S1–23

High–Resolution Integrated Stratigraphy in Era of Earth System Science

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Summary

High resolution chronostratigraphic system is the foundation for the research of Earth system science. High resolution integrated stratigraphy makes an attempt to establish high resolution stratigraphic framework with both resolution less than a biozone of a stratigraphic unit and correlation error of a stratigraphic boundary. In the present paper the stratigraphic methods are divided into 3 kinds generally used to establish chronostratigraphic system. They are biostratigraphy, the various subdisciplines of modern stratigraphy, and isotope chronostratigraphy. Their advantages and disadvantages of the 3 kinds of stratigraphic methods are discussed. It is considered that resolution is limited of any kind of stratigraphic method, and integrated stratigraphy may provide an effective approach for the high resolution division and high precision correction of strata. Biostratigraphy is used to establish a believable relative chronostratigraphic framework, the subdisciplines of modern stratigraphy contribute the high resolution division and high precision correction of strata, and isotope chronostratigraphy give absolute age of both biostratigraphic boundaries and other kinds of stratigraphic boundaries. The combination of all three (biostratigraphy, modern stratigraphy and isotope chronostratigraphy) commonly constitute high resolution integrated stratigraphy.

Keywords: Earth system science, geological time scale, international stratigraphic chart, high resolution integrated stratigraphy, Deep time, Earth time

1. Introduction

In the mid–1980s, the Earth System Science theory was proposed, laying a solid foundation for all earth science sub–disciplines and has gradually become an essential guiding ideology for the 21st century earth science. However, in order to explore the evolution of earth system in geological history, it is an important basis and prerequisite to establish a chronology framework for global stratigraphic correlation.

Stratigraphy is a fundamental discipline in geology, providing the time and spatial framework for all geological science research, and a highly precised time and spatial framework is indispensable for all research of Earth System Science.

Currently, biostratigraphy, modern stratigraphy and isotope chronostratigraphy are commonly used stratigraphic branches in building a high–resolution chronostratigraphic system or to correlate strata in a highly precised pattern. They have different properties and characteristics, and play different roles in high–resolution stratigraphic division and high–precision stratigraphic correlation.

2. Biostratigraphy

Biostratigraphy is based on the irreversible nature of biological evolution, and the stratigraphic units identified by biostratigraphy are unrepeatable. It is relatively independent and reliable in establishing stratigraphic sequences and determining the stratigraphic age utilizing biostratigraphy. It is the basis of stratigraphy. The best identification marks of the global standard chronostratigraphic unit stratotypes (GSSP) are mainly the biogenetic events preserved in rocks. Stratigraphic correlation by other stratigraphic branches rejecting biostratigraphy as the basis may not be acceptable.

The shortcomings of biostratigraphy are mainly the following. First, the boundary of the biostratigraphic unit generally has a certain degree of stratum diachronism and is not easy to be correlated accurately. Biostratigraphy can hardly be used to locate where the bottom boundary of a biozone lies. Migration of organisms, formation and preservation of fossils, change of sedimentary facies and the research degree of biostratigraphy may influence the locating. For a long time, biostratigraphicunits with diachronic features have been often employed to identify isochronous surfaces, whose correlation error may sometimes reach one biozone. Second, biostratigraphic units have neither absolute age signs nor stable lasting time, therefore they do not reflect duration and developing speed of geological events. In addition, ecological differentiation caused by different sedimentary environments makes it impossible to conduct direct biostratigraphic correlation among different facies zones. Moreover, the time resolution of biostratigraphic units is generally over one million years, and the correlation error is over one million years too.

Consequently, high–resolution stratigraphic division and high–precision stratigraphic correlation cannot be accomplished by biostratigraphy alone. A series of modern stratigraphy approaches emerged after the 1960s and made up the deficiency of biostratigraphy to a certain degree.

3. Modern stratigraphy

As for modern stratigraphy, the one–biozone error and the millions–of–year (Ma) resolution, which are common in stratigraphic correlation by traditional stratigraphy such as lithostratigraphy, biostratigraphy and chronostratigraphy are dissatisfied. Researchers, of all branches of modern stratigraphy, attempt to establish high–resolution stratigraphic units. Although there are divergences in the meaning of “high–resolution stratigraphic unit”, the time resolution of high–resolution stratigraphic units is generally smaller than one biozone, and the correlation error of stratigraphic boundaries is smaller than one biozone. On the other hand, every branch of modern stratigraphy has the same nature as event stratigraphy, in which sudden and instantaneous geological events and their records are taken as the basis for stratigraphic division and correlation. As a result, the modern stratigraphic unit boundary is generally a natural boundary, widely distributed, strongly identifiable, easily operable and strictly isochronal in theory. It can be utilized to conduct high–precision stratigraphic correlation across sedimentary facies, even globally. This makes up the precision shortcomings of biostratigraphy caused by biozone diachroneity and environmental control on biological distribution.

However, stratigraphic units determined by modern stratigraphy are generally lack of independent time signs, they are reversible and can be repeated in the geologic history. It's hard to identify only by modern stratigraphy the time, duration, speed and the order of geological events. The time and order can rely on biostratigraphy and isotope chronostratigraphy. The correlation of modern stratigraphic units should not be conducted alone and should be carried out within a certain chronostratigraphic or biostratigraphic scope. Except cyclostratigraphy controlled by astronomical factors, the unit periodicity of each branch of modern stratigraphy is not very obvious, and the period is usually too long to perform high−resolution stratigraphic division. But, within the stratigraphic framework established by biostratigraphy, the boundaries of modern stratigraphy units are conducive to further division and accurate correlation on biostratigraphic unit.

4. Isotope chronostratigraphy

As for biostratigraphy and each branch of modern stratigraphy, it is impossible to determine the specific age, duration and speed of geological events and geological processes, for only relative geological age can be derived. Isotopic geochronology can serve as a basis to determine the absolute age, duration and speed of geological events, and offer the initial absolute age constraint to biostratigraphy, subdisciplines of modern stratigraphy, cyclostratigraphy, etc. As a stratigraphy break through research, isotopic geochronology has greatly improved the geological research level and deepened the geological cognition of researchers.

Geochronology was born in 100 years ago. This technology is developing continuously, and Phanerozoiccan can be identified to the 10, 000 year level, or even better, compared to millions of years before, but geochronology still has the following two shortcomings. On the one hand, the suitable radiometric dating samples in the strata are not pervasive, especially it is almost impossible to continuously obtain several suitable radiometric dating samples on a complete section, and thus it is almost impossible to obtain continuous high−resolution geologic time sequences. On the other hand, a number of factors affect the absolute age of high−precision testing−−thus achieving the absolute age of the geologic time scale may be a dynamic process for a long time.

Besides the testing materials, status of the closed system and laboratory analysis conditions, factors influencing high−precision absolute age testing include at least the following.

First, there are errors in radioisotope measurement. With the improvement of testing technology, the error of radioisotope dating will be smaller, but it will not disappear. The physics definition of error is the difference between the test value and the real value. However, the real value cannot be measured and cannot be obtained.

Second, there is a systematic error between results of different dating systems. U−Pb and Ar−Ar methods are the most commonly used methods of high−precision radioisotope chronology. The results of U−Pb method and Ar−Ar method on the same sample will have a systematic error, and the Ar−Ar's result is about 0.7~1.5% younger than the U−Pb's.

Thirdly, different methods have different precision. Modern zircon U−Pb geochronology is developing towards two directions: high spatial resolution and high precision. For the former, the in−situ microanalytical dating technique, such as SIMS (Secondary Ion Mass Spectrometry) and La−ICP−MS (Laser denudation Inductively Coupled Plasma Mass Spectrometry), is utilized to achieve the age of U−Pb in different areas of zircon. For the latter, the ID−TIMS technique (Isotope Dilution Thermal Ionization Mass Spectrometry) is employed to conduct U−Pb isotope composition analysis on the single grain zircon or part of grain solution calibrated by tracer. Compared to age accuracy 3~5% of U−Pb zircon dating (SIMS or LA−ICP−MS), using the ID−TIMS technology can obtain single mineral particle/part of the particle's age with the precision reaching or exceeding 0.1%, when the sampling depth and size change using SIMS and LA−ICP−MS, the dating object changes, which also affects the results.

Fourth, optimization of the experimental process and development of the testing technology−−namely improvement of the experimental technology, affect the zircon U−Pb age accuracy.

Fifth, the difference of labs, experiment processes adopted by testers, and processing methods, leads to different testing accuracy. There may be different dating results for a same sample.

Because of the factors above, the real value of the geological age is never obtained. The geologic time scale represented using numbers is always in a dynamic development process, and many stratigraphic boundary ages change with development of the dating technology.

Therefore, any stratigraphy branch, including high−precision chronostratigraphy, only focuses on the characteristics and attributes of a certain aspect of strata, with its specific adaptation scope, with both advantages and disadvantages. None can be independently employed to establish the high−resolution geological time scale. Various physical, chemical and paleontological features of strata are utilized to divide and correlate in integrative stratigraphy. On the basis of single−discipline in−depth study, multidisciplinary research is carried out to set up the internal origin relationship and space−time relationship among various stratigraphic units. The established biostratigraphic framework, plus the event stratigraphic boundaries and other strictly isochronal natural boundaries, provides an effective way to build the high−resolution chronostratigraphic system, using biostratigraphy to build the chronostratigraphic framework, using modern stratigraphy to achieve high−resolution stratigraphic division and high−precision stratigraphic correlation, using isotope stratigraphy to provide the biostratigraphic boundary or other stratigraphic boundaries the absolute age. Combination of the three constitutes the high−resolution integrative stratigraphy.

5. Main conclusions

(i) High−resolution integrated stratigraphy makes the geological chronostratigraphic system have higher resolution and correlation accuracy. The high−precision chronology framework is very important for research of Earth System Science and related to meeting the needs of human society development.

(ii) Resolution of any stratigraphic method is limited. Integrated stratigraphy provides an effective way to achieve high−resolution stratigraphic division and high−precision stratigraphic correlation.

(iii) Using biostratigraphy to build the chronostratigraphic framework, using modern stratigraphy to achieve high−resolution stratigraphic division and high−precision stratigraphic correlation, using isotope stratigraphy to provide the biostratigraphic boundary or other stratigraphic boundaries the absolute age. Combination of the three constitutes the high−resolution integrative stratigraphy.