Revised correlation of Silurian Provincial Series of North America with global and regional chronostratigraphic units and $\delta^{13}$C$_{\text{carb}}$ chemostratigraphy

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Recent revisions to the biostratigraphic and chronostratigraphic assignment of strata from the type area of the Niagaran Provincial Series (a regional chronostratigraphic unit) have demonstrated the need to revise the chronostratigraphic correlation of the Silurian System of North America. Recently, the working group to restudy the base of the Wenlock Series has developed an extremely high-resolution global chronostratigraphy for the Telychian and Sheinwoodian stages by integrating graptolite and conodont biostratigraphy with carbonate carbon isotope ($\delta^{13}$C$_{\text{carb}}$) chemostratigraphy. This improved global chronostratigraphy has required such significant chronostratigraphic revisions to the North American succession that much of the Silurian System in North America is currently in a state of flux and needs further refinement. This report serves as an update of the progress on recalibrating the global chronostratigraphic correlation of North American Provincial Series and Stage boundaries in their type area. The revised North American classification is correlated with global series and stages as well as regional classifications used in the United Kingdom, the East Baltic, Australia, China, the Barrandian, and Altai. Twenty-four potential stage slices, based primarily on graptolite and conodont zones and correlated to the global series and stages, are illustrated alongside a new composite $\delta^{13}$C$_{\text{carb}}$ curve for the Silurian. Conodont, graptolite, isotope, New York, Ontario, series, Silurian, stage.

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The Silurian System was the first to have a globally applicable classification of series and stages when the present definitions of the four Silurian series (Llandovery, Wenlock, Ludlow, and Pridoli) and seven stages (Rhuddanian, Aeronian, Telychian, Sheinwoodian, Homerian, Gorstian, and Ludfordian) were established. DOI 10.1111/j.1502-3931.2010.00234.x © 2010 The Authors, Journal compilation © 2010 The Lethaia Foundation
were formalized by the International Subcommission on Silurian Stratigraphy (ISSS) more than 25 years ago (Holland 1984; Bassett 1985). Stable chronostratigraphic nomenclature and the comparatively cosmopolitan nature of Silurian marine fauna have led most regional stratigraphic bodies to abandon regional chronostratigraphic terms in favour of the global Silurian series and stages ratified by the ISSS. North America is among the last examples where regional chronostratigraphic terms (particularly at the series level) are still in use (Fig. 1).

As early as 1970, it was becoming clear that correlation within North America accomplished using North American Provincial Series and Stages (e.g. Alexandrian, Niagaran, and Cayugan series) had been problematical and calls for the adoption of the global series and stages for the Silurian of North America had begun (Berry & Boucot 1970). Decades of misuse of stratigraphic terms throughout North American Silurian literature, and the inconsistency between Silurian chronostratigraphic terms used by the United States Geological Survey (USGS), the American Association of Petroleum Geologists (AAPG), the Geological Survey of Canada (GSC), and the Ontario Geological Survey (OGS), have adversely impacted the utility and meaning of these regional chronostratigraphic terms. The purpose of this report is to show how commonly used regional terms from North America correlate with each other and to show how recent findings change their placement within the global chronostratigraphic scheme. In addition, we present an improved composite $\delta^{13}C_{\text{carb}}$ curve for the Silurian. Finally, following the lead of the International Subcommission on Ordovician Stratigraphy (Bergström et al. 2009), we informally introduce potential subdivisions of the global Silurian stages that are biochemostratigraphically defined, referred to as stage slices. It is important to note that this report does not constitute ISSS support for or official revision of any regional stratigraphic scheme. The authors are in agreement with Berry & Boucot (1970), Norford (1997), and many others that the global series and stages should be used for the North American Silurian succession.

**Global correlation of Silurian chronostratigraphic units**

Silurian biostratigraphy underwent a period of major advancement at the end of the last century (late 1990s) with the publication of a generalized graptolite zonation (Koren’ et al. 1996; Loydell 1998) for the entire Silurian as well as major revisions to Silurian conodont taxonomy and biostratigraphy during a

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**SILURIAN CHRONOSTRATIGRAPHIC CHART**

![Chart showing proposed correlation between the revised North American classification and global and regional series and stages presently in use from regions of major Silurian outcrop. The GSSP boxes show the location of the Global Boundary Stratotype Section and Point for the global Silurian series and stages.](chart.png)
span of just a few years (Jeppsson 1997; Männik 1998). The current Silurian timescale (Ogg et al. 2008) assumes a correlation between stage (and therefore series and systemic) boundaries and graptolite zones and as a result graptolite-bearing successions can be correlated directly to the global chronostratigraphic classification. Conodont-bearing successions have traditionally been more difficult to correlate precisely with the global scheme, but significant improvements to Silurian conodont biostratigraphic zonations have begun to alleviate this problem (e.g. Jeppsson 1997, 2005; Männik 1998, 2007; Jeppsson & Aldridge 2000; Jeppsson & Calner 2003; Jeppsson et al. 2006; Corriga & Corradini 2009). Major advancements in correlation of conodont and graptolite zones (e.g. Loydell et al. 1998, 2003) and their integration with carbonate carbon isotope δ13C_carb chemostratigraphy as a chronostratigraphic tool (Kaljo et al. 2003, 2007; Munnecke et al. 2003; Cramer et al. 2006a,b; Kaljo & Martma 2006; Melchin & Holmden 2006; Jeppsson et al. 2007) have made it possible to correlate some intervals of the Silurian globally and with precision far finer than the stage level (Cramer et al. 2010). A detailed discussion of global chronostratigraphic correlation at the stage level (and finer) is beyond the scope of this report and below we include a few brief notes as updates on Silurian chronostratigraphic issues from selected regions worldwide.

United Kingdom

Seven of the eight Silurian Global Boundary Stratotype Section and Point (GSSP) ‘golden spikes’ are located in the United Kingdom, which means that British Silurian chronostratigraphy is necessarily coupled to the global chronostratigraphic classification (the exception is the base of the Pridoli Series). A recent compilation produced for the British Geological Conservation Review Series (Aldridge et al. 2000) combined with the seminal work of Holland & Bassett (1989) provide an excellent overview of British Silurian stratigraphy and the reader is referred to these works for more detailed information. The results of two working groups of the ISSS to restudy Silurian chronostratigraphic boundaries have recently revised or suggested revision to the biostratigraphic correlation of the base of the Silurian System and the base of the Wenlock Series respectively, and their findings are summarized briefly here.

The new biostratigraphic definition of the base of the Silurian System proposed by Melchin & Williams (2000), as coincident with the first appearance of the graptolite Akidograptus ascensus and the base of the A. ascensus graptolite Zone, 1.6 metres above the base of the Birkhill Shale at the GSSP, was accepted by the ISSS in 2006 and ratified by the International Union of Geological Sciences (IUGS) in 2007 (see Rong et al. 2008). The GSSP for the base of the Sheinwoodian Stage and Wenlock Series was originally stated to coincide with the first appearance of the graptolite Cyrtograptus centrifugus (Bassett et al. 1975) and the base of the C. centrifugus graptolite Zone. Based upon information not yet available when the base Wenlock GSSP was ratified (Martinsson et al. 1981), it is now clear that the position of the GSSP is significantly above the first appearance of C. centrifugus (e.g. Mabillard & Aldridge 1985; Loydell et al. 2003; Mullins & Aldridge 2004; Cramer et al. 2010). Therefore, the ISSS was faced with a decision, either: (1) to move the GSSP to a location known to be coincident with the base of the C. centrifugus graptolite Zone; or (2) retain the current GSSP and redefine the biostratigraphic correlation of this position.

In a report to the ISSS, the working group to restudy the base of the Wenlock Series suggested that the GSSP for the base of the Wenlock Series be retained, but that the biostratigraphic correlation, as coincident with the base of the C. centrifugus graptolite Zone, needed to be revised (Loydell 2008). There are two potential new levels (one graptolite and one conodont) for the base of the Wenlock Series: (1) correlating to a position at or slightly above the base of the C. murchisoni graptolite Zone, marked by the first appearance of C. murchisoni (a full zone higher than the original position); or (2) close to the Ireviken Event Datum 2, the base of the Upper Pseudooneotodus bicornis conodont Zone, marked by the last appearance of the conodonts Ozarkodina polinclinata polinclinata, Apsidognathus ruginosus, and A. walmsleyi (see Jeppsson 1997). Recent integration of detailed global graptolite and conodont biostratigraphy with high-resolution δ13C_carb chemostratigraphy surrounding the base of the Wenlock Series has documented the global utility of these definitions and suggested that these two positions (base of the C. murchisoni Zone and Ireviken Event Datum 2) are likely separated by less than 100 kyr (Cramer et al. 2010). Therefore, following Loydell (2008), Cramer et al. (2010) considered the base of the C. murchisoni graptolite Zone to correlate with the base of the Wenlock Series.

The most recent iteration of the Geological Time Scale (Ogg et al. 2008) also recognized that the GSSP correlates with this biostratigraphic position (their table 6.1), but in their correlation chart (their fig. 6.4) showed the base of the Wenlock at the base of a combined C. centrifugus–C. murchisoni graptolite Zone. An official position regarding revisions to the base of the Wenlock Series has yet to be reached by the ISSS, and although the de facto correlation of the GSSP is
currently at a level that approximates the base of the *C. mucronisoni* graptolite Zone, that is subject to change should the ISSS choose in the future to select a new GSSP that coincides with the originally intended biostratigraphic level (i.e. the base of the *C. centrifugus* graptolite Zone).

Silurian units smaller than the stage level have been formally described for the Homerian Stage of the Wenlock Series from the Welsh Borderlands (Basset et al. 1975). The two Homerian divisions, Glededon and Whitewell, although not officially recognized by the ISSS, are still occasionally found in print (e.g. Jeppsson et al. 2006). The four-stage division of the Ludlow Series (Eltonian, Bringewoodian, Leintwardian, and Whitcliffian) defined by Holland et al. (1963) was replaced by the late 1970s with the present two stage (Gorstian and Ludfordian) division. Because the type localities for all six terms are located in the United Kingdom, the older terms were absorbed by the present global classification. These regional terms have been largely abandoned and are in disuse, as is the term, Downton, which had been proposed as the fourth Silurian Series (Basset et al. 1982) and for a time was common (sometimes as Downtonian) in UK Silurian literature. Following the suggestions of the ISSS, the term Pridoli has been used in the United Kingdom for more than 20 years.

**North America**

The Silurian succession of North America has been divided into a complex array of chronostratigraphic units and schemes over the past 150 years. Varying use of classical terms such as Alexandrian, Niagaran, and Cayugan series, combined with ‘official’ use of the unofficial terms Lower, Middle, and Upper Silurian, have crippled international correlation of North American Silurian units. Here we have included the relevant portion of the current AAPG–COSUNA (Correlation of the Stratigraphic Units of North America) chart (Shaver et al. 1985), the recently revised Silurian terms in use by the OGS (Brunton 2009), and the Silurian terms utilized by the USGS (Brett et al. 1995) for comparison in Figure 2. A revised correlation of the USGS classification scheme is presented here (far right panel in Fig. 2) and represents the North American column shown in Figure 1. Terms such as Lockport were formally introduced as lithostratigraphic terms (Lockport Formation or Lockport Group, see Brett et al. 1995) but have been misused for decades as stage level terms throughout North America (e.g. Lockportian in Fig. 2). To compare these terms and their use with global and regional classifications, we follow the common (incorrect) treatment of these terms as being chronostratigraphic for this report. Again, we point out that these regional series and stage names should be abandoned in favour of the global classification. The Geological Survey of Canada has demonstrated that the global Silurian series and stages can be recognized throughout the Canadian succession (Norford 1997) and use of regional terms within Canada is now largely restricted to the Ontario region. Work is currently underway to identify properly the global Silurian series and stage boundaries within Ontario and the Great Lakes region (Bancroft 2008; Brunton 2008, 2009; Brunton et al. 2009) and the United States as well (Saltzman 2002; Bergström et al. 2006; Cramer et al. 2006a; b; McLaughlin et al. 2008; Barrick et al. 2009; Kleffner et al. 2009).

The classic term Alexandrian Series has been applied traditionally to an interval spanning from the base of the Silurian System to somewhere in the middle of the Llandovery Series and remains pervasive in North American literature (e.g. AAPG-COSUNA). However, revisions to the North American timescale and recent biochemostratigraphic data have combined to make the Alexandrian Series a meaningless term. The original type area of the Alexandrian is located in the American mid-continent (SW Illinois and SE Missouri) and covers an interval from the base of the Girardeau Limestone to the top of the Brassfield Limestone. Bergström et al. (2006) demonstrated that the base of the Girardeau Limestone correlates to a position within the lower part of the global Hirnantian Stage, which by necessity would force the base of the Alexandrian Series down into the Ordovician. The top of the Alexandrian Series contains strata (Brassfield Limestone) that are undoubtedly of Silurian age (Berry & Boucot 1970) and likely belong to the Aeronian Stage. Therefore in present global terms, the classical Alexandrian Series would cover an interval from the Hirnantian Stage to the Aeronian Stage and as a series would cross a systemic boundary. This was avoided in the present definition of the North American Ordovician System by extending the term Cincinnatian Series to the top of the Ordovician (Bergström et al. 2009). Similarly, Brett et al. (1995) placed the base of the previously overlying Niagaran Series at the base of the Silurian System, and thus rendered the term Alexandrian Series obsolete.

The Niagaran Provincial Series, as defined by Brett et al. (1995) from the Niagara region of western New York State was thought to encompass all of the Llandovery Series, all of the Wenlock Series, and most of the Ludlow Series. The Niagaran Series is equivalent to the antequated Lower and Middle series traditionally used by the OGS (Johnson et al. 1992 – but abandoned by Brunton 2009) in that both systems of nomenclature include all Silurian strata below the Salina Group. Brett et al. (1995) include three groups within the Niagaran Series (Medina, Clinton, and
Lockport groups). Brett et al. (1995) and Brunton (2009) provide a detailed correlation between the OGS classification and the USGS classification of this interval, and we restrict ourselves here to discussion and refinement of the USGS terms unless otherwise indicated. At present only the base of the Lockport Group has been precisely correlated with the global chronostratigraphic classification and global correlations of the remaining units (Medina, Clinton, Salina, etc.) require further refinement. Major research projects are currently underway to constrain more precisely the remaining North American regional boundaries and a few notes of update are included here.

The base of the Clinton Group was placed historically at the base of the Thorold Sandstone in New York (Gillette 1947) and continued to be placed at this level by the Ontario Geological Survey (Johnson et al. 1992), such that the OGS Cataract Group + Thorold Sandstone = USGS Medina Group (Fig. 2). However, the base of the Clinton Group was elevated to the base of the Neahga Shale by the USGS (Brett et al. 1995) because the latter unit was found to be separated from the Thorold Formation by a regionally angular unconformity in western New York and Ontario, whereas the Thorold Formation is underlain, and locally overlain, conformably with red mudstones and sandstones typical of the Medina Group. A similar position (above the Thorold Formation) has been adopted by the OGS (Brunton 2009). Here, we restrict our use of the term ‘Clinton Group’ to the USGS (Brett et al. 1995) sense as placing the base of the Clinton Group at the base of the Neahga Shale and including the Thorold Sandstone within the underlying Medina Group.
order the Neaghga, Reynales, Merritton (upper part of the Fossil Hill Formation in Ontario, e.g. Brintnell et al. 2009; Brunton 2009), Williamson, Rockway, Irondequoit, Rochester, and Decew formations. In central New York the Clinton is much more complete and includes in ascending order the Reynales or equivalent Bear Creek Shale, Lower and Upper Sodus, Walcott, Sauquoit, Williamson-Willowvale, Rockway, Irondequoit, Rochester or equivalent Herkimer, and Decew formations.

The base of the Wenlock Series is likely located within, or at the top of, the Rockway Formation as the base of the Irondequoit Formation clearly coincides with the lower part of the Shewiwoodian Stage (Cramer et al. 2006a, 2010), although the precise position has yet to be determined. The lowermost Williamson Formation, at the type section in Rochester, New York, contains the graptolite Stimulograspis clintonensis as well as the conodont Pterospathodus amorphognathoides angulatus clearly indicative of a position no higher than the middle part of the Telychian Stage (Loydell et al. 2007). According to Kleffner in McLaughlin et al. (2008, p. 124), the conodonts from the Merritton Formation referred to as belonging to the Neospathognathodus celloni conodont Zone by Rexroad (1970, though the genus is no longer in use and zone redefined), likely belong to the Pterospathodus eopennatus Super Zone of Männik (2007). The conodont fauna and the position of the Merritton below the Williamson indicate that the Merritton correlates with the lower part of the Telychian Stage.

The base of the Merritton overlies a major unconformity at which underlying Reynales and Neaghga formations are truncated westward into Ontario. This unconformity appears to be coextensive with a regional, angular unconformity at which the Sauquoit, Wolcott, Upper Sodus, Lower Sodus, and Reynales are successively removed from east to west commencing in central New York. In westernmost New York–southwestern Ontario this unconformity separates the Neaghga and Reynales formations from the rest of the Clinton Group. The assignment of these lower Clinton units to the Aeronian Stage by Brett et al. (1995) is supported by the presence of the conodont Pranognathus tenuis throughout the Reynales Formation and upper part of the Neaghga Formation in New York (Kleffner 2004). Rhuddanian–Aeronian conodont biozonations require significant improvement and for the moment it is unclear where the base of the Telychian should be placed in North American carbonate successions if it is preserved at all. It is clear, however, that the base of the Telychian must lie somewhere between the top of the Reynales and the base of the Merritton. The base of the Clinton Group, therefore, correlates with a position no higher than the Aeronian Stage.

The term ‘Lockport’ was first introduced by Hall (1839) at the rank of formation. Rickard (1975) raised the term to group status and this assignment was maintained by Brett et al. (1995) for the USGS. The term Lockport has continued to be occasionally used at the formational level in Ontario (e.g. Johnson et al. 1992), but Brunton (2009) has abandoned this practice. Based upon conodont biostratigraphy and δ¹³C.carb chemostratigraphy from the type area of the Niagaran Series, Cramer et al. (2006a, 2010) demonstrated that the base of the Gasport Formation and therefore the base of the Lockport Group coincides with the middle part of the Shewiwoodian Stage (Fig. 2). The upper limit of the Lockport Group however remains a source of confusion, both chronostatigraphically and nomenclaturally. The USGS includes all strata between the base of the Gasport Formation and the base of the Salina Group within the Lockport Group (Brett et al. 1995). The OGS had traditionally varied from this viewpoint and removed the uppermost units (Guelph and Eramosa formations) from the Lockport Group (or Lockport Formation with Gasport, Goat Island, and Eramosa members, Johnson et al. 1992) and left them without a group designation. Brunton (2008, 2009) demonstrated that the USGS sense of a Lockport Group (as one that contains the Gasport, Goat Island, Eramosa, and Guelph formations) can be extended throughout southern Ontario, which illustrates that the Ontario terms ‘Albemarle Group’ and Amabel Formation are redundant and should be abandoned. Here, we use the term ‘Lockport Group’ in the recently uniform OGS-USGS sense as including all strata between the base of the Gasport Formation and the base of the Salina Group. Conodonts indicative of the late Shewiwoodian (K. ortus ortus) have been found in strata belonging to the upper part of the Lockport Group (within the Eramosa Formation, Bancroft 2008). The base of the Homerian Stage can be correlated at the formation level throughout the mid-continent (e.g. Cramer et al. 2006b; Barrick et al. 2009), although its placement in the Appalachian Basin remains less clear. The base of the Homerian Stage however, likely correlates with a position in the lower part of the Guelph Formation.

The term ‘Salina’ was introduced by Dana (1863) as the Salina Period to refer to the time represented by the Guelph and overlying limestones and salts of the then so-called Saliferous Epoch of New York State. After the labyrinthine evolution of the term in New York, it has come to be used at the group level (Salina Group) and has become virtually synonymous with the Cayugan Provincial Series as well. The term is more broadly known from what is called the Salina Group in the Michigan Basin that contains over 700 metres of chiefly alternating salts and limestones,
however the term is defined by its use in New York State. As currently recognized by the USGS and the Ontario Geological Survey, the Guelph Formation is included within the Lockport Group as its uppermost formation (Brett et al. 1995; Brunton 2009), which places the Niagaran–Cayugan series contact at the Lockport-Salina group contact.

The position of the base of the Ludlow Series with respect to the base of the Cayugan Provincial Series is currently unknown. The next positive correlation in the northern Appalachian Basin comes from the recovery of the Ludfordian conodont Polygnathoides siluricus from the Vernon Formation in New York (Miller et al. 1988). Therefore the interval from the base of the Homeric Stage to the base of the Ludfordian Stage is likely contained within the Guelph to Vernon (upper Lockport–lower Salina) succession, and significant further research is required to refine the chronostratigraphic classification of this interval of the North American sequence. As a result we have tentatively placed the base of the regional Cayugan Series as coinciding with the base of the global Ludlow Series until further research can be conducted.

The use and meaning of group designations for the uppermost part of the Cayugan Series have been highly variable and it remains among the least chronostratigraphically understood intervals of the Silurian System in North America. The Cayugan Series includes strata assigned to the Salina Group, Bertie Group (or Bertie Formation), and Bass Islands Group (or Bass Islands Formation). These strata appear to lie within the upper Ludlow to Pridoli, although bio-stratigraphic control is very poor. The Helderberg Group was previously considered to be entirely of Devonian age but it now appears that the lower formations (e.g. Manlius and Coeymans) contain strata that cross the base of the Devonian System (e.g. Kleffner et al. 2009). Based on conodont and δ13C data, the base of the Devonian has begun to be refined in the Appalachian Basin (e.g. Saltzman 2002) but recent findings have highlighted the continuing uncertainty of the position of this boundary in North America (Kleffner et al. 2009).

**Eastern Baltic**

A variety of stratigraphic classifications of the Silurian System of the eastern Baltic (particularly Estonia and Latvia) were in place by the 1970s (e.g. Aaloe et al. 1976) and regional stages have been erected throughout the region. Referred to as 'gorizont' in Russian literature (e.g. Adavere Regional Stage = Adaverskij Gorizont [in Russian]), this term directly translates to 'horizon', as in 'sky line'. However, because in English the term 'stratigraphic horizon' is a geological term particularly noted for its thinness (e.g. Salvador 1994) 'gorizont' is better translated as 'regional stage' for geological use. Bassett et al. (1989) considered these terms to be regional stages and presented their correlation with global series and stages and gradually it has become common for East Baltic studies to include global series and stages in addition to regional stages in publication (e.g. Männik 2007). The current East Baltic classification of a three-stage Llandovery, three-stage Wenlock, two-stage Ludlow, and two-stage Pridoli has changed little from what was presented by Bassett et al. (1989). The correlation shown in Figure 1 for the East Baltic is modified slightly from Nestor (1997) and a few notes are included here.

Traditionally, the base of the Telychian Stage has been considered to lie in the lower part of the Adavere Regional Stage and to be coincident with the boundary between the Rumba and Velise formations (e.g. Nestor 1997). However, a stratigraphic gap at this position throughout much of the East Baltic has obscured the precise correlation between global and regional units in this interval (Loydell et al. 1998; Pöldvere 2003). Similarly, the Jaani Stage has been considered to be coincident with the lower part of the Sheinwoodian Stage (the lower stage of the Wenlock Series), although increasing evidence has begun to indicate that the base of the Jaani Stage may be slightly below the base of the Wenlock Series (Männik 2007; Cramer et al. 2010). The base of the Jaagarahu Stage is within the global Sheinwoodian Stage (e.g. Kaljo & Martma 2006) and correlates with a position above the base of the Lockport in North America. The base of the Rootsiküla Stage is within the global Homeric Stage (Loydell et al. 1998) and the base of the Paadla Stage is taken to be coincident with the base of the Ludlow Series. The base of the Kuresaare Stage is clearly within the Ludfordian Stage and the Pridoli Series is divided into the Kaugatuma and Ohesaare regional stages. Refinements of these regional stages within the global classification are ongoing, but whereas North American revisions are requiring boundary positions to be moved by tens of metres, recent refinements to East Baltic boundary positions are requiring only minor changes of a few metres at most (centimetres in most cases). With the exception (perhaps) of the United Kingdom, the East Baltic is the chronostratigraphically best constrained major Silurian region in the world.

**Australia**

At the time of publication of Holland and Bassett (1989 – A Global Standard for the Silurian System), the bio- and chronostratigraphic correlation of the Silurian System in Australia was known only in a general way, which prompted Jell & Talent (1989) in the
same volume to comment that the Australian Silurian succession was likely to be of limited global importance. The work of Young & Laurie (1996) began the process of standardizing the Australian Silurian within the global classification. Later, Talent et al. (2003) presented a significantly different view from that of Jell & Talent (1989) and demonstrated that the Australian Silurian succession contains areas with more than a kilometre of fossiliferous Silurian marine sedimentary rocks that can be easily tied to the global scheme and can serve as an important source of data from outside of the well-known regions of Baltica, Laurentia, and Avalonia. A recent review by Strusz (2007) documented in detail the application of global series and stage boundaries to the Australian sequence and no regional chronostratigraphic terms are currently in use. Jeppsson et al. (2007) demonstrated high-resolution global correlation much finer than the stage level for the Ludlow portion of the Australian sequence and it is likely that such resolution is possible for the rest of the Silurian succession as well (Talent et al. 2003; Strusz 2007). Future research from this region may prove to be of considerable global importance.

China

A tripartite division of the Silurian System of China into Lower, Middle, and Upper Series (Yin 1949) had been erected by the middle of the last century and Mu (1962) proposed the names Lungmachi, Lojoping, and Hanchiatien for the Lower, Middle, and Upper Series respectively. Following the work of Ge et al. (1979), the Lower Series was considered to be roughly equivalent to the Llandovery Series, the Middle Series roughly equivalent to the Wenlock Series, and the Upper Series encompassed both the Ludlow and the Pridoli Series. Following the establishment of a standard global Silurian chronostratigraphic classification, Mu et al. (1989) suggested that the Chinese regional terms should be abandoned in favour of the global classification. This decision followed Mu et al. (1986) and was supported by Rong & Chen (2003) who demonstrated unequivocally that the global Silurian classification can be readily identified within the Chinese succession and regional stratigraphic terms are now largely in disuse. There is however, one historically significant feature of the Silurian System in China that for some years after its ratification, the base of the Silurian System continued to be placed at the base of the Normalograptus persculptus graptolite Zone, which is the base of the uppermost zone of the Ordovician System in the global classification (see editorial note in Mu et al. 1989, p. 205). This practice was formally abandoned by Chen et al. (1995).

Barrandian

Over the past 100 years, the only major addition to the division of the Silurian System has been the addition of the Pridoli Series as the fourth and final Silurian series (Bassett 1985). The Pridoli Series is unique in the Phanerozoic as it is the only series recognized by the IUGS that has not been divided into stages. The GSSP for the base of the Pridoli Series is also unique in that it is the only Silurian GSSP located outside of the United Kingdom. The GSSP is located in the Pozáry Section, near Prague, in the Czech Republic (Kříž 1989) and was placed to coincide with the first appearance of the graptolite Monograptus parultimus and the base of the M. parultimus graptolite Zone. Following Berdan et al. (1969), a four-fold division of the Barrandian Silurian System, essentially equivalent to the current global classification, was adopted by Chlupač (1972) and by Kříž (1975), and since then, regional chronostratigraphic terms have been in disuse. Kříž (1990) demonstrated that the global Silurian series and stages can be easily identified in the highly graptolitic Barrandian succession. The lack of good conodont control for the Pridoli Series in the type region as well as the United Kingdom however has hindered global correlation of Pridoli strata in carbonate sequences and significant improvement in our understanding of latest Silurian conodont biostratigraphy and palaeobiology is still needed.

Altaj

Silurian strata in the modern Altaj were deposited on the tectonically passive south-western shelf of the Siberian Paleocent (Yolkin et al. 2003). Following the work of Kulkov (1967), Yolkin & Zheltonogova (1974), Sennikov (1976), and several others, the Silurian succession in this region was divided into seven formations that were shown to be allostratigraphic units (Yolkin & Zheltonogova 1974). Recent studies have demonstrated that these units are nearly coeval across the Altaj region and are now considered to be regional stages (horizons; e.g. Sennikov et al. 2008). The Altaj column in Figure 1, and the correlations briefly discussed below are modified from Yolkin et al. (2003) and Sennikov et al. (2008) unless otherwise stated.

The base of the Syrovaty Formation (Stage) and the base of the Gromotukha Series correlate to a position within the uppermost Aeronian Stage, likely near the base of the Stimulograptus sedgwickii graptolite Zone. It is unclear if this is equivalent to the base of the Adare Stage of the East Baltic, but is likely above the base of the Clinton Group in North America. Based on conodont data of Moskalenko (1970), the base of
the Polaty Formation is no lower than the middle part of the Telychian Stage. The base of the Chesnokovka Formation and the Tigerek Series has been correlated with the uppermost part of the Oktavites spiralis graptolite Zone in the upper part of the Telychian Stage. Above the lower part of the Chesnokovka Formation graptolites do not occur in this region, and therefore the positions of the remaining regional boundaries within the global scheme are less precise. Kul’kov (1967) demonstrated that the Chagyryka Formation likely belongs to the upper part of the Wenlock Series. The base of the Kuimov may be coincident with the base of the Ludlow Series and the base of the Chernyj Anui is correlated tentatively with the base of the Pridoli Series.

Other regions

We have discussed only some regions with extensive Silurian exposures although the mainland European sections in, for instance, Belgium, Sardinia, Germany, and Austria, have been of significant historical importance as well. Their absence here, along with many other regions, is simply the result of limited space in this article and the fact that most of these other regions now employ the global standard chronostratigraphic classification. The reader is referred to the summary of Kríž et al. (2003) for data from classical European regions. In the same volume (Landing & Johnson 2003) good summaries of Silurian strata from many other regions not discussed in this article are provided as well. Another useful overview of the Silurian stratigraphy of Europe was provided by Verniers et al. (2008). It should be noted here that the excellent Silurian exposures on the Swedish Island of Gotland span an interval from the uppermost part of the Telychian Stage to the upper part of the Ludfordian Stage and serve as the type area for Wenlock and Ludlow conodont biostratigraphy and $\delta^{13}$C$_{\text{carb}}$ chemostratigraphy. It has been primarily through comparison with Gotland that global correlation of Wenlock and Ludlow carbonate successions has begun to improve. Samtleben et al. (1996, 2000), Calner et al. (2004), Eriksson & Calner (2005), and Jeppsson et al. (2006) provide a summary overview of the lithostratigraphy, biostratigraphy, and chemostratigraphy of Gotland.

A new Silurian $\delta^{13}$C$_{\text{carb}}$ chemostratigraphic curve

Starting in the late 1980s to early 1990s, it was becoming apparent that the stable carbon isotopic ratio of Silurian seas was highly variable and several discrete features in the $\delta^{13}$C$_{\text{carb}}$ curve began to be documented (Popp et al. 1986; Veizer et al. 1986; Corfield et al. 1992; Wadleigh & Veizer 1992; Talent et al. 1993). The pioneering data produced from the Swedish island of Gotland and the East Baltic region during the middle to late 1990s (Samtleben et al. 1996; Wenzel & Joachimski 1996; Bickert et al. 1997; Kaljo et al. 1997, 1998) demonstrated three positive $\delta^{13}$C$_{\text{carb}}$ excursions within the Wenlock to Ludlow interval, and these excursions have since been documented worldwide (Saltzman 2001; Połębska et al. 2004; Cramer & Saltzman 2005; Noble et al. 2005; Cramer et al. 2006a; b; Jeppsson et al. 2007; Kaljo et al. 2007), even in non-tropical settings (Lehnert et al. 2007). A fourth Silurian positive $\delta^{13}$C$_{\text{carb}}$ excursion was also found to be associated with the Silurian–Devonian boundary interval in the type area of the Barrandian (Czech Republic) by Hladikova et al. (1997). Since then, this feature has been recognized in other parts of the world as well (Saltzman 2002; Buggisch & Mann 2004), yet the $\delta^{13}$C$_{\text{carb}}$ record of the Pridoli Series remains less well documented globally than that of the Wenlock and Ludlow Series. The most significant positive $\delta^{13}$C$_{\text{carb}}$ excursions appear to occur within the Wenlock, Ludlow, and Pridoli Series however important isotopic features have been recognized within the Llandovery Series as well. Positive $\delta^{15}$C$_{\text{carb}}$ excursions during the early Aeronian, late Aeronian, and early Telychian (each approximately +2.0‰ change) have been documented (Kaljo & Martma 2000; Kaljo et al. 2003; Pöldvere 2003; Melchin & Holmden 2006; Munnecke & Männik 2009), but the Llandovery is the least known portion of the Silurian $\delta^{13}$C$_{\text{carb}}$ curve on the global scale. At present, only the early Aeronian and early Telychian $\delta^{13}$C$_{\text{carb}}$ excursions have been documented from more than one paleobasin, although the late Aeronian excursion has been documented in $\delta^{13}$C$_{\text{org}}$ records from multiple paleobasins.

Previous versions of a composite $\delta^{13}$C$_{\text{carb}}$ curve for the Silurian (e.g. Azmy et al. 1998) suffered from poor biostratigraphic control and low stratigraphic resolution, which complicated the use of Silurian $\delta^{13}$C$_{\text{carb}}$ chemostratigraphy as a chronostratigraphic tool (Kaljo & Martma 2006). An improved $\delta^{13}$C$_{\text{carb}}$ curve for the entire Silurian is included here that allows direct correlation between $\delta^{13}$C$_{\text{carb}}$ chemostratigraphy and the Silurian graptolite and conodont biozonations. It is beyond the scope of this report to discuss the Silurian $\delta^{13}$C$_{\text{carb}}$ record in detail, but there are a few points worth mentioning here.

The middle Ludfordian (Lau) $\delta^{13}$C$_{\text{carb}}$ excursion appears to be the highest magnitude positive $\delta^{13}$C$_{\text{carb}}$ excursion in the post-Cambrian Phanerozoic. Middle to late Ludfordian $\delta^{13}$C$_{\text{carb}}$ values typically reach
Stage slices

In regions that are well constrained within the global chronostratigraphic classification, intercontinental correlation far finer than the stage level is possible. As noted above, the terms Gleedon and Whitwell were introduced from the Homeric of the United Kingdom (Bassett et al. 1975), and the use of allostratigraphic units finer than the stage level in correlations of Silurian strata within North America is common practice (e.g. Brett et al. 1998; McLaughlin et al. 2008), whilst biozones (especially graptolite, conodont, and chitinozoan) are routinely used in intercontinental correlation. Frequently in stratigraphic studies, it is necessary or useful to apply units between the stage level and the biozone level. In particular, Silurian carbonate sequences that have as yet yielded little or no conodont biostratigraphic information often can be correlated only at a level coarser than the biozone, and providing a level of correlation between the stage level and biozone level would be useful. Here we informally introduce the ‘stage slice’ for the Silurian as such a unit.

The term ‘stage slice’, as used in the Ordovician System (Bergström et al. 2009), refers to biochemostratigraphically defined units most closely resembling the concept of assemblage zones (Salvador 1994). At present there is no accepted term for a stratigraphic unit that is defined on the basis of more than one taxon and/or more than one faunal group together with the chemostratigraphic content of a given set of strata, but that is effectively what stage slices are. Clearly, further discussion about the rank, utility, definition, and scope of stage slices is warranted, and their introduction to the Silurian here is informal.

In this article, the levels defined as boundaries of the stage slices are selected based on their chronostratigraphic utility. That is, they are levels that can be reliably identified and correlated on several different paleocontinents. Following Bergström et al. (2009) we have used a two-letter-number designation for each stage slice where the two letters refer to the global stage (global series in the case of the Pridoli) and the number refers to the relative position within the stage. With the exception of Sh3, the base of each stage slice is defined by the base of a graptolite or conodont zone (Fig. 3). The definition of each stage slice and their relationship to the generalized Silurian δ13Ccarb curve is provided here. The graptolite biozones referred to below are slightly modified and refined from Melchin et al. (2004) and Sadler et al. (2009), and the conodont biozones are a composite of several different biozonations combined here for global (as opposed to regional) utility. The first or last appearances (FADs and LADs) used to define the base of each Silurian conodont biozone are shown in Figure 3, and the total biozonation follows, in stratigraphic order: Männik (2007); Jeppsson (1997); Jeppsson & Calner (2003); Jeppsson & Aldridge (2000); Jeppsson et al. (2006); Corradini & Serpagli (1999); and Corriga & Corradini (2009).

Fig. 3. Silurian graptolite and conodont biostratigraphic zonations, shown in relation to global stages and a generalized δ13Ccarb curve for the Silurian System. With the exception of Sh3, the base of each stage slice is coincident with the base of either a graptolite or conodont zone. The generalized δ13Ccarb curve is based on a composite from the following sources: Rhuddanian-Aeronian: Poldvere (2003); Uppermost Aeronian: Melchin & Holmden (2006); Telychian: Kaljo et al. (2003), and Cramer et al. (2010); onset of the Ireviken Excursion: Munnecke et al. (2003); Sheinwoodian: Cramer et al. (2006a) and Cramer & Saltzman (2005); Homeric: Cramer et al. (2006b); Ludlow: Samtleben et al. (2000) and Jeppsson et al. (2007); Pridoli: Saltzman (2002). The graptolite zonation is slightly modified and refined from Sadler et al. (2009) and the FADs and LADs shown to the right of the conodont zonation refer to the definition of the conodont zones utilized in this report. Graptolite abbreviations: N. = Noedovertograptus; A. = Akidograptus; P. = Parakidograptus; C. = Cyrtograptus; M. = Monograptus; Co. = Coronograptus; D. = Demiandrastrites; Pr. = Pribylograptus; L. = Lituitograptus; S. = Stimulosagratop; St. = Streptograptus; Sp. = Spirograptus; Mcl. – Monocardium; Cy. – Cyrtograptus; G. – Gothograptus; Pri. – Pribylograptus; Col. – Colonograptus; Lo. – Lobograptus; Sa. – Saetograptus; Po. – Polograptus. CONODONT ABBREVIATIONS: D. – Distomodus; Asp. – Aspandina; Pr. – Pranograthus; Pt. – Pterospathodus; am. – amorphognathoides; procerus – Pterospathodus pennatus procerus; K. – Kockelella; rani. – raniformis; O. – Ozerkodina; s. – sagitta; v. – variabilis; A. – Anasagratina; Po. – Polysagratina; Ou. – Oulodus; w. – woschmidtii; S.Z. – SuperZone; I.Z. – Interval Zone; s.l. – sensu lato. A slash between names in the graptolite zonation indicates a single ‘combined’ zone (e.g. Co. cyphus / M. revolutus). Dashed lines in the graptolite column denote uncertainty in the placement of that boundary with respect to Silurian series and stage boundaries and the relative duration of the zone. Dashed lines in the conodont column denote uncertainty in the placement of that boundary with respect to the graptolite biozonation. The base of the Wenlock Series is shown with a solid line (base C. murchisoni – Ireviken Event Datum 2) representing the approximate correlation of the current GSSP, and a dashed line (base C. centrifugus) representing the originally intended correlation of the base of the Wenlock Series. See text for discussion of this boundary.
Definitions of potential Silurian stage slices

Rh1. – Base of the Silurian (first appearance of the graptolite Akidograptus ascensus) to the base of the Cystograptus vesiculosus graptolite Zone. This includes the Parakidograptus acuminatus graptolite Zone and is within the Distomodus kentuckyensis conodont Zone, roughly covering the lower half of the Rhuddanian Stage. The end of the Hirnantian δ13C_carb excursion is well within the Hirnantian and baseline values persist throughout this stage slice.

Rh2. – Base of the Cystograptus vesiculosus graptolite Zone to the base of the Coronograptus cyphus/Monograptus revolutus graptolite Zone. This includes the Cystograptus vesiculosus graptolite Zone and is within the Distomodus kentuckyensis conodont Zone, roughly covering the middle of the Rhuddanian Stage. A distinct negative excursion near the top of this stage slice is known from the eastern Baltic but the global presence and precise chronostratigraphic position of this excursion has not been demonstrated. This excursion may occur either within the C. vesiculosus graptolite Zone or the lower part of the C. cyphus/M. revolutus graptolite Zone and may correspond to one of two weak negative excursions present in this interval in Arctic Canada (Melchin & Holmden 2006) but it has yet to be studied in detail elsewhere.

Rh3. – Base of the C. cyphus/M. revolutus graptolite Zone to the base of the Demirastrites triangularis/D. pectinatus graptolite Zone. This includes the C. cyphus/M. revolutus graptolite Zone and most of the stage slice is within the upper part of the Distomodus kentuckyensis conodont Zone. The lowermost part of the Aspelundia expansa conodont Zone is included in the upper part of this stage slice that represents the upper part of the Rhuddanian Stage. The base of the Raikkila Stage in the East Baltic probably lies low within this stage slice.

Ae1. – Base of the Demirastrites triangularis/D. pectinatus graptolite Zone to the base of the Monograptus argenteus/Pribylograptus leptotheca graptolite Zone. This includes the D. triangularis/D. pectinatus graptolite Zone and is within the Asp. expansa conodont Zone roughly corresponding to the lower third of the Aeronian Stage. There is a positive δ13C_carb excursion recorded in strata from this interval in the East Baltic (upper part of the D. triangularis graptolite Zone in the Ruhnu core; Pöldvere 2003), which was also observed in lower Aeronian strata from Arctic Canada by Melchin & Holmden (2006), but this has yet to be recognized elsewhere. It is restricted to this stage slice.

Ae2. – Base of the Monograptus argenteus/Pribylograptus leptotheca graptolite Zone to the base of the Stimulograptus sedgwickii graptolite Zone. This includes the M. argenteus/Pr. leptotheca and Lituigraptus convolutus graptolite zones as well as the upper part of the Asp. expansa and lower part of the Pranognathus tenius conodont zones of the middle part of the Aeronian Stage. Generally, non-excursion or ‘baseline’ δ13C_carb values have been recovered from strata within this stage slice. The base of the Clinton Group in North America is likely located within this stage slice.

Ae3. – Base of the Stimulograptus sedgwickii graptolite Zone to the base of the Spirograptus guerichii graptolite Zone. This includes the St. sedgwickii graptolite Zone, the top of the Pr. tenius and the lower part of the Distomodus staurognathoides conodont zones and represents the uppermost part of the Aeronian Stage. A positive δ13C_carb excursion has been recorded in Ae3 strata from the Canadian Arctic and appears to be restricted to this stage slice. This excursion has yet to be reproduced elsewhere in δ13C_carb records, but occurs in δ13C_org records from Scotland (Melchin & Holmden 2006) and Bohemia (Storch & Fýdra 2009). A protracted interval of low δ13C_carb values has been recovered from the uppermost part of this stage slice (and the lowermost part of Te1) from Arctic Canada that appears to follow immediately the positive δ13C_carb excursion. The base of the Syroyaty Formation and the Gromotukha Series in Altaj coincide with the base of this stage slice. A similar position (or within Ae3) is likely for the base of the Adavere Stage in the East Baltic.

Te1. – Base of the Spirograptus guerichii graptolite Zone to the base of the Pterospathodus copenatus conodont Superzone and the Pterospathodus copenatus ssp. n. 1 conodont Zone. This includes all of the Sp. guerichii and almost all of the Sp. turriculatus graptolite zones, is within the upper part of the D. staurognathoides conodont Zone, and represents the lowermost part of the Telychian Stage.

Te2. – Base of the Pterospathodus copenatus conodont Superzone and the Pt. copenatus ssp. n. 1 conodont Zone to the base of the Monoclimacis crenulata graptolite Zone. This includes the uppermost part of the Spirograptus turriculatus, and all of the Stiopograptus crispus, Stiopograptus sartorius, and Mcl. grieseniensis graptolite zones, as well as all of the Pterospathodus copenatus ssp. n. 1 conodont Zone and most of the Pt. copenatus ssp. n. 2 conodont Zone (most of the Pt. copenatus conodont Superzone). A positive δ13C_carb excursion (the Valgu excursion) has been known from Te2 strata in the eastern
Baltic for more than a decade and this excursion has recently been identified in North America (Munnecke & Männik 2009). This excursion appears to be restricted to this stage slice. The base of the Polaty Formation in Altaj may correlate with a position within this stage slice (Sennikov et al. 2008, p. 13 record graptolites of the Mcl. griestoniensis Zone).

**Te3.** – Base of the Monoclimacis crenulata graptolite Zone to the base of the Pterospathodus amorphognathoides amorphognathoides conodont Zone. This includes the uppermost part of the Pterospathodus cepennatus ssp. n. 2 conodont Zone, all of the Pt. amorphognathoides angulatus, Pt. am. lennarti, and Pt. am. lithuanicus conodont zones, as well as all of the Mcl. crenulata and Oktavites spiralis graptolite zones. Stage slice Te3 covers roughly the middle third of the Telychian Stage. The base of the Tigerek Series and Chesnokovka Formation in Altaj are probably within this stage slice.

**Te4.** – Base of the Pterospathodus amorphognathoides amorphognathoides conodont Zone to the base of the Cyrtograptus insectus graptolite Zone. This includes the lower part of the Pterospathodus amorphognathoides amorphognathoides conodont Zone and probably all of the Cyrtograptus lapworthi graptolite Zone corresponding to an interval within the upper part of the Telychian Stage.

**Te5.** – Base of the Cyrtograptus insectus graptolite Zone to the base of the Cyrtograptus murchisoni graptolite Zone. This includes the Cyrtograptus insectus and C. centrifugus graptolite zones as well as most of the upper part of the Pterospathodus amorphognathoides amorphognathoides conodont Zone of the uppermost Telychian Stage. The base of the Jaani Stage in the East Baltic likely correlates with a level within this stage slice.

**Sh1.** – Base of the Cyrtograptus murchisoni graptolite Zone to the base of the Upper Kockelella ranuliformis conodont Zone within the K. ranuliformis conodont Superzone. At present, the base of the C. murchisoni graptolite Zone is tentatively considered to correlate with the base of the Wenlock Series (see Loydell 2008; Cramer et al. 2010), and the base of this stage slice correlates with the base of the Sheinwoodian Stage and Wenlock Series as defined by the current GSSP (see discussion above). This stage slice includes all of the Cyrtograptus murchisoni, Monograptus firmus, and lower part of the M. riccartonensis graptolite zones. This stage slice contains the uppermost part of the Pterospathodus amorphognathoides amorphognathoides conodont Zone and the entirety of the Ireviken Event (Datum 1-8), which includes the Lower and Upper Pseudooneotodus bicornis (Datum 1-2 and Datum 2-3 respectively), Lower and Upper Pterospathodus penatus procerus (Datum 3-4 and Datum 4-6 respectively), and Lower Kockelella ranuliformis (Datum 6-8) conodont zones. The onset of the well-known early Sheinwoodian (Ireviken) positive δ13C_carb excursion lies within the lower part of this stage slice and δ13C_carb values continue to rise throughout the rest of Sh1. At present, the base of the Cyrtograptus murchisoni graptolite Zone is tentatively considered to correspond to the base of the Wenlock Series (see Loydell 2008; Cramer et al. 2010), and the base of this stage slice correlates with the base of the Sheinwoodian Stage and the Wenlock Series.

**Sh2.** – Base of the Upper K. ranuliformis conodont Zone (within the K. ranuliformis conodont Superzone) to the end of the early Sheinwoodian (Ireviken) δ13C_carb excursion. This includes the remainder of the Monograptus riccartonensis graptolite Zone and the lower part of the Cyrtograptus rigidus/Monograptus belophorus graptolite Zone as well as all of the upper K. ranuliformis, Ozarkodina sagitta rhenana and lower part of the Kocellella walliseri conodont zones. δ13C_carb values first reach their maximum near the base of this stage slice and return to a level consistently at or below pre-excursion values by the top of Sh2. The base of the Lockport Group in North America correlates with a position in the middle of Sh2 and may be equivalent to the base of the Jaagarahu Stage in the East Baltic.

**Sh3.** – End of the early Sheinwoodian (Ireviken) δ13C_carb excursion to the base of the Cyrtograptus lundgreni graptolite Zone. This includes the remainder of the Cyrtograptus rigidus/Monograptus belophorus graptolite Zone, the Cyrtograptus perneri graptolite Zone, as well as the upper part of the K. walliseri, all of the K. ortus ortus, and the lowermost part of the Ozarkodina sagitta sagitta conodont zones. This stage slice coincides with the upper part of the Sheinwoodian Stage above the Ireviken δ13C_carb excursion.

**Ho1.** – Base of the Cyrtograptus lundgreni graptolite Zone to the base of the Pristioanagrus parvus/Gothograptus nassa graptolite Zone. This includes most of the Ozarkodina sagitta sagitta and the lower part of the Oz. bohemica longa conodont zones. This stage slice is equivalent to the Cy. lundgreni graptolite Zone and approximates to the Gleedon Chronozone of Bassett et al. (1975) (see discussion in Zalasiewicz & Williams 1999). The Mulde Event (conodonts) and the ‘big crisis’ (graptolites) begin near, and at the top respectively, of this stage slice.

**Ho2.** – Base of the Pristioanagrus parvus/Gothograptus nassa graptolite Zone to the base of the Colonograptus
ludensis graptolite Zone. This includes the Pri. Parvus/G. nassa, Col. praeuebaeri, and Col. deubeli graptolite zones as well as the remainder of the Ozarkodina bohemica longa, and lower part of the Kockelella ortus abisdata conodont zones. The first peak of the Homerian (Mulde) $\delta^{13}$C_carb excursion appears to be restricted to Ho2. The base of the Rootsikula Stage in the eastern Baltic lies within Ho2.

Ho3. – Base of the Colonograptus ludensis graptolite Zone to the base of the Neodiversograptus nilssonii/Lobograptus progenitor graptolite Zone. This includes the upper part of the Kockelella ortus abisdata conodont Zone to the base of the Kockelella crassa conodont Zone and is equivalent to the Col. ludensis graptolite Zone. Ho2 and Ho3 combined approximate to the Whitwell Chronozone of Bassett et al. (1975). This stage slice represents the uppermost part of the Homerian Stage and includes the second peak of the Homerian (Mulde) $\delta^{13}$C_carb excursion.

Go1. – Base of the Neodiversograptus nilssonii/Lobograptus progenitor graptolite Zone to the base of the Lobograptus scanicus graptolite Zone. This includes all of the Kockelella crassa conodont Zone and lowermost part of the Kockelella variabilis variabilis conodont Interval Zone. This stage slice is equivalent to the N. nilssonii/L. progenitor graptolite Zone covering the lower part of the Gorstian Stage. The base of Go1 is coincident with the base of the global Gorstian Stage and Ludlow Series, with the base of the regional Paadla Stage in the East Baltic, and potentially with the base of the Salina Group and Cayugan Series in North America.

Go2. – Base of the Lobograptus scanicus graptolite Zone to the base of the Saetograptus leintwardinensis/Saetograptus linearis graptolite Zone. This includes the remainder of the Kockelella variabilis variabilis conodont Interval Zone of the upper part of the Gorstian Stage. Go2 is equivalent to the Lobograptus scanicus graptolite Zone and contains the biotic event termed the Linde Event (Jeppsson 1993).

Lu1. – Base of the Saetograptus leintwardinensis/Saetograptus linearis graptolite Zone to the base of the Ozarkodina snajdri conodont Interval Zone. This includes all of the Sa. leintwardinensis/ Sa. linearis and the lower part of the Bohemograptus graptolite zones as well as all of the Ancoradela ploeckensis and Polygnathoides silicurus conodont zones. The position of the base of the A. ploeckensis conodont Zone with respect to the base of the Sa. leintwardinensis/Sa. linearis graptolite Zone, and the position of the base of either of these biozones with respect to the base Ludfordian GSSP remains uncertain and these three positions are tentatively correlated at the same level here. It may however be that the base of the A. ploeckensis conodont Zone is below the base of the Sa. leintwardinensis/Sa. linearis graptolite Zone, which says nothing of their correlation to the GSSP. A low amplitude (but stratigraphically consistent) positive $\delta^{13}$C_carb excursion associated with the underlying Linde Event has been found on Gotland from Gorstian–Ludfordian boundary strata, but this feature remains to be reproduced from other regions. The onset of the much higher amplitude middle Ludfordian (Lau) $\delta^{13}$C_carb excursion begins in the uppermost part of this stage slice.

Lu2. – Base of the Ozarkodina snajdri conodont Interval Zone to the base of the Ozarkodina crispa conodont Zone. This includes the upper part of the Bohemograptus, all of the Neodiversograptus kozlowski/Polonograptus podoliensis, and lowermost part of the Monograptus formosus graptolite zones. This stage slice is equivalent to the Oz. snajdri conodont Interval Zone spanning the middle part of the Ludfordian Stage. The middle Ludfordian (Lau) $\delta^{13}$C_carb excursion is largely restricted to this stage slice where $\delta^{13}$C_carb values rise over most of the lower part of this stage slice, peak values are restricted to the middle part of Lu2, and $\delta^{13}$C_carb values decrease through the upper part of this stage slice.

Lu3. – Base of the Ozarkodina crispa conodont Zone to the base of the Monograptus parultimus graptolite Zone. This includes the remainder of the M. formosus graptolite Zone and is equivalent to the O. crispa conodont Zone coinciding with the upper part of the Ludfordian Stage. Primarily, this stage slice contains Ludfordian strata above the middle Ludfordian (Lau) $\delta^{13}$C_carb excursion. The base of the Kuressaare Stage in the East Baltic region may be coincident with the base of Lu3 or lies somewhat below it.

Pr1. – Base of the Monograptus parultimus graptolite Zone to the base of the Monograptus bousecki graptolite Zone. This includes all of the M. parultimus, M. ultimus, and M. branikensis/M. lochikovensis graptolite zones as well as the majority of the Ozarkodina coteinbornensis sensu lato conodont Interval Zone and represents roughly the lower half of the Pridoli Series. The base of the regional Kaugatuma Stage in the East Baltic is considered to be coincident with the base of the global Pridoli Series. The top of the Salina Group in North America is likely within this stage slice.

Pr2. – Base of the Monograptus bousecki graptolite Zone to the base of the Monograptus uniformis graptolite Zone. This includes all of the M. bousecki and M.
transgressiens/M. perner graptolite zones, the remainder of the Ozarkodina osteinhornensis sensu lato conodont Interval Zone, all of the Oulodus elegans detortus conodont Zone, and likely the lowest part of the Icriodus woschmidtii woschmidtii conodont Zone. The onset of *Icriodus woschmidtii woschmidtii* Interval Zone, all of the Pridoli Series and the base of the Ohesaare Stage in the East Baltic probably lies within this stage slice.

**Conclusions**

The chronostratigraphic correlation of the Silurian System of North America is currently undergoing major revision. As a result, the global correlation of much of the Silurian strata of North America remains uncertain by more than a stage in most cases, and more than a series in others. This report serves as an update on changes to the global correlation of Silurian chronostratigraphic terms in use within North America as well as a framework for improved global chronostratigraphic correlation. The new composite δ¹³C_carb curve for the Silurian is directly tied to the biochemostratigraphically defined stage slices introduced here, which facilitates the use of δ¹³C_carb chemostratigraphy as a chronostratigraphic tool in well studied and biostratigraphically well-constrained intervals such as the Wenlock. With the new Silurian δ¹³C_carb curve and the recent improvements in Silurian conodont biozonations there remains little justification for retaining regional chronostratigraphic classifications of the Silurian System. As more data become available, refinements to this curve will be required and the definitions of the stage slices will remain similarly open to revision.

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