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CURRENT STATUS OF THE INTERNATIONAL CARBONIFEROUS TIME SCALE

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The Carboniferous System comprises the Mississippian and Pennsylvanian subsystems and Tournaisian, Viséan, Serpukhovian, Bashkirian, Moscovian, Kasimovian and Gzhelian stages in ascending order (Figs. 1-2). The first use of the name Carboniferous for the rock succession to which it now applies is attributed to William Conybeare and William Phillips in 1822 for coal-bearing strata in England and Wales and was referred to as the Carboniferous System by Phillips in 1835 (Ramsbottom, 1984). This system is unique by comprising two subsystems, the Mississippian (name proposed by Winchell in 1870 for predominantly marine rocks in the upper Mississippi Valley, USA) and overlying Pennsylvanian (name proposed by Stevenson in 1888 for coal measures and terrigenous clastics in the state of Pennsylvania, USA), each of which was proposed as an independent system by Williams (1891). A vote by the International Commission on Stratigraphy (ICS) in 1999 resulted in approval of the names Mississippian and Pennsylvanian together with a reconfirmation of the previous decisions of the ICS Subcommission on Carboniferous Stratigraphy (SCCS) to regard their rank as global subsystems.

In 2003, the SCCS voted to divide the two subsystems into Lower, Middle, and Upper Mississippian series and Lower, Middle, and Upper Pennsylvanian series. This vote, with its implicit acceptance of the stage names used in Russia as the global stage names for the Carboniferous now provides the Carboniferous with its official global series and stage names (Heckel and Clayton, 2006a, b), and all effort by the SCCS is now focused on selecting events and GSSPs for the stage boundaries. In 2013 at the 34th International Geological Congress in Brisbane, Australia, the ICS voted in favor of the formal recognition of global substages. Global substages have not been selected for the Carboniferous, and there are several suites of regional names in use. Figures 1 and 2, the accompanying stratigraphic charts for the Carboniferous, are based on figure 8.5 of Heckel et al. (2008), with radiometric dates updated from Davydov et al. (2012) and the 2013 version of the ICS international stratigraphic chart by Cohen et al. (2013).

A GSSP defines the base of the Carboniferous System (358.9 ± 0.4 Ma), which is co-incident with the Mississippian–Devonian (D-C) boundary and bases of the Lower Mississippian Series and Tournaisian Stage. Studies by Ji et al. (1989) and subsequent analysis (Kaiser, 2009) demonstrated severe problems exist with the D-C boundary GSSP (Paproth et al., 1991) at La Serre Hill, southern France. At La Serre the boundary is defined by the first appearance datum (FAD) of the conodont *Siphonodella sulcata* (Huddle, 1934) in the lineage *Siphonodella praesulcata* Sandberg, 1972-*S. sulcata*, but both the definition and section are considered deficient. Current search for a better boundary index is focused on conodonts and the geochemical-sedimentologic events in the multi-phase Hangenberg Event (Kaiser et al., 2008). Since 2008, the *S. praesulcata*-*S. sulcata* lineage used to define the boundary has been re-evaluated by several scientists, including Kaiser and Corradini (2011), and the protognathodids, the other conodont group that had shown potential for boundary definition, is being re-studied (Corradini et al., 2011). The conodont studies have been disappointing because it appears that neither the siphonodellid lineage nor the protognathodids are ideal for D-C boundary definition, and other appropriate taxa have not been discovered.

The FAD of the foraminifer *Eoparastaffella simplex* Vdovenko, 1954 in the lineage *Eoparastaffella ovalis* Vdovenko, 1954-*E. simplex* defines the Tournaisian–Viséan boundary GSSP (346.7 ± 0.4 Ma) in the Chinese Pengchong section (carbonate turbidites), which is coincident with the base of the Middle Mississippian Series. Gosselet (1860) introduced Etage du Calcaire de Tournai and Etage du Calcaire de Visé after the towns of Tournai and Visé in Belgium, but Dupont (1861) recognized the units in the Dinant area of Belgium, and in 1883 introduced the terms Tournaisian Stage and Viséan Stage (Devuyst et al., 2003). Using the FAD of *E. simplex* for boundary definition, Devuyst et al. (2003) proposed the Pengchong section in Guangxi Province, south China, for the GSSP, and Devuyst et al. (2004) provided supplementary information on correlating that position into regions where the defining index does not occur. The SCCS task group appointed to establish the boundary voted unanimously to approve the Pengchong GSSP in 2004 and presented the proposal to the SCCS for ballot in late November 2007. The proposal was unanimously approved by the SCCS and ratified by the ICS and IUGS; a final report is in preparation.

The base of the Serpukhovian Stage (330.9 ± 0.2 Ma), coincident with the base of the Upper Mississippian Series, is not defined by a GSSP; however, the SCCS task group appointed to establish this boundary has located a suitable index for boundary definition and is preparing a proposal for SCCS and ICS approval. Nikitin (1890) proposed the name Serpukhovian for a carbonate-dominant succession in the Moscow Basin near the city of Serpukhov. For boundary definition, the SCCS task group is using the FAD of the conodont *Lochriea ziegleri* Nemirovskaya, Perret and Meischner, 1994 in the lineage *Lochriea nodosa* (Bischoff, 1957)-*Lochriea ziegleri*. *L. ziegleri* appears in the upper Venevian Substage somewhat below the current base of the Serpukhovian as defined by its lectostratotype in the Zaborie quarry by Serpukhov in the Moscow Basin, Russia (Kabanov, 2004; Kabanov et al., 2012). Nikolaeva et al. (2002) reported that in Zaborie quarry *L. ziegleri* appears with *Lochriea senckenbergica* Nemirovskaya, Perret and Meischner, 1994 in the basal bed of the lectostratotype but not as a first evolutionary appearance. At the nearby Novogurovsky quarry, the FAD of *L. ziegleri* is in the uppermost Venevian Substage Kabanov et al. (2012) of the Viséan rather than in the lowermost Tarusian Substage of the Serpukhovian as reported for the Zaborie quarry.

Work is well advanced at the two prime GSSP candidates for the lower boundary of the Serpukhovian: the Verkhnyaya Kardailovka section in the southern Ural Mountains of Russia (Nikolaeva et al., 2009; Pazukhin et al., 2010) and the Nashui section in southern Guizhou Province, China (Qi and Wang, 2005; Qi, 2008; Groves et al., 2012). Both are deep-water carbonate-dominant sections containing the selected lineage, but the Kardailovka section has abundant ammonoids in addition to conodonts (Nikolaeva et al., 2009).

The mid-Carboniferous boundary (323.2 ±0.4 Ma), co-incident with bases of the Lower Pennsylvanian Series and Bashkirian Stage, is fixed with a GSSP in the lower Bird Spring Formation at Arrow Canyon, Nevada, U.S.A. (Lane et al., 1999). Semikhatova (1934) proposed the Bashkirian Stage and its stratotype is on the Yuruzan River in the Russian Urals. In Arrow Canyon, the basal Pennsylvanian GSSP is defined by the FAD of the conodont *Declinognathodus noduliferus* (Ellison and Graves, 1941) *sensu lato* in the chronocline *Gnathodus girtyi simplex* Dunn, 1966-*D. noduliferus* and lies in neritic lime grainstone (Richards et al., 2002). When *D. noduliferus sensu lato* was chosen as the index at the 10th International Congress of Carboniferous Geology and Stratigraphy in Madrid (1983), the taxon included the subspecies *D. noduliferus noduliferus* (Ellison and Graves, 1941), *D. noduliferus inaequalis* (Higgins, 1975), and *D. noduliferus japonicus* (Igo and Koike, 1964). But several conodont experts now separate those forms into discrete species, and many biostratigraphers (e.g. Sanz-Lopez et al., 2006) use the FAD of *D. noduliferus inaequalis* (*D. inaequalis*) for boundary definition because

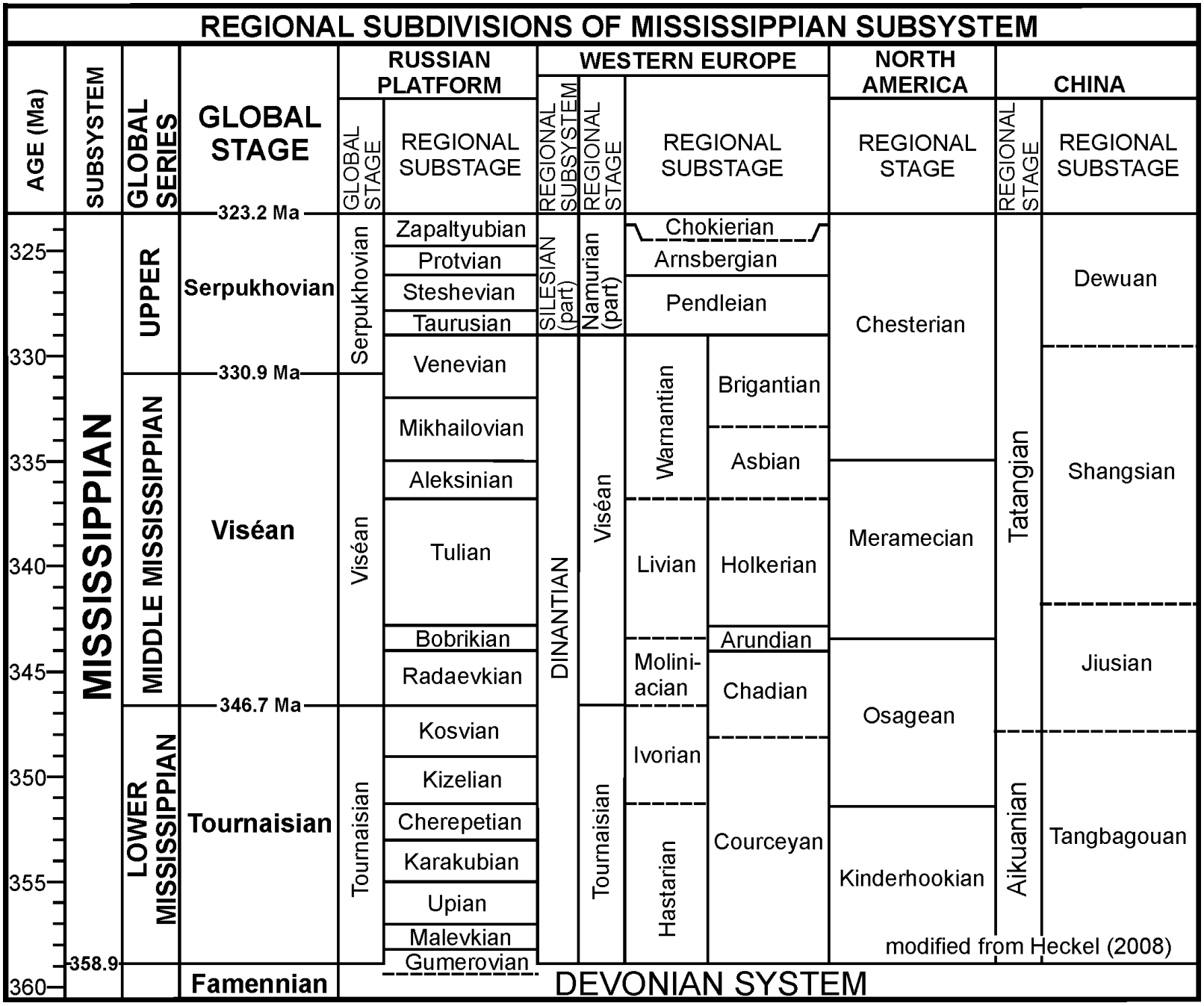

FIGURE 1. Global and regional subdivisions of the Mississippian Subsystem of the Carboniferous System.

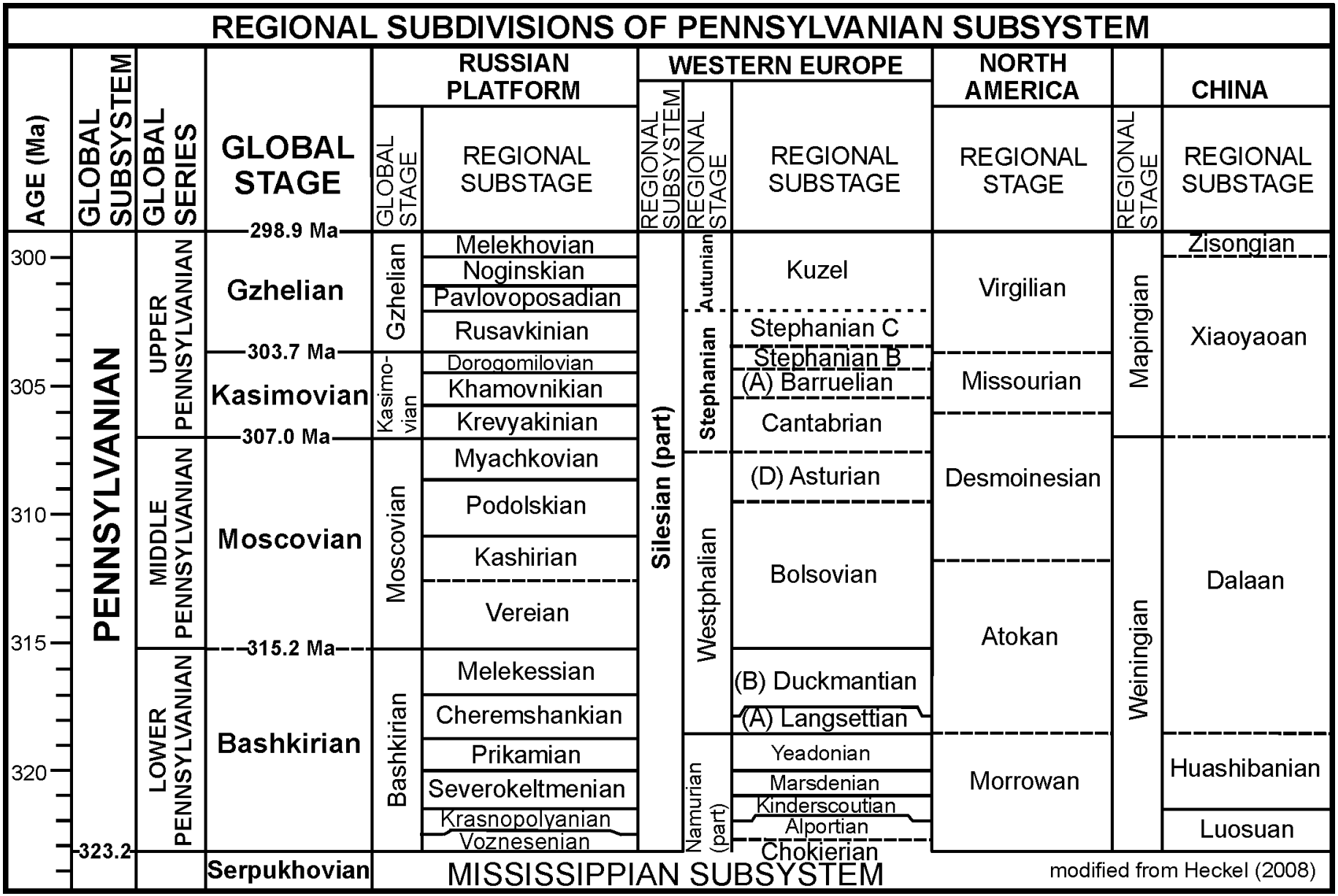

FIGURE 2. Global and regional subdivisions of the Pennsylvanian Subsystem of the Carboniferous System.

the lowest stratigraphic occurrence of *Declinognathodus* in the bed containing the GSSP at Arrow Canyon (Brenckle et al., 1997, pl. 1, figs. 2-4) is apparently *D. noduliferus inaequalis* (Nemyrovska et al., 2011).

The base of the Moscovian Stage (315.2 ± 0.2 Ma), coincident with the base of the Middle Pennsylvanian Series, is not defined by a GSSP, and an index for the boundary definition has not been selected. Nikitin (1890) proposed the name Moscovian for deposits in the Moscow Basin, Russia. A carbonate-dominant section in the Domodedovo quarry southeast of Moscow has been designated as the neostratotype because the stratotype by the village of Myachkovo was covered by the urban spread of Moscow (Goreva et al., 2009). Several conodonts and fusulinids have been recently proposed as potential indices for the GSSP, but only two--*Diplognathodus ellesmerensis* Bender, 1980 and *Declinognathodus donetzianus* Nemirovskaya, 1990--have received substantial support from the SCCS task-group members. Data from the Nashui section in Guizhou Province, South China (Qi et al., 2007; 2010; Groves, 2011) indicate that the FAD of *D. ellesmerensis* in the lineage *Diplognathodus coloradoensis* Murray and Chronic, 1965-*D. ellesmerensis* is one of the best potential boundary markers. *D. ellesmerensis* is easy to identify, the species has a wide geographic distribution (China, Russia, North America), and it occurs in the lowermost Moscovian strata (Alyutovo Formation; Kashirian Russian regional Substage) in the type Moscovian area (Makhlina et al., 2001). The FAD of *D. donetzianus* has long been consider as a potential index, but its apparent absence in North America prevented it from being an ideal candidate; however, Work et al. (2012) recently found the species in the Appalachian Basin, U.S.A. Goreva and Alekseev (2012) proposed moving the lower boundary of the Moscovian one substage higher than the position discussed above; that is from the base of the Vereian regional Substage (lowermost Moscovian substage) to the base of Kashirian regional Substage. A proposed marker for the new level is the FAD of *Neognathodus bothrops* Merrill, 1972 evolving from its ancestor *Neognathodus atokaensis* Grayson, 1984; both species are widely distributed (Goreva and Alekseev, 2012). Several successions, including slope carbonates in the Nashui section, are being intensively studied as potential GSSP candidates.

The base of the Kasimovian Stage (307.0 ± 0.1 Ma), coincident with the base of the Upper Pennsylvanian Series, is not defined by a GSSP, but the SCCS task group studying this boundary has located two conodont taxa that have good potential for boundary definition and are developing a proposal. Originally included in the Moscovian by Nikitin (1890), the Kasimovian is the last Pennsylvanian Stage established in the Moscow Basin (Teodorovich, 1949) and its neostratotype is in the Afansievo quarry in the Moscow Basin southeast of Moscow (Makhilina et al., 2001a).

The SCCS task group responsible for defining the base of the Kasimovian has concluded that the FADs of *Idiognathodus sagittalis* Kozitskaya, 1978 and *Idiognathodus turbatus* Rosscoe and Barrick, 2009a have good potential as markers for the base of the Kasimovian (Ueno et al., 2011). Their occurrence (near base of Khamovnikian regional Substage, the second substage of the Kasimovian in current definition) is approximately one substage higher than the traditional base of the Kasimovian (base of Krevyakinian Substage), but raising the boundary level would facilitate global correlation, and most task-group members consider it appropriate. If the FAD of *I. turbatus* is used for boundary definition, the Nashui section (by village of Naqing) in southern Guizhou Province, China is an excellent candidate for the GSSP (Barrick et al., 2010), preserving the transition from *I. swadei* to *I. turbatus* without interruption.

The base of the Gzhelian Stage (303.7 ± 0.1 Ma) has not been anchored by a GSSP, but an index for boundary definition has been approved by the SCCS and ICS. Its historical stratotype lies in the abandoned Gzhel quarry in the Moscow Basin east of Moscow (Alekseev et al., 2009). The SCCS task group appointed to establish the Kasimovian–Gzhelian boundary selected the FAD of the conodont *Idiognathodus simulator* (Ellison, 1941) *sensu stricto* in its potential lineage *Idiognathodus eudoraensis* Barrick, Heckel and Boardman 2008-*I. simulator* as the event marker for the base of the Gzhelian (Heckel et al., 2008; Villa et al., 2009) and is directing research toward selecting a suitable section for the GSSP. To date the only section that has been formally proposed as a candidate for the GSSP is the Usolka section, a deep-water turbidite-dominated succession in the southern Ural Mountains, Russia (Chernykh et al., 2006; Davydov et al., 2008) but other proposals are being developed. Because the Moscow Basin provides good sections through the Kasimovian-Gzhelian boundary level, Alekseev and his colleagues plan to prepare a proposal for the GSSP at base of the Gzhelian based on either the Rusavkino quarry section or the stratotype of the Gzhelian Stage in the Gzhel quarry (Ueno et al., 2012).

A GSSP defines the top of the Carboniferous (298.9 ± 0.15 Ma), coincident with the base of the Permian System and tops of the Upper Pennsylvanian Series and Gzhelian Stage. The Carboniferous-Permian boundary GSSP lies in northern Kazakstan above the north side of Aidaralash Creek (Davydov et al., 1998). The FAD of the conodont *Streptognathodus isolatus* Chernykh, Ritter and Wardlaw, 1997 in the *Streptognathodus wabaunsensis* Gunnell, 1933-*Streptognathodus isolatus* chronocline defines the Gzhelian- Permian Boundary GSSP in the Aidaralash section (clastic-dominant marine shelf deposits), northern Kazakstan.

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