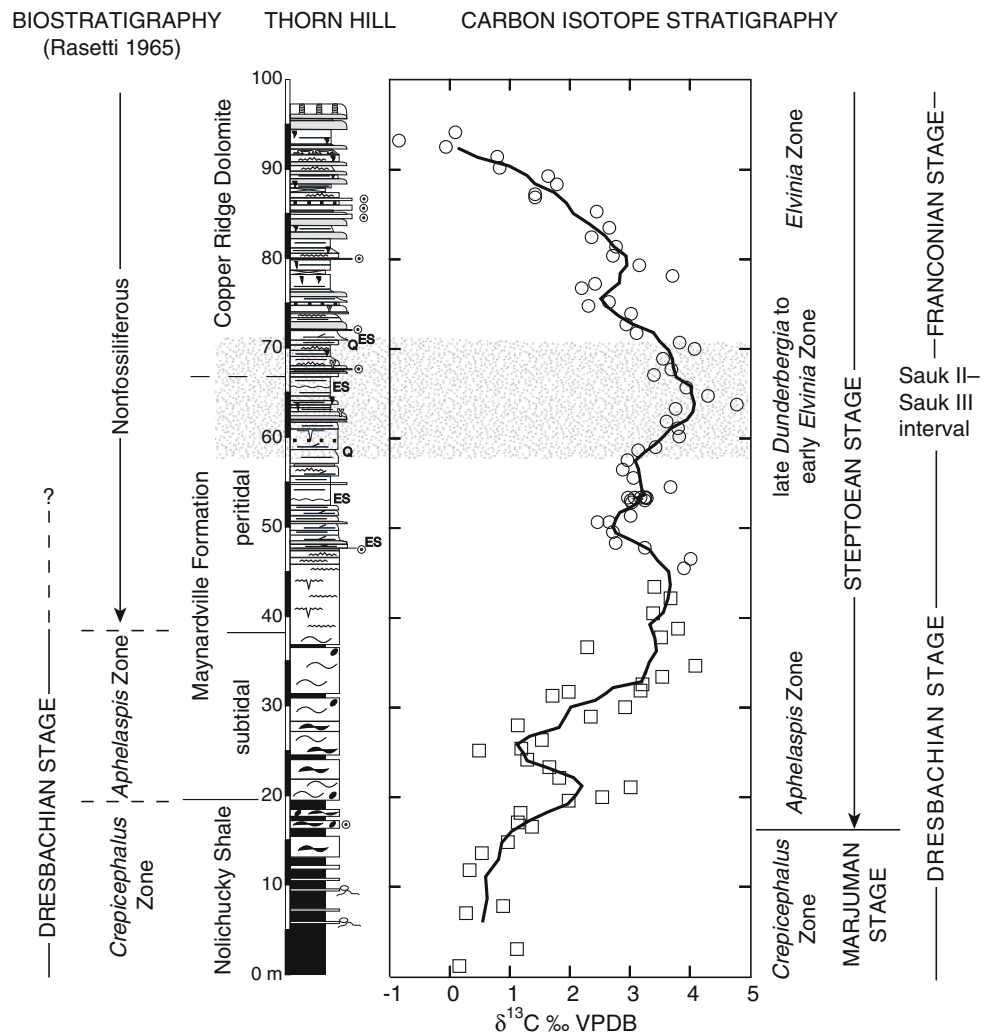
Trilobites of the *Cedaria* through the *Aphelaspis* zone have been identified from the Upper Nolichucky and the Lower Maynardville, and the Trempealeuan fauna is present in the Upper Copper Ridge (Bridge 1956; Derby 1965; Rasetti 1965), but the remaining portion of this Upper Cambrian succession is extensively dolomitized and poorly fossiliferous (Fig. 5). Therefore, carbon isotopes provide a means for substantially improving the stratigraphic interpretation of this succession (Fig. 5). The start of the excursion in the southern Appalachians confirms that the base of the *Aphelaspis* zone and Pterocephaliid biomere is in the upper Nolichucky Formation (Fig. 5). The return to background  $\delta^{13}\text{C}$  values in the lower Copper Ridge Dolomite, prior to the end of the Pterocephaliid biomere and during the *Elvinia* zone, supports an early Franconian

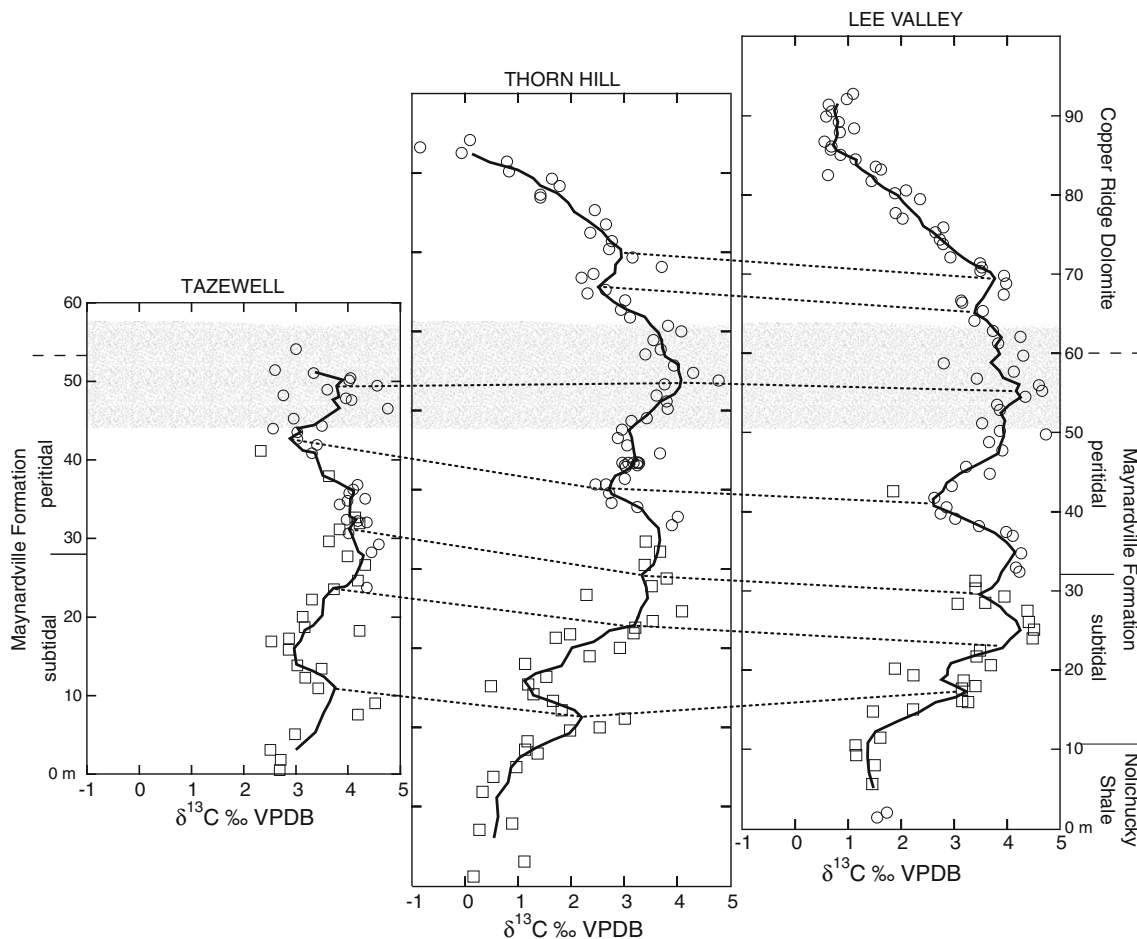
or late Steptoean age for the lowermost Knox Group in the southern Appalachians (Fig. 5). The maximum carbon isotope excursion in the southern Appalachians corresponds with the occurrence of common siliciclastic detritus (Fig. 5). The excursion maximum occurred during the late *Dunderbergia* (late Dresbachian) and early *Elvinia* (early Franconian) faunal zones and is coincident with siliciclastic influx during sea-level lowstand and formation of the correlative conformity associated with the craton-wide Dresbachian–Franconian unconformity or Sauk II–Sauk III hiatus and sequence boundary (Figs. 1, 5).

Comparison with the Lee Valley and Tazewell sections

The carbon isotope record at the Thorn Hill locality is first compared with the  $\delta^{13}\text{C}$  record from the Lee Valley locality (Fig. 6). The Lee Valley and Thorn Hill outcrops are about 30 km apart and are both in the Copper Creek thrust block (Fig. 2). These outcrops contain successions of strata that represent similar depositional environments on a

**Fig. 5** Biostratigraphy versus lithostratigraphy and carbon isotope stratigraphy of the Thorn Hill section. Note the limits of biostratigraphy due to the poorly fossiliferous nature of the strata. Anatomy of the Steptoean carbon isotope excursion was determined through detailed sampling of calcimicritic (*squares*) and dolomicritic (*circles*) matrix samples (data from Glumac and Walker 1998) and is represented as a 5-point running average curve. Carbon isotopes were used to significantly improve stratigraphic interpretations for this interval. See Fig. 4 for the explanation of symbols and the text for more detailed discussion





**Fig. 6** Comparison of carbon isotope records shown as a 5-point running average curve based on analysis of calcimicritic (*squares*) and dolomitic (*circles*) matrix samples from the Thorn Hill section with those at the Lee Valley and Tazewell sections. The diagrams are

hung at the occurrence of sandy siliciclastic detritus (stippled area; see also Fig. 4). Segments of the curves showing similar carbon isotope trends are identified and their correlation is shown with dotted lines

large carbonate platform that was separated from the exposed Laurentian craton to the west by the Conasauga intrashelf shale basin (Figs. 3, 4).

Lithostratigraphic correlation between these two very similar stratigraphic successions includes the correlation of the formation boundaries and the boundary between the subtidal and peritidal lithofacies successions of the Maynardville Formation (Fig. 4). The placement of the formation boundaries is fairly arbitrary and variable as many different criteria have been used by previous workers. The base of the Maynardville is placed at the base of the first thick carbonate layer above the Nolichucky Shale (Fig. 4). The most common criteria for the placement of the boundary between the Maynardville and the Copper Ridge Dolomite include the first appearance of: (1) abundant chert (Rodgers 1953; Bridge 1956); (2) thick-bedded, coarsely crystalline dolostone (Bridge 1956; Milici 1973); or (3) thin quartz sandstone layers (Finlayson et al. 1965; Oder and Milici 1965; see also Hasson and Haase 1988). A

combination of these criteria was used in this study (Fig. 4). The Maynardville–Copper Ridge boundary is contained within a conformable interval that is 10–15 m thick and characterized by the occurrence of quartz and feldspar sand grains (Fig. 4). As defined, these formation and lithofacies boundaries could be diachronous across platform, but in this situation (closely spaced outcrops) they may be coeval and their correlation may have chronostratigraphic significance. Carbon isotopes were used to test this hypothesis.

A comparison of the  $\delta^{13}\text{C}$  records between the Thorn Hill and Lee Valley successions was accomplished using 5-point running average curves and by correlating segments of the curves that show similar trends (Fig. 6). This comparison showed a remarkable similarity between the  $\delta^{13}\text{C}$  records for the two localities and provided the means for the detailed correlation of these two stratigraphic successions as well as for testing the isochroneity of the correlated lithostratigraphic units (Fig. 6).

A similar comparison was made with strata from the Tazewell section (Fig. 6), which is substantially thinner in comparison with the Thorn Hill and Lee Valley sections, and it also differs from these two sections lithologically (Fig. 4). This section represents the northwesternmost exposure of Cambrian deposits in the area (Fig. 2) and it exposes strata deposited closer to the carbonate platform margin (Fig. 3). Lithostratigraphic correlation of the Tazewell section and its more eastern platform equivalents was therefore more challenging (Fig. 4). The carbon isotope record for the Tazewell section, however, nicely matches those recorded at the Thorn Hill and Lee Valley sections (Fig. 6) and was therefore used to improve stratigraphic correlation between these carbonate platform margin and interior successions.

## Discussion

Stratigraphic correlation based on the comparison of carbon isotope records (Fig. 6) was applied to the previously established lithostratigraphic correlation (Fig. 4). This comparison is illustrated in Fig. 7. High-resolution stratigraphy was attempted by correlating segments of the carbon isotope curves that show similar trends and may be coeval. Such correlation, for example, confirms that the input of coarse-grained siliciclastics affected a large portion of the carbonate platform at about the same time (Fig. 7). This platform-wide siliciclastic input is related to the Sauk II–III regression (Lochman-Balk 1971; Palmer 1981; Bond et al. 1988) and reflects a changing style of carbonate platform sedimentation in response to a sea level lowering. The recognition of this change allows interpretations of this interval in sequence stratigraphic terms as a correlative conformity interval or a sequence boundary zone, which can be correlated with the Sauk II–III unconformity on the craton (Kozar et al. 1990; Osleger and Read 1993; Glumac and Walker 1998). Carbon isotopes are very useful for the recognition of this important stratigraphic interval in the Appalachians because large unconformities were not developed along the subsiding passive margin of eastern Laurentia. The record of carbonate platform deposition is instead characterized by highly condensed sections and the presence of coarse-grained siliciclastic detritus (James and Stevens 1986; Koerschner and Read 1989; Read 1989; Cowan and James 1993). These records of sea-level fall are usually subtle and difficult to recognize, especially in the absence of large laterally extensive outcrops and prominent biostratigraphic markers in geographically isolated, commonly poorly exposed, highly dolomitized and structurally deformed sections that characterize the Appalachian region.

In addition, the high-resolution carbon isotope stratigraphy illustrates subtle differences in sedimentation rates

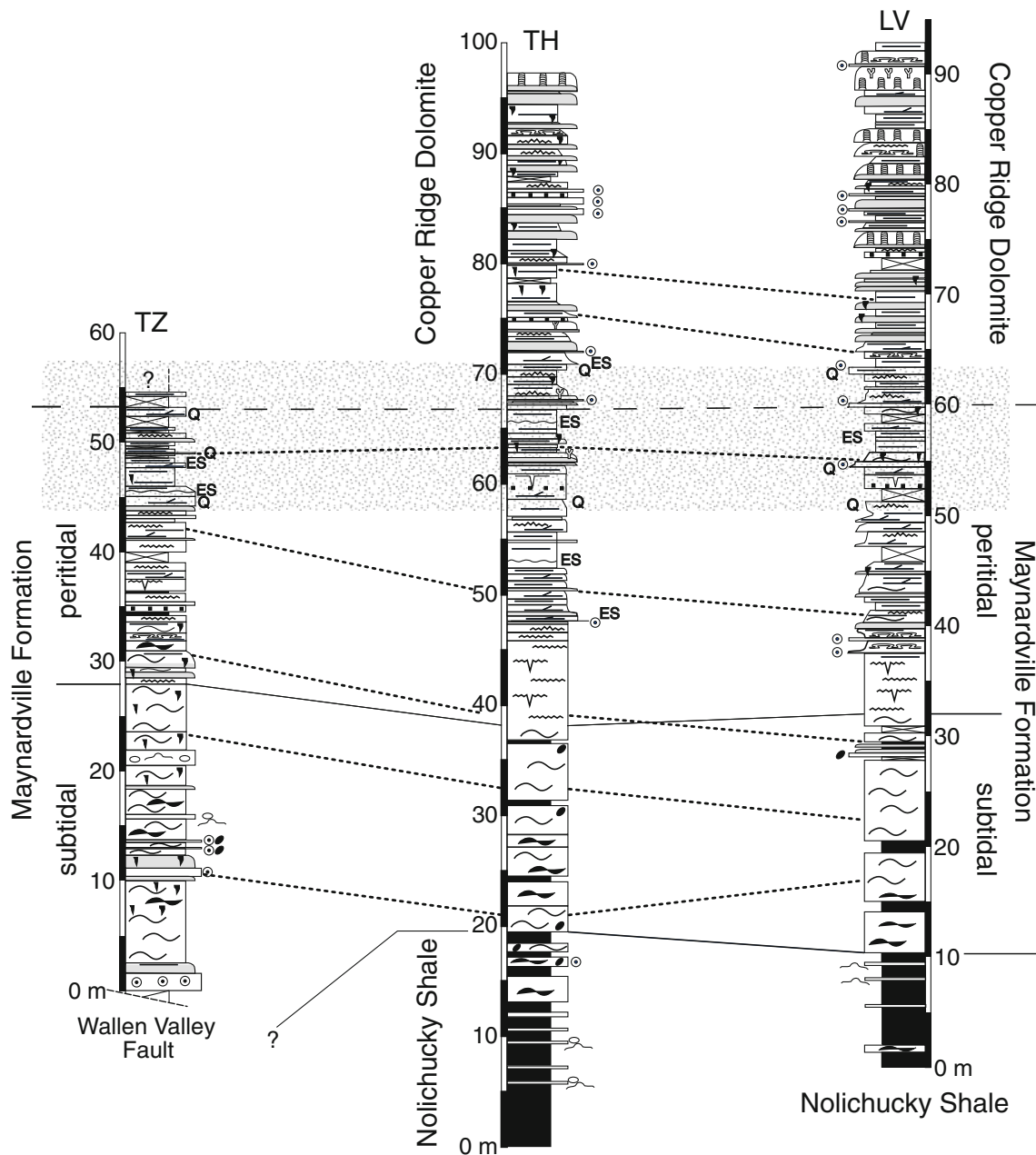
among the successions (Fig. 7). One example is the lower sedimentation rate indicated for the Tazewell section in association with the first input of coarse siliciclastics in the area (about 40–50 m above the base of the section) relative to the interpreted coeval time slice at Thorn Hill and Lee Valley (Fig. 7). The Tazewell area represented a slightly elevated carbonate platform margin located to the west of the vast carbonate platform interior (Fig. 3). Therefore, carbonate sedimentation at Tazewell may have been reduced more than in the regions farther east due to the sea level lowering and siliciclastic input from the exposed craton to the west (Fig. 3). The slightly elevated topography at the Tazewell locality may have also been responsible for the slightly earlier onset of peritidal deposition in this area as compared to the Thorn Hill and Lee Valley localities (Fig. 7).

The correlation based on carbon isotopes also suggests that the deposition of microbial laminites, and thus the initiation of peritidal deposition, started slightly earlier at Thorn Hill than at the Lee Valley section (Fig. 7). In addition, carbon isotope stratigraphy supports a coeval nature for some of the subaerial exposure events and their lateral continuity, such as the exposure surface immediately below the Maynardville–Copper Creek boundary at Thorn Hill and Lee Valley (Fig. 7). On the other hand, most other exposure surfaces do not appear to be laterally correlative between the successions (Fig. 7). This observation is in agreement with the previously proposed notion that the meter-scale shallowing-upward cycles or parasequences in these strata cannot be laterally correlated with certainty (Glumac and Walker 2000).

The final example of the use of carbon isotopes in improving stratigraphic determination and correlation involves the boundary between the Nolichucky and the Maynardville Formations. The correlation between the Lee Valley and Thorn Hill successions based on carbon isotopes supports placing this boundary somewhat lower in the Thorn Hill succession than currently indicated (Fig. 7). Placing the boundary at the base of the 2.5-m thick carbonate unit located about 13 m above the base of the section may make better sense not only lithologically but also chronologically (Fig. 7).

Similar to this example of different possibilities for the placement of lithologic correlation lines, there may be other options for defining and correlating segments of the carbon isotope curves. In chemostratigraphy, it is generally accepted that if carbon isotope records show similar fluctuations, such fluctuations can be correlated within a dating uncertainty, but also that the correlation of records with different absolute values and amplitudes could be challenging and may result in controversial interpretations (Weissert et al. 2008). To minimize the amount of uncertainty in stratigraphic correlation, the carbon isotope curves





**Fig. 7** Superposition of carbon isotope correlation from Fig. 6 (dotted lines) and lithologic correlation from Fig. 4. See the text for discussion

analyzed in this study were subdivided into the smallest number of segments that exhibit the greatest similarity in amplitudes and absolute values (Fig. 6). The observed differences between the correlated curve segments, on the other hand, likely reflect variable influence of local to regional elements on carbon isotope signatures of these shallow-water marine carbonates superimposed on secular isotope variations (Immenhauser et al. 2008). Therefore, when carefully documented and interpreted, carbon isotopes can provide unique information about the details of carbonate platform anatomy and depositional dynamics that are not available otherwise.

## Conclusions

A comparison of the  $\delta^{13}\text{C}$  records between three stratigraphic sections of Steptoean (Furongian, Upper Cambrian) strata from the northeastern Tennessee Appalachians reveals a remarkable similarity and provides the means for a detailed correlation of these successions. These strata were deposited on a carbonate platform along the passive Laurentian margin. The platform was separated from the exposed Laurentian craton to the west by an intrashelf shale basin and faced the Iapetus Ocean to the east. The stratigraphic successions that consist of the Nolichucky

Shale and the Maynardville Formation of the Conasauga Group and the lower part of the overlying Copper Ridge Dolomite (Knox Group) record the large global Steptoean positive carbon isotope excursion (SPICE). Two of the sections are closely spaced successions of similar shallowing upward carbonate platform strata and are separated from the third section by three thrust faults. The third section is in the northwesternmost outcrop belt of Lower Paleozoic strata in the area and was deposited more closely to a slightly elevated western carbonate platform margin. The record of the Steptoean carbon isotope excursion establishes concurrent deposition of all three stratigraphic successions and enhances stratigraphic interpretations of the poorly fossiliferous and partially dolomitized strata that contain only subtle evidence for the presence of the major Sauk II–III sequence bounding interval. The comparison of segments of the carbon isotope curves with similar trends allowed for the high-resolution stratigraphic correlation and provided unique insights into the anatomy and dynamics of carbonate platform deposition during the times of changing sea levels and major perturbations in the global carbon cycling. The results encourage application of similar approaches in stratigraphic studies of Steptoean strata elsewhere.

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