Chapter 25
International correlation

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Globally, the Carboniferous System can be subdivided into two time intervals, associated with a climatic change which produced quite distinct floral and faunal distribution and characteristics of sedimentation (Wagner & Winkler Prins 1991). The early Carboniferous, equivalent to the Mississippian of the U.S.A. and Lower Carboniferous of Russia, was a time of equitable climate in which sea levels were generally high and successions within low latitudes are typically marine. Unobstructed marine communication between the Palaeo-Tethys and Panthalassan shelves (Davydov *et al*. 2004) allowed marine fauna to have a world-wide distribution, in which latitudinal variations were stronger than longitudinal differences (Ross & Ross 1988). The late Carboniferous, equivalent to the Pennsylvanian of the U.S.A., and Middle and Upper Carboniferous of Russia, is typified by coal-bearing successions that displayed marked latitudinal climatic differentiation associated with the Gondwanan Ice Age. The mid-Carboniferous boundary, which separates the two climatic periods, is associated with widespread regression and on many cratonic areas by the presence of a non-sequence or unconformity. The comparable transition is seen in Western Europe between the Visean and Namurian stages, though this is not a direct time equivalent of the Mississippian – Pennsylvanian boundary (Fig. 2.1). The carbonate-dominated succession of the Visean and terrestrial clastic-dominated succession of the Namurian are interpreted as a facies change with no world-wide significance (Wagner & Winkler Prins 1991).

During the Carboniferous, Gondwana was located at high southern latitudes. South America, Africa, India, Arabia, Australia and Antarctica were affected by near-field glaciations. The dominance of non-marine cold-climate deposits lacking ammonoids, conodonts and foraminifers has hindered correlation with the North American, Western European and Russian equatorial successions, within which the standard stages have been defined (Stephenson 2008). Within Gondwanan basins correlation has relied upon palynology but few taxa exist in common with these high-latitude successions and the equatorial successions (Stephenson 2008).

The evolution of the chronostratigraphical nomenclature relevant to the Carboniferous System in Western Europe is described in detail in Chapter 2. In North America the Carboniferous was divided into the Mississippian and overlying Pennsylvanian, which were proposed as independent systems (Williams 1891). The Mississippian was subdivided into the Kinderhookian, Osagean, Meramecian and Chesterian Series, with type localities in the upper Mississippi valley (Fig. 2.1). The Pennsylvanian was subdivided into the Morrowan, Atokan, Desmoinesian, Missourian and Virgilian Series, with type localities in Arkansas, Oklahoma, Iowa, Missouri and Kansas, respectively (Heckel 1999). These series are now redefined as regional stages, with the Bursumian spanning the Carboniferous–Permian boundary (Fig. 2.1; Davydov *et al*. 2004).

In Russia, the Carboniferous was subdivided into Lower, Middle and Upper Carboniferous series. The Western European Tournaisian and Visean Series were adopted as the lowermost two stages of the Lower Carboniferous in Russia. A major difference was that the base of the Carboniferous was placed at the base of the

Quasiendothyra kobeitusana foraminiferal Zone in Russia, lower than in Western Europe. All of the remaining Carboniferous stages were named from localities in Russia (Fig. 2.1). The uppermost stage of the Lower Carboniferous of Russia, the Serpukhovian Stage, broadly equated with the lower Namurian (Pendleian to Alportian stages) of Western Europe. The Middle Carboniferous of Russia comprised the Bashkirian and Moscovian Stages and broadly equated with the Kinderscoutian to Asturian stages of Western Europe. The Upper Carboniferous of Russia was broadly equivalent to the Stephanian and early Autunian of Western Europe. Generally, the Russian stages were of longer duration than the stages defined in Western Europe.

Bouroz *et al*. (1978) were first to attempt an integration of the main classifications. They recognised two subsystems using the American nomenclature, the Mississippian and Pennsylvanian. This nomenclature was recognised by the IUGS subcommission, with Mississippian and Pennsylvanian Subsystems replacing the ambiguous Lower and Upper Carboniferous, respectively, which had had different connotations in different parts of the world (Heckel & Clayton 2006).

Six unnamed global series have been proposed for the Carboniferous (Fig. 2.1), comprising Lower, Middle and Upper Mississippian and Lower, Middle and Upper Pennsylvanian (Heckel & Clayton 2006). Seven global stages (Tournaisian, Visean, Serpukhovian, Bashkirian, Moscovian, Kasimovian and Gzhelian) with names based upon those used in Western Russia, have been identified (Heckel & Clayton 2006). Recognising the importance of retaining definition of regional variance in stratigraphy, the series previously identified in the U.S.A. and Western Europe have been retained as regional stages. The former stages recognised in Western Europe have been demoted to regional sub-stages (Heckel & Clayton 2006). Importantly, the new global stages are approximately of equivalent duration to the global stages identified for the adjacent Devonian and Permian Systems. The identification of the global stages and correlation with the regional chronostratigraphies is described below.

Tournaisian Stage

The Tournaisian is the only stage of the Lower Mississippian Series. The stage was originally defined in southern Belgium. The lower boundary of the Tournaisian Stage, and of the Carboniferous System, has been defined at the transition from the conodont *Siphonodella praesulcata* to *S. sulcata* (Paproth *et al*. 1991). The GSSP is taken at the La Serre section, Montagne Noire, France in Bed 89 at the First Appearance Datum (FAD) of *S. sulcata* (Paproth *et al*. 1991). The base of the Tournaisian also coincides with the FAD of *Gattendorfia* and *Gattenpleura* ammonoids (Kullmann *et al*. 1990) and the FAD of the foraminifers *Chernyshinella glomiformis* and *Tournayella beata* in the Franco-Belgian region (Conil *et al*. 1990). As a result, the base of the Tournaisian Stage and Western European Courceyan Substage are now almost coincident. The Tournaisian Stage equates with the Kinderhookian and lower Osagean regional stages of North America (Fig. 2.1).

Visean Stage

The Visean is the only stage of the Middle Mississippian Series. The stage was originally defined in southern Belgium at the lowest black limestone at the Bastion Section in the Dinant Basin (George *et al.* 1976), marked by the incoming of the foraminifer *Eoparastaffella*, occurring less than 1 m below the FAD of the conodont *Gnathodus homopunctatus* (Conil *et al*. 1990). The definition of the base of the Visean

Stage has subsequently been recognised at the lowermost presence of *Eoparastaffella simplex* (Work 2002), with the GSSP base proposed at the base of Bed 83 at Pengchong, Guangxi, China (Devuyst *et al*. 2003). *G. homopunctatus* occurs about 2.5 m above the base of the stage at this locality at the base of Bed 86. Further work has refined the early evolution of *Eoparastaffella* in Eurasia (Devuyst & Kalvoda 2007), of value in the global correlation of the base of the Visean Stage. The application of gamma-ray spectrometry and magnetic susceptibility techniques, interpreted as indicating sea-level fluctuations, permit a possible correlation of the regressive event (sequence boundary) at the Tournaisian/Visean boundary along the Wales-Brabant High from eastern Ireland to western Germany (Bábek *et al*. 2010). The technique also permits potential correlation of the boundary into deeper marine environments where the index taxon may be absent. The Visean Stage equates with the upper Osagean, Meramecian and lower Chesterian regional stages of North America (Fig. 2.1).

Serpukhovian Stage

The Serpukhovian is the only stage of the Upper Mississippian Series. The stage was originally proposed by Nikitin (1890) as the uppermost stage of the Lower Carboniferous, named after quarries and sections along the Oka River at Serpukhov City, located within the Moscow Basin. The base of the stage is likely to be at the first evolutionary appearance of the conodont *Lochriea ziegleri* in the lineage *Lochriea nodosa-L. ziegleri* (Richards 2009). The GSSP for the Serpukhovian has yet to be defined, but is likely to be at a eustatic maximum flooding surface. The base of the stage will closely coincide with the base of the Pendleian Regional Substage and Namurian Regional Stage of Western Europe, defined by the base of the *Cravenoceras leion* Marine Band (see Chapter 2), also a widespread marine flooding surface (Ramsbottom *et al*. 1978). Oxygen and carbon isotopic studies for the American Midcontinent and Russian Platform suggest that the stage boundary coincides with a major Gondwanan glaciation event (Mii *et al.* 2001; Grossman *et al*. 2008).

Some of the Namurian ammonoid biozones recognised widely in Europe have also been recognised in North America (Manger & Sutherland 1984) and Russia. The Serpukhovian Stage equates with the middle and upper part of the Chesterian regional stage of North America (Fig. 2.1).

Bashkirian Stage

The Bashkirian is the only stage of the Lower Pennsylvanian Series. The stage was originally defined in Bashkiria in the southern Urals, Russia by the appearance of the foraminifer *Pseudostaffella antiqua* (Semikhatova 1934). The lower boundary of the Bashkirian Stage, and of the Pennsylvanian Subsystem, was subsequently fixed at a lower level corresponding to a largely world-wide sequence boundary. This mid-Carboniferous boundary was originally considered to mark the onset of a major Gondwanan glaciation (Veevers & Powell 1987), but is now thought to represent an acme of glaciation in an event likely to have commenced during the Serpukhovian (Mii *et al*. 2001; Grossman *et al*. 2008). The exact position of the mid-Carboniferous boundary between the two subsystems was defined as the appearance of the conodont *Declinognathodus noduliferus* in the transition from *Gnathodus girtyi simplex* to *D. noduliferus s.l.* (Lane *et al*. 1999), with the GSSP at Arrow Canyon, Nevada, U.S.A. The archaediscid foraminifers *Eosigmoilina robertsoni* and *Brenckleina rugosa* are last recorded slightly above the boundary and the FAD of the foraminifers *Globivalvulina bulloides*, *Millerella pressa* and *M. marblensis* represent approximate markers for the

boundary (Davydov *et al*. 2004). The suitability of the GSSP is now questioned, with recognition of subaerial exposure surfaces in the boundary interval and the contention that many glacio-eustatic oscillation events are not represented in the succession, in contrast to the Namurian strata of northern England (Barnett & Wright 2008).Outside of the U.S.A., the base of the Bashkirian is marked by the occurrence of the foraminifers *Plectostaffella varvariensis*, *P. jakhensis*, *P. posochovae* and *P. bogdanovkensis*.

The Chokierian stratotype at Stonehead Beck, North Yorkshire (Riley *et al*. 1987; Varker *et al*. 1991; Riley *et al*. 1995) accumulated within a basinal setting and appears to lack an erosional break at the key interval of the mid-Carboniferous boundary seen elsewhere. The first appearance of the conodont *Declinognathodus* in the section occurs 9.4 m above the base of the Chokierian, defined by the *Isohomoceras subglobosum* Marine Band. This indicates that the base of the Bashkirian Stage and Chokierian Regional Substage are not coincident. *Isohomoceras subglobosum* is also recognised in Nevada and Central Asia, but occurring earlier than in Western Europe, during latest Serpukhovian (Nemirovskaya & Nigmadganov 1994; Titus *et al*. 1997). The Bashkirian Stage equates with the Morrowan and lower part of the Atokan regional stages of North America (Fig.~~ure~~ 2.1).

Moscovian Stage

The Moscovian is the only stage of the Middle Pennsylvanian Series. The stage was originally defined in the Moscow area by Nikitin (1890). Here, in the Moscow Basin, the base of the stage is marked by a prominent unconformity, with strata of Bashkirian age absent. The definition of the base of the global stage and GSSP are yet to be ratified. However, it is likely to be based upon the conodonts *Declinognathodus donetzianus* derived from *Idiognathoides sulcatus*, *Id. postsulcatus* derived from *D. marginodosus*, and the appearance of *Diplognathodus ellesmerensis*, which are widely distributed across Russia, Western Europe, North America and Japan (Nemirovskaya 1999). The first of these appears about 3 m above the stage boundary as currently defined in the Moscow Basin (Makhlina *et al*. 2001). In the same section, the fusulinid foraminifer *Aljutovella aljutovica* appears at the same level as *D. donetzianus* (Makhlina *et al*. 2001) and can be correlated widely across the northern and eastern margins of Pangaea (Solovieva 1986).

It is likely that in North America the base of the stage coincides with the FAD of the conodont *Profusulinella* (Groves *et al*. 1999). The stage is likely to coincide with the base of the *Winslowoceras–Diaboloceras* Zone of the Russian Platform and Urals (Ruzhenzev & Bogoslovskaya 1978) or the *Eowellerites* Zone in Western Europe and North America (Ramsbottom & Saunders 1985), although the former is probably slightly younger than the latter (Davydov *et al*. 2004). The Moscovian Stage equates with the upper part of the Atokan and lower Desmoinesian regional stages of North America (Fig.~~ure~~ 2.1).

Kasimovian Stage

The Kasimovian is the lower stage of the Upper Pennsylvanian Series. The stage was originally included in the Moscovian by Nikitin (1890), but was recognised as being a distinct stage of the Russian Upper Carboniferous by Ivanov (1926).

The definition of the base of the global stage and GSSP are yet to be ratified. There is a prominent internationally recognised boundary coinciding with a eustatic sea-level low

and prominent disconformities at the base of the Missourian and Kasimovian of the American Midcontinent and Russian Platform, respectively (Bouroz *et a*l. 1978; Wagner & Winkler Prins 1997), though Davydov *et al*. (2004) indicated that the base Kasimovian disconformity occurs 2 cycles below the base of the Missourian. However, with the limited presence of Stephanian strata in Britain, neither of these disconformities can be recognised. The conodonts *Idiognathodus sagittalis* and *Id. turbatus* are currently being investigated as potential markers for the base of the stage. The Kasimovian Stage equates with the upper part of the Desmoinesian and Missourian regional stages of North America (Fig. 2.1).

Gzhelian Stage

The Gzhelian is the upper stage of the Upper Pennsylvanian Series. The stage was originally proposed by Nikitin (1890), but not widely used in the Moscow Basin until the fusulinid zonation became established (Rauser-Chernousova 1941). The definition of the base of the global stage is defined as the appearance of the conodont *Idiognathodus simulator*, which is widely distributed across Russia, Western Europe, North America and China (Villa *et al*. 2009). The GSSP is yet to be ratified. Traditionally, the base of the Gzhelian was defined by the first appearance of *Rauserites rossicus* and *R. stuckenbergi,* although according to Davydov *et al.* (2004) in the type locality at Gzhel' only *Rauserites rossicus* has been recorded*.* The base of the stage is exposed near the village of Gzhel' in the Moscow Basin and is an unconformity (Makhlina *et al.* 1979) and a second-order sequence boundary (Briand *et al.* 1998).

In North America (north-central Texas) the earliest species of the ammonoid genus *Shumardites* (*S. cuyleri*) occurs in the same cyclothem (Finis) as the first *Idiognathodus simulator* (Boardman *et al.* 1994; Bogoslovskaya *et al.* 1999; Boardman & Work 2004; Boardman *et al.* 2006). The Gzhelian Stage equates with the Virgilian, and lowest part of the Bursumian regional stages of North America (Fig. 2.1).

The Carboniferous-Permian boundary is defined in the South Urals, with the Permian GSSP established in Aidaralash Creek, Kazakhstan, at the first appearance of the conodont *Streptognathodus isolatus* in the *S. wabaunsensis* chronocline (Davydov *et a*l. 1998). The current tentative correlation with Western Europe suggests the basal Permian equates with mid-Autunian (Wagner 1998).

Geochronology

The main sources of internationally recognised ages are U-Pb Zircon and Ar-Ar sanidine (Davydov *et al*. 2004, 2010), although inconsistencies are recognised between sources and laboratory techniques (Menning *et al*. 2000). Key dates have been determined for volcanic ash deposits in the Donets Basin of Russia, with Davydov *et al*. (2010) providing twelve new high resolution ages ranging from Tournaisian to Moscovian, a selection of which are shown on Fig. 2.1. An age for the Carboniferous–Permian boundary is constrained at the Usolka auxiliary stratotype in the Urals as 298.90 + 0.31/- 0.15 Ma (2σ).