Cadernos Lab. Xeolóxico de Laxe
Coruña. 2009. Vol. 34, pp. 59 - 74 ISSN: 0213-4497

Regional Stages: Their Types and Chronostratigraphic Utility

Etapas regionales: sus tipos y utilidad cronoestratigráficas

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Recibido: 4/6/2008 Revisado: 20/8/2008 Aceptado: 15/12/08

Abstract

The Earth's history is continuous and global, but we package it into international and regional geologic stages. Among the latter one can distinguish alternative, concurrent, biogeographical, and land regional stages. Progress in global chronostratigraphy now provides a precise international language and attainment of high-precision correlations, therefore many of the regional stages have outlived their usefulness and should be abandoned. Indeed, retention of the multitude of regional stages, which are often redundant (e.g., the Neogene stages of the Eastern Paratethys), merely confuses geoscientists and leads to significant misunderstandings. The main useful regional stages are those established for a paleobiogeographically distinct region or some terrestrial records that cannot yet be correlated with certainty into the international stages.

Key words: Regional stage, global stage, land mammal age, chronostratigraphy, paleobiogeography.

INTRODUCTION

It is fortune for present-day geologists to live at a time of such remarkable progress in the chronostratigraphy. The activities of the International Commission on Stratigraphy and efforts of many individual specialists have brought together a significant modification of the geological time scale (BERGGREN et al., 1995; REMANE et al., 1996; AUBRY et al., 1999; STEININGER, 1999, 2002; REMANE, 2000, 2003; GRADSTEIN & OGG, 2004, 2006; GRADSTEIN et al., 2004; OGG, 2004; WALSH, 2005a-c; WALSH et al., 2004). This comprises two important procedures, namely (1) the formal definition of the globally-recognized stages by establishing the Global Stratotype Section and Point (GSSP) for their lower boundaries (see SALVADOR, 1994; REMANE et al., 1996 for rules), and (2) the precise evaluation of the absolute ages for stage boundaries. Although the improvement and increased resolution of chronostratigraphic knowledge will never be completed, the present "International Chronostratigraphic Chart" (GRADSTEIN et al., 2004; and www.stratigraphy.org) has greatly improved our knowledge on the subdivisions of Earth's history.

A significant question, which arises with the formal definition of the stages, is what to do with the traditionally used regional stages: a typical example is the Paratethyan standard of the Neogene (RÖGL, 1996; STEININGER & WESSELY, 1999; HARZHAUSER et al., 2002; NEVESSKAJA et al., 2005). If the *status quo* remains, difficulties in use of stratigraphic nomenclature will occur. It is difficult for specialists to choose between the chronostratigraphic and regional stages, as well as to correlate between them. This issue has already been raised, particularly by CARTER (1974), SENEŠ (1990), CARTER & NAISH (1998), STEININGER (1999), MCGOWRAN (2005), and RUBAN (2005), but a detailed discussion of this topic is still necessary. A brief review of the types of regional stage and their utility in the development of chronostratigraphy is included in this paper, although its main purpose is to initiate a broad discussion on the management of regional stages.

TYPES OF REGIONAL STAGES

General terms and brief historical background

According to the "International Stratigraphic Guide" (SALVADOR, 1994), the *stage* is the lowest ranking unit in chronostratigraphy and includes all rocks formed during a given age. In this paper, I use the term *chronostratigraphic stage* (as also used by STEININGER, 1999) in the formal sense of stage following ICS-recommended procedures (SALVADOR, 1994) and recognized globally; an equivalent term would be a *global stage*. The *regional stage* is a chronostratigraphic unit initially proposed for a particular region. A sequence of several successive regional stages forms a *regional stage standard*. The latter is intended to represent the true chronostratigraphy of a given region.

The first attempts to establish the global stages, which were undertaken as far as in the XIX century, required to attach them to the concrete successions of rocks. This was caused evidently by a great lack of data from the entire world, when a good reference section (*stratotype*) with its characteristic fossil assemblage(s) was necessary to trace the deposits of the same age in the other regions. Perhaps establishing these first stage stratotypes, now called *historical stratotypes*, was linked closely to the implications of the lithostratigraphic techniques, because the local fossil assemblages were found in the particular kind of strata. A complete stratigraphic interval (volume) of a stage was preserved in the historical stratotype. Stratigraphy progressed rapidly, but those first-established stratotypes remain the same and served for global correlation of stages for many decades. After the mid-XX century, the amount of stratigraphic data collected across the world became so great that it allowed searching for better reference sections. Why any other section would be better than the historical stratotype? This should be answered in terms of completeness and utility of fossil assemblage. But another big problem is a significant diachrony of biostratigraphic units. It is especially significant if tracing the stages by their full interval referring to the historical stratotype. Finally, an absolutely new strategy in the development of a global time scale was proposed in the mid-1970's. The stratotype is established for the lower stage boundary only, and this boundary is fixed by a globally-recognized event (this may be not only bioevent). Thus, new stratigraphic references, namely the *Global Stratotype Sections and Points* (*GSSPs*) are defined. This permit to avoid most of the problems related to the usage of the historical stratotypes. The new procedure is managed by the International Commission on Stratigraphy, and a part of available global stages is already re-defined. Besides of the definition of a new kind of stage stratotypes, a significant re-consideration of the earlier developed stage standards is attempted. In some cases, the newly-defined stages are rooted directly in those, which were established with historical stratotypes, whereas in other cases, the new stages are proposed. This strongly depends on the activity of the particular subcommissions and working groups of the International Commission on Stratigraphy. Ideally, it would be necessary to abandon the previous chronostratigraphic developments and create an absolutely new scale with the new stages. However, it is difficult to imagine that one can attempt this. More information on the history of stage definition and the present principles of the chronostratigraphy can be found in REMANE et al. (1996), REMANE (2000, 2003), WALSH et al. (2004), MCGOWRAN (2005), and WALSH (2005a-c).

The regional stages are those stages with historical stratotypes, which were established for the particular regions. The correlation of some stages based on the data from the historical stratotypes was a difficult deal and sometimes it was impossible. This led to the definition of the stages for particular regions. Thus, for some stratigraphic intervals, a number of stage sequences, differed between regions, exists. Before deciding what it is possible to do with these regional units in a new reality, when GSSP-based chronostratigraphy is so efficient, we need to distinguish several types of regional stages, which are characterized below.

Alternative regional stages

The *alternative regional stages* (type 1) are those regional stages which exist together with the formally-defined chronostratigraphic stages and provide alternatives for the global chronostratigraphy in a particular region. An example is the Paratethyan Regional Stages of the Neogene (Fig. 1). The Paratethys was a sea which occupied a large part of southern Europe and Southwest Asia from the Oligocene to the Quaternary (RÖGL, 1998, 1999; STEININGER & WESSELY, 1999; GOLONKA, 2004; POPOV et al., 2006). It was separated from the Mediterranean part of the Neotethys Ocean following the initiation of the orogeny in the Alpine regions. Biostratigraphic evidence (particularly, events in the evolution of bivalves and microfossils) was used to develop a detailed regional stage standard (Fig. 1), which has been in use for more than a century. However, even this standard differs between the central (Pannonian) and eastern parts of the Paratethys (RÖGL, 1996; STEININGER & WESSELY, 1999; HARZHAUSER et al., 2002; NEVESSKAJA et al., 2005) (see Fig. 1). E.g., the Pontian of the Central Paratethys is not the Pontian of the Eastern Paratethys. Such a difference is explained mostly by the differences in national traditions of strati-graphical/palaeontological studies, rather than by the difference between the local faunas. During the past decade, the International Commission on Stratigraphy has formally defined six Neogene chronostratigraphic stages which include the Aquitanian, Serravallian, Tortonian, Messinian, Zanclean, Piacenzian, and Gelasian (GRADSTEIN et al., 2004; GRADSTEIN & OGG, 2006). Developing the GSSP candidates for the Burdigalian and Langhian stages is not a simple task; however, the development of the Neogene chronostratigraphy is about three quaters complete. In this case, the regional stage standards of the Paratethys exist together with a well-developed chronostratigraphic framework and form a regional alternative to the latter. And this is a bad alternative because it breaks down the fundamental principle of the present-day chronostratigraphy, which reaches to be global.

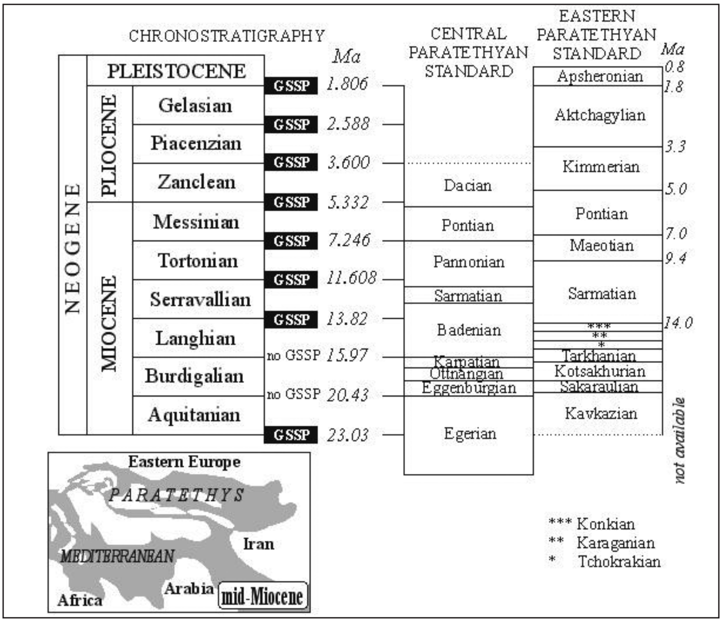

Fig. 1. The Neogene chronostratigraphy (after GRADSTEIN et al., 2004; GRADSTEIN & OGG, 2006; International Stratigraphic Chart of the International Commission on Stratigraphy (version September, 2006) - www.stratigraphy.org) and regional stages of the Eastern Paratethys (after RÖGL, 1996; STEININGER & WESSELY, 2000; HARZHAUSER et al., 2002; NEVESSKAJA et al., 2005; RUBAN, 2005). The middle Miocene-Pliocene regional stages of the Eastern Paratethys are correlated to the global stages with absolute ages of TCHUMAKOV et al. (1992). Direct relations of the chronostratigraphic units to the Central and Eastern Paratethys stages are presented, whereas correlations between Paratethyan units (like those by STEININGER & WESSELY, 2000) are omitted. The Paratethys-Mediterranean palaeogeographic outline is simplified from RÖGL (1998) and STEININGER & WESSELY (1999).

Concurrent regional stages

The *concurrent regional stages* (type 2) are traditionally-used or newly-introduced regional stages which occur with others as chronostratigraphic stages in cases in which global stages have not yet been formally defined. This means that such regional stage standards exist when there is a gap in the global chronostratigraphy of a particular time interval. When chronostratigraphic stages become formally defined the concurrent regional stages become alternative regional stages or global chronostratigraphic stages. OGG (2004) considers the "hybridization" of the regional stages. They may also be only partly used. A choice of one of the regional stage standards does not necessarily mean that regional stage directly becomes a chronostratigraphic stage. Its stratigraphic extent may be shortened or enlarged, and GSSP may not only be established in the historical area. As an example, the Darriwilian Stage originally used in Australia for regional stratigraphic purposes has now become a chronostratigraphic stage for the Middle Ordovician, although its GSSP was established in Southeast China (MITCHELL et al., 1997). Additionally, the introduced chronostratigraphy may be absolutely new and not take into account any regional evidence. An example of concurrent regional stages is found in the Carboniferous: the global chronostratigraphic framework of this system is not yet finalised, other than the definition of the Tournaisian and Bashkirian GSSPs and whether to distinguish the Mississippian and Pennsylvanian subsystems (GRADSTEIN et al., 2004; GRADSTEIN & OGG, 2006). Three principal historical stage standards have been discussed for the Carboniferous and come from Western Europe, Russia, and North America. An overview of their relationships is presented by MENNING et al. (2000, 2001, 2006). These standards concurred with one another to form the global chronostratigraphic framework for the Carboniferous. At now, it seems that the International Commission on Stratigraphy prefers the Russian standard (GRADSTEIN & OGG, 2006), which will be anyhow modified. This is to some degree the same situation we have in the Cambrian period where several regional stage standards have been proposed (PALMER, 1998, ZHURAVLEV, 1995). However, it is possible that none of the regional standards will be used in a new four-fold Cambrian, which consists of 10 new stages, two of which (Drumian and Paibian) have their own names (GRADSTEIN & OGG, 2006).

Biogeographical regional stages

The *biogeographical regional stages* (type 3) provide an alternative to chronostratigraphy in those cases in which differences in the palaeoenvironments on a global scale were the highest. The biogeographical regional stage standards represent biogeographically distinct regions and are used in which the tracing of chronostratigraphic stages is difficult. Examples of such regional stages can be found in the Mesozoic-Cenozoic of New Zealand and southern Australia (FINLAY & MARKWICK, 1940, 1947; MARKWICK, 1951; WELLMANN, 1959; CARTER, 1974; HOSKINS, 1982; PILLANS, 1991; DAMBORENEA & MANCEÑIDO, 1992; CRAMPTON et al., 1995, 2000, 2001; MORGANS et al., 1996; CARTER & NAISH, 1998; GRANT-MACKIE et al., 2000; MCGOWRAN, 2005). These regional stages were first proposed around the middle of the 20th century and are extensively used in local stratigraphy. Their nomenclature is still debated, and their correspondence to global chronostratigraphic units is often unclear. This is explained by the difficulties of long-distance correlations due to the lack of reliable biostratigraphical evidence, which has resulted from significant palaeobiogeographical differences between southern Australia and New Zealand (see, e.g., GRANT-MACKIE et al., 2000; CRAMPTON et al., 2001; MCGOWRAN, 2005). It is necessary to distinguish the biogeographical regional stages from the alternative regional stages. The latter are usually defined in regions where the palaeontological record differs from those used for global reference. However, these differences are not large and mostly occur as a result of regional-scale palaeogeographic specific factors and not because of global-scale palaeobiogeographical differences. An example is the similarity between gastropod faunas of the Mediterranean and Paratethys (HARZHAUSER et al., 2002) which was markedly higher than that of New Zealand and European faunas.

Regional land stages

The *regional land stages* (type 4) are alternatives to the chronostratigraphic units developed from the terrestrial record. The most known of them are the European Land Mammal Ages (FAHLBUSCH, 1976; STEININGER, 1999), the North American Land Mammal Ages (WOOD et al., 1941; WOODBURNE, 1987; BERGGREN et al., 1995; CLYDE, 2001; CLYDE et al., 2001; WALSH, 2005c), and the South American Land Mammal Ages (BERGGREN et al., 1995; FLYNN et al., 2002, 2003). In other regions, divisions of a similar kind have been also proposed, as for example, in China (BERGGREN et al., 1995; BEARD & DAWSON, 1998; WANG et al., 2003). These regional land stages are used widely. Some can be confidently linked to global chronostratigraphic divisions whereas the correlation of some others is not so clear.

CHRONOSTRATIGRAPHIC UTILITY OF THE REGIONAL STAGES

The regional stage standards played an important role in the development of the stratigraphy. They permitted to group the evidences from the particular regions and to weight up this evidence. This provided vast information for further global tracing of stratigraphic units and events. However, the use of the regional stages together with the development of the global chronostratigraphy produces significant problems in the understanding of geological history and interregional correlations. As already observed (CARTER, 1974; SENEŠ, 1990; CARTER & NAISH, 1998; STEININGER, 1999; RUBAN, 2005), a clear decision on the chronostratigraphic utility of the regional stages is required.

The principal purpose of chronostratigraphy is to develop a global time scale correctly reflecting the Earth's history. According to the International Stratigraphic Guide (SALVADOR, 1994), stages should reflect ages. If we have several regional stage standards, this means we expect that the geological time scale differed within global palaeospace! This does not match sense because at each point in geological history, time was equal everywhere. We may conclude regional stages are not necessarity. *A priori* they cannot be analogous to the global chronostratigraphic units (see also STEININGER, 1999; RUBAN, 2005). This conclusion is appropriate to the alternative regional stages. They continue to exist *after* the formal definition of global chronostratigraphic stages, and, consequently, they should no longer serve as references to chronostratigraphy.

The continued use of them rather than global stages is an inappropriate way to develop both global and regional stratigraphy. However, the concurrent regional stages seem to make sense because they were proposed and used *before* the appearance of the widely accepted global chronostratigraphy. Moreover, they are used to make progress in the development of the latter and provide regional evidence to establish the global divisions. Hence the concurrent regional stages may be used prior to the formal definition of global chronostratigraphic units, although it is necessary to understand that they have only a potential chronostratigraphic sense. The evidence from the concurrent regional stage standard may be used in its entirety, partly, or not at all (see above). In conclusion, this type of regional stage has utility only as a «generator» of evidence on which to develop the global geological time scale. After the formal definition of the chronostratigraphic units, concurrent regional stages become alternative regional stages, and consequently redundant. Historical arguments should not be presented to use a regional standard as a base for global chronostratigraphy or to continue its use after the establishment of global units. Historical importance indicates a rich scientific heritage of any region or country but brings nothing useful to the development of modern science.

An example of the Paratethyan Neogene standards is of special interest. Differences between the Central and Eastern Paratethyan stages are a powerful argument to abandon their entire suite to avoid confusions. E.g., the Pontian is a regional stage considered both in the Pannonian Basin (Central Paratethys) and in the Ciscaucasus (Eastern Paratethys). However, their stratigraphic volume differs (Fig. 1). If someone reads about the Pontian, he will be always confused, which Pontian is considered. Moreover, in some basins of the Eastern Paratethys, the local stage standard exists. E.g., the upper Miocene-Pliocene time scale of the Dacian Basin (VASILIEV *et al*., 2004) includes the stages from the Eastern Paratethys, but also operates with the Dacian and the Romanian stages, which are not recognized in the Eastern Paratethys. The author feels that a strong re-evaluation of the palaeontological data from the Eastern Paratethys is urgent. Some taxa from this territory may be the same known from the Mediterranean basins. One can hypothesize that long isolation of studies in the Paratethys and the Mediterranean could lead to the *artificial* strengthening of their faunal differences, when one taxon was distinctly identified. All these suggest a strong necessity to replace all the Paratethyan standards and to establish the chronostratigraphic units.

To understand chronostratigraphic untility for the biogeographical stages is a more complicated task. We have assumed above that geological time was equal at every point on a planet, although this time is constrained by biostratigraphical and other data, which might have different between distant regions. If the biogeographical differentiation of global palaeospace was robust, it would be very difficult to combine evidence from distinct biogeographical realms to develop a unique scale and correlation between biogeographically distinct regions would be very uncertain. Global biogeographic patterns have changed significantly through the Earth's history and WESTERMANN (2000), who analyzed Mesozoic marine faunal realms, suggested that significant palaeobiogeographical differentiation occurred in the Early-Middle Jurassic. True realms appeared at that time.

An overview of floral evolution by MEYEN (1987) allows us to conclude that the first palaeophytogeographical differentiation occurred during the Late Carboniferous-Permian, and the second began in the Jurassic and increased into the Cenozoic. This is supported by a recent summary of BURGOYNE et al. (2005). Thus, at least since the Late Paleozoic-middle Mesozoic, regional stage standards make sense for some large and remote regions like Australasia as similarly proposed by MCGOWRAN (2005). In those cases, regional stage standards can be used as real alternatives to chronostratigraphy and should be further developed to account for data from remote and biogeographically distinct regions. However, any simplifications should be avoided. Any regional stratigrapher can proclaim his region as biogeographically-specific to preserve the traditional regional stages. Perhaps, Australia and New Zealand are only regions remote so far to deserve their own stage standards.

Three possible considerations on the utility for the regional land stages are proposed:

1. if the regional land stages exist when no global chronostratigraphy for a particular interval has been developed, they should be considered as concurrent regional stages;
2. if the regional land stages exist together with global chronostratigraphic units and their correlations are clear, they have little utility and should be abandoned (see also STEININGER, 1999);
3. if the regional land stages exist together with the developed global chronostratigraphic scale, but their correspondence is unclear, they should be considered the same as biogeographical regional stages.

It should be underlined finally that all regional stages are similar to the historical global stages, because they are attached to the stratotypes representing their entire interval. If so, all regional stages are *essentially* different from the GSSP-based chronostratigraphic stages.

DISCUSSION

As concluded above, at least some of regional stages should be abandoned. However, some useful information may be extracted from the regional stage standards. Below, two examples to demonstrate this are given.

Most of the regional stages were originally established on the basis of biostratigraphic evidence and are continue to be meaningful in a regional context. For example, the Neogene regional stages of the Eastern Paratethys are based on very detailed study of mollusc, foraminifer, and ostracod assemblages (NEVESSKAJA et al., 2005). To trace the stratigraphic ranges of taxa in more detail it would be necessary to develop a precise regional biostratigraphic scale of mollusc, foraminifera, and ostracod-based biozones established from the first and last occurrences (FOLs and LOLs, respectively). Some of them will entirely or partly correspond to the regional stages. Such an approach was attempted by RUBAN (2005) who turned the regional Neogene stage standard of the Eastern Paratethys into a regional bivalve-based biozonation within the Rostov Dome. STEININGER (1999) has demonstrated the efficacy of the Neogene mammal zones in Europe in contrast to the European Land Mammal Ages. Thus, some regional stage standards may be replaced by the regional biostratigraphic scales although this should not be considered as a compromise between specialists who continue to defend regional stages. Such replacement is only possible when it is efficient and does not bring chaos to stratigraphic nomenclature.

In some cases, regional alternatives to the chronostratigraphic units are essentially lithostratigraphic units. In other words, they are alternative regional stages, appeared thanks to the strong specificity of sedimentary successions, where they were established. An example may be found in the Precambrian. The Riphean is considered by some as an eonothem, whereas its subdivisions, namely the Burzjanian, Jurmantinian, and Karatavian, are considered as erathems (Fig. 2). These units were proposed for the territory of the former USSR, i.e., North Eurasia (SEMIKHATOV et al., 1991). However, the Riphean was originally established as a lithostratigraphic unit in the Southern Urals (SHATSKIJ, 1945, 1963). From my studies in the stratotype area I have concluded that the Riphean is nothing more than a supergroup and its major subdivisions should be considered as groups. The Riphean units do not correlate with the present-day chronostratigraphic divisions of the Precambrian time scale (PLUMB, 1991; GRADSTEIN et al., 2004). Similarly, the Rotliegend, which forms a significant part of the Late Paleozoic of Western-Central Europe, is a sedimentary complex only (see overview in GLENNIE, 1997) and subdivision at the stage level yields merely the lithostratigraphic units. Although the Rotliegend was formerly a unit used in regional timetables (MENNING et al., 2006), it should now be considered only in lithostratigraphic context. Thus, some of the regional stages and units of other rank may be preserved as lithostratigraphic units. If so, they should not be proclaimed as chronostratigraphic units or their equivalents.

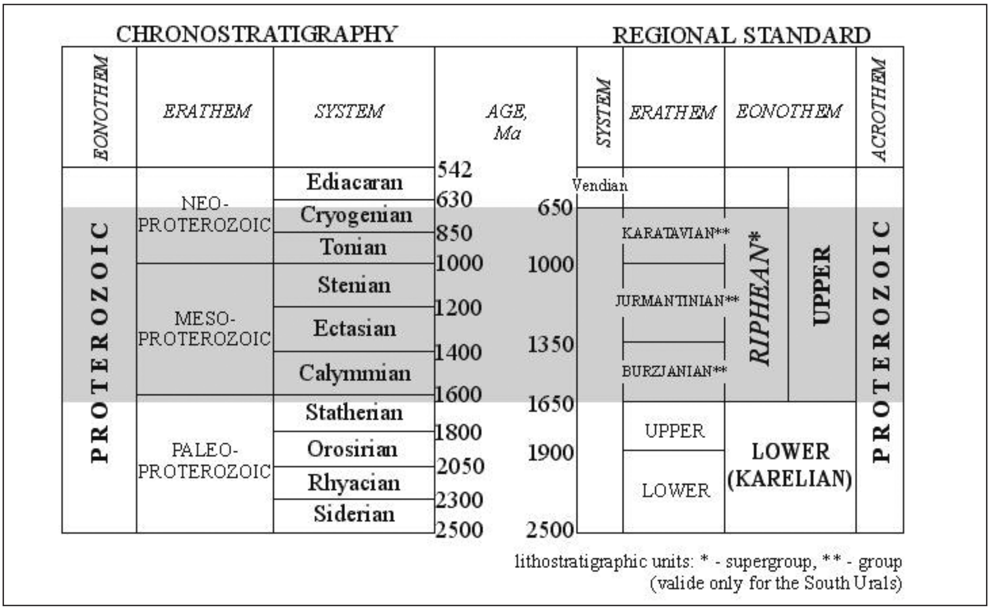

Fig. 2. The Proterozoic chronostratigraphy (after PLUMB, 1991 and GRADSTEIN et al., 2004) and the Riphean regional stratigraphy (SEMIKHATOV et al., 1991). The Riphean interval is shaded.

CONCLUSIONS

Four types of regional stage are distinguished, namely 1) alternative regional stages; 2) concurrent regional stages; 3) biogeographical regional stages; and 4) regional land stages. Alternative regional stages as some of land stages should be abandoned and, where possible, replaced by biozones or lithostratigraphic units since they make no contribution in the development of chronostratigraphy. Concurrent regional stages provide evidence for the further establishment of globally-recognized chronostratigraphic stages. Biogeographical regional stages may exist as alternatives to the existing chronostratigraphic units, when the global stages cannot be traced to distant and biogeographically distinct regions. However, all regional stages are essentially incomparable with the global stages, established with GSSPs.

It is hoped that conclusions from this paper may stimulate further discussion on the relationship between the regional stages and chronostratigraphic scales.

ACKNOWLEDGEMENTS

The author gratefully thanks J.R. VIDAL ROMANÍ (Spain) for his help, J.G. EATON (USA) and J.D.A. PIPER (UK) for their preliminary reviews and linguistic corrections, J. OGG (USA) for his constructive suggestions, and also N.M.M. JANSSEN (Netherlands), M. MENNING (Germany), and many other colleagues for help with literature and useful comments.

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