Chapter 24
General Magnetostratigraphic Scale: Present Status and Outlook of Development

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Abstract Geomagnetic Polarity Time Scale (GPTS) and Generalized Magnetostratigraphic scale (GMSS) which is in use in Russia synthesize the paleomagnetic data of the world. Ideally, there should be only one global scale of geomagnetic polarity (GPTS or GMSS, or a new scale constructed through their synthesis). All other paleomagnetic scales may be of local or regional (possibly, sub-global) character. But since the GPTS chrons are referenced to the International Stratigraphic Scale (ISS), and the GMSS magnetozones—to the General Stratigraphic Scale (GSS), the necessity of equiponderant coexistence of the GPTS and the GMSS will persist until all the correlation problems between the two scales are solved or until these are merged together. Practical use of a domestic version of paleomagnetic scale for geologic investigations requires construction of an updated and verified GMSS version—with regard to recent magnetostratigraphic data. Simultaneously with the process of data verification, procedural problems should be solved which may arise while further development of the General Magnetostratigraphic Scale: to continue improving the GMSS hierarchic structure on the quantitative basis, to take into account the diachronism of biostratigraphic boundaries for integration of a paleomagnetic scale with detailed biostratigraphic units, to develop theoretical grounds for the use of paleomagnetic criteria for identifying the boundaries of common stratigraphic units.

Keywords Magnetostratigraphy · Geological Time Scale · Geomagnetic Polarity Time Scale · General Magnetostratigraphic Scale · Magnetic chron

Geomagnetic Polarity Time Scale (GPTS) and Generalized Magnetostratigraphic scale (GMSS) which is in use in Russia synthesize the paleomagnetic data of the world. Ideally, there should be only one global scale of geomagnetic polarity (GPTS or GMSS, or a new scale constructed through their synthesis). All other paleomagnetic scales may be of local or regional (possibly, sub-global) character.

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But since the GPTS chrons are referenced to the International Stratigraphic Scale (ISS), and the GMSS magnetozones—to the General Stratigraphic Scale (GSS), the necessity of equiponderant coexistence of the GPTS and the GMSS will persist until all the correlation problems between the two scales are solved or until these are merged together. Practical use of a domestic version of paleomagnetic scale for geologic investigations requires construction of an updated and verified GMSS version—with regard to recent magnetostratigraphic data. Simultaneously with the process of data verification, procedural problems should be solved which may arise while further development of the General Magnetostratigraphic Scale: to continue improving the GMSS hierarchic structure on the quantitative basis, to take into account the diachronism of biostratigraphic boundaries for integration of a paleomagnetic scale with detailed biostratigraphic units, to develop theoretical grounds for the use of paleomagnetic criteria for identifying the boundaries of common stratigraphic units.

Classification of the geomagnetic polarity scales by their construction methods into magnetostratigraphic (magnetozones are referenced to relative age), magnetochronological (magnetozones are referenced to absolute age) and anomaly scales (the magnetozone sequence is identified with spatial distribution of linear magnetic anomalies—LMA) is of mere historical interest nowadays. The present-day scales—the Geomagnetic Polarity Time Scale (GPTS), representing a part of the Geological Time Scale (GTS) (Ogg et al. 2016), and the General Magnetostratigraphic Scale (GMSS) (Khramov and Shkatova 2000)—synthesize the global paleomagnetic data by means of all the three methods. In both scales, the magnetic-polarity structures of the intervals from the Bajocian to the Quaternary are based on the results of the reference section studies and on the LMA data, while those from the Cambrian to the Aalenian—exclusively on magnetostratigraphic data. There are still no generally accepted paleomagnetic scales for the Precambrian.

Ideally, there should be only one global scale of geomagnetic polarity (GPTS or GMSS, or a new scale constructed through their synthesis). All other paleomagnetic scales may be of local or regional (possibly, sub-global) character. But since the GPTS chrons are referenced to the International Stratigraphic Scale (ISS), and the GMSS magnetozones—to the General Stratigraphic Scale (GSS), the necessity of equiponderant coexistence of the GPTS and the GMSS will persist until all the correlation problems between the two scales are solved or until they are merged together.

Both the GSS and the GMSS make a part of the Stratigraphic Code of Russia (2006) and are mandatory for any geologic surveying and geologic prospecting throughout our country. Regretfully, since publication in 2000 (Khramov and Shkatova 2000) the GMSS has not been actualized, except for the Quaternary GMSS, updated to comply with the latest amendments in the MSS and the GSS (Guzhikov and Shkatova 2016). By comparison, the GSSP has been actualized four times after 2000: in 2004 (Gradstein et al. 2004), 2008 (Ogg et al. 2008), 2012 (Gradstein et al. 2012) and 2016 (Ogg et al. 2016).

The GSS structure has been substantially modified during that period. Among other things, tripartition of the Permian has been accepted (Stratigraphic … 2006), views on positions of many stage boundaries relative to geomagnetic reversal sequence have changed owing to adopting new global stratotype sections and points (GSSP, "golden spikes"). Thus, upon adopting the Tercis section from France as the GSSP, the lower boundary of the Maastrichtian stage was shifted relative to the paleomagnetic scale from the basis of the C32n2 polarity chron to the upper part of the C32n1 chron (Odin and Lamaurelle 2001) (Fig. 24.1a), and the lower boundary of the Thanetian, upon selection of the Zumaia section from Spain as the GSSP stage, was shifted from the C25r chron bottom to the basis of the C26n chron (Fig. 24.1b) (Schmitz et al. 2011).

At present, substantial differences are recorded in paleomagnetic structures of some coeval intervals of the GMSS and the GPTS. In certain instances, the differences are fundamental. For example, according to the GMSS, the Wenlock series and the Pragian stage are peculiar for alternated polarity (Fig. 24.2a, b), while in the

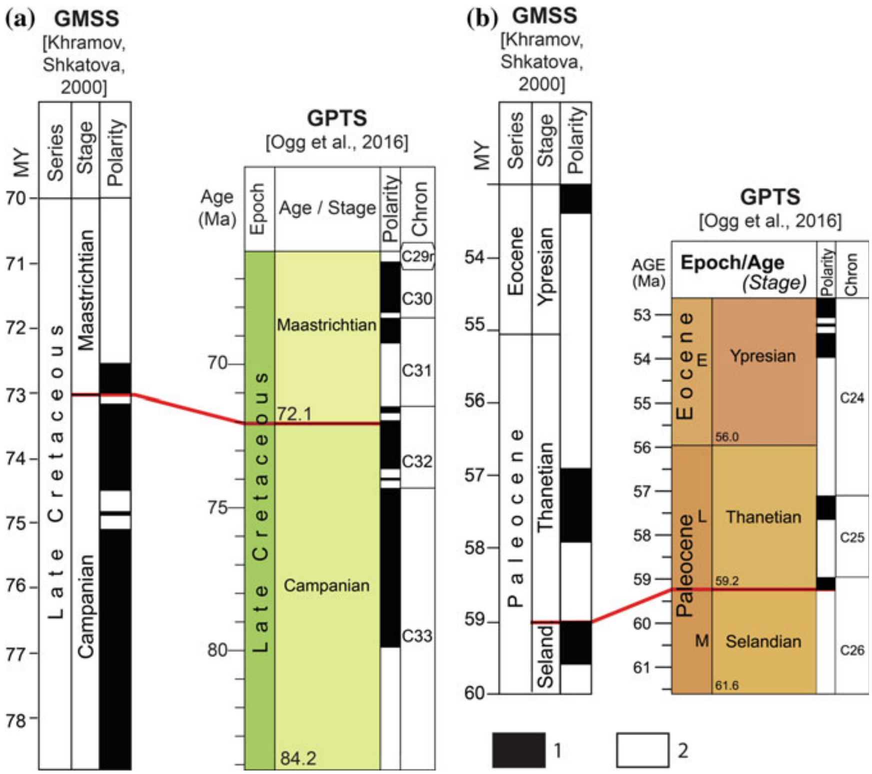

Fig. 24.1 Changes in the relations between the lower boundaries of Maastrichtian (**a**) and Thanetian (**b**) with geomagnetic reversals after the approval of the GSSP of stages. (1)—normal polarity, (2)—reverse polarity

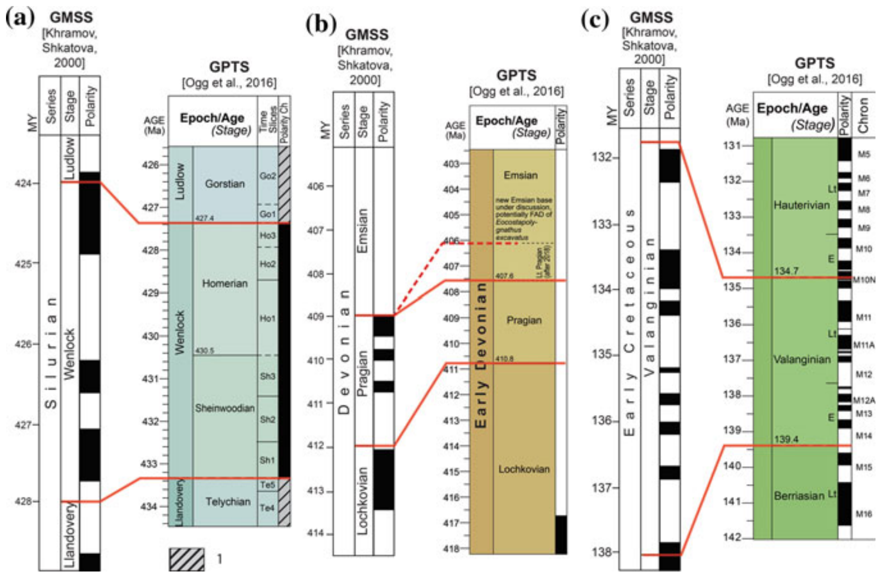

Fig. 24.2 Contradictions between GMSS and GPTS in the paleomagnetic structure of the Wenlock series (**a**), Pragian stage (**b**) and Valanginian stage (**c**). (1)—uncertain polarity. For other explanations see Fig. 24.1

GPTS they correspond to monopolar magnetozones: normal (N) polarity corresponds to the Wenlock (Fig. 24.2a), and reverse polarity (R)—to the Pragian stage (Fig. 24.2b). While similar contradictions are still rare in comparing the GMSS and the GPTS, less significant disparities, on the contrary, occur quite frequently, especially in the Paleozoic and in the Mesozoic scale intervals. Those are manifested in different numbers and durations of magnetozones characteristic of the same stratigraphic unit, e.g. the Valanginian stage (Fig. 24.2c).

Therefore, practical use of a domestic version of paleomagnetic scale for geologic investigations requires construction of an updated and verified GMSS version —with regard to recent magnetostratigraphic data. Contradiction between the GMSS and the GPTS should be either eliminated or thoroughly substantiated. Anyway, a few pages in the Supplements to the Stratigraphic Code of Russia (Khramov and Shkatova 2000) are insufficient for complete characteristics of the GMSS. By comparison, in the fundamental treatise "Geologic Time Scale" (Gradstein et al. 2012), the magnetostatigraphic aspect is dealt with on more than 100 pages.

It is obvious, that the scale actualization should be achieved jointly, in close cooperation between the Magnetostratigraphy Commission at the Interdepartmental Stratigraphic Committee (ISC), the ISC commissions on the systems and the Regional Interdepartmental Stratigraphic Commissions (RISC).

Simultaneously with the process of data verification, procedural problems should be solved that may arise in the course of further development of the General

Magnetostratigraphic Scale. Approaches to the GMSS construction and structuring should not indiscreetly simulate the experience of the GPTS authors.

The GMSS hierarchy is among its advantages. The ranks of super- and hyperzones reflect the principal stages in geomagnetic field evolution. It is necessary to continue improving the GMSS hierarchic structure on the quantitative basis (Molostovskii et al. 2007). Meanwhile, at D. M. Pechersky's suggestion (2003), quantitative reliability (quality) estimates for magnetostratigraphic data from various sites should be developed and introduced into the scale.

At present, the GMSS, except for the Quaternary, is incomparable with the GPTS in terms of detailed referencing of paleomagnetic and stratigraphic units. While the GPTS chrons are tied to the zonal (macro- and microfauna) scales of various paleobiochores, the GMSS magnetozones are tied only to the stage sequence. The Geologic Time Scale (Gradstein et al. 2012; Ogg et al. 2008, 2016), however, mechanically unites absolute dating and geomagnetic reversals with zonal standards, sequences, event levels (oceanic anoxic events, isotopic anomalies, etc.), superimposing stratigraphic boundaries of different nature and with known different spatial and temporal stabilities. This is methodically wrong, because the boundaries of all the biostratigraphic units are diachronic to a varying degree. Theoretically, this has been clear for a long time, but the documentary evidence and quantitative estimates of the time shift in some stratigraphic units (of both, macro- and microfauna grounding) from various regions have emerged only recently, owing to the use of geomagnetic reversal scale. Due to short durations of the reversals ($<10^4$ years), they may be regarded as practically isochronous references for thorough correlations of the deposits and for calibrating zonal scales of various paleobiochores. Detailed complex bio- and magnetostratigraphic correlations have revealed the ages of the Lower-Upper Barremian boundary in the Tethyan and Boreal super-region to differ by no less than one million years, judging from magnetic chron durations (Guzhikov and Baraboshkin 2006). A diachroneity value of similar order is recorded at the bottom of the NKT nanoplankton zone in the Jurassic-Cretaceous boundary interval from the Northern Mediterranean; moreover, this is observed in the sections spaced apart by less than 150 km (Channell et al. 2010). The boundaries of the Lower Aptian ammonite zones in the North Caucasia, Russian Plate and West Europe are also prone to time shifting, though to a lesser degree (Guzhikov and Baraboshkin 2006).

Since the time shift at comparing the maximally remote paleobasins or at calibrating scales based on various fauna groups amounts up to 10^6 years, integration of a paleomagnetic scale with detailed biostratigraphic units should be accompanied, whenever possible, with indicating boundary diachroneity in the provincial zones relative to geomagnetic reversals (Fig. 24.3). Horizontal lines as the boundaries of detailed stratigraphic units are appropriate, when the boundary isochroneity is proved (solid lines) or cannot be disproved at the present stage of investigation by means of independent methods (dotted lines).

Boundaries of the global stratigraphic units—stages, though they also serve as the zone boundaries, will remain in the GMSS as horizontal lines, because in the

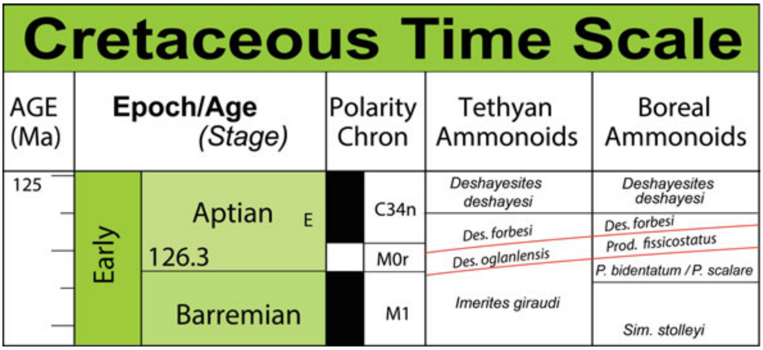

Fig. 24.3 The possibility of showing (red lines) of the ammonite zone boundaries diachronism while integrating a paleomagnetic scale with ammonite zone scales [on the example of the Lower Aptian interval of GTS-2012 (Gradstein et al. 2012)] in connection with the data on the diachroneity of the Lower Aptian ammonite zones boundaries relative to the M0 (Guzhikov and Baraboshkin 2006)

GSSP (to be provided for all the stages in the foreseeable future) the position of the stage bottom is fixed relative to the sequence of geomagnetic reversals.

As for synchronization of the stage boundaries in spatially separated areas, involvement of paleomagnetic criteria as the primary features for their substantiation seems to be quite attractive. This statement does not encroach upon the priority of the biostratigraphic method in distinguishing the GSS stratons and substantiating their boundaries. Selection of a paleomagnetic marker for the stage bottom is inevitably preceded by paleontologic grounding of the stratigraphic boundary; it is only afterwards, that a geomagnetic reversal may be selected—the nearest to the level of fauna assemblage change in a GSSP.

Irrespective of the lack of any strict theoretical grounding, the idea of using the paleomagnetic criteria for identifying the boundaries of common stratigraphic units has been put into practice. For example, the Matuyama-Bruhnes reversal is used to identify the GSS Eo- and Neopleistocene boundary (Calabrian-Ionian (Lower—Middle Pleistocene) in the International Stratigraphic Scale—ISS (Cohen et al. 2013; Guzhikov and Shkatova 2016). The magnetostratigraphic boundary of the Kiama-Illawarra hyperzones lies close to the lower boundary of the Tatarian series (Kotlyar et al. 2013). It seems quite assignable, that magnetic polarity features were primarily wanted to substantiate the Quaternary and the Upper Permian units, i.e. by the specialists who are frequently involved in correlations of heterofacies (marine and continental) deposits. Similar situation arises with correlations of marine deposits formed in maximally separated paleobiogeographic provinces. For example, the problem of global tracing of the Jurassic-Cretaceous boundary cannot be solved on the basis of exclusively paleontological data. Such situation may result from both diachroneity of the biostratigraphic boundaries [inclusive of the *C. alpina* (Lakova et al. 2017) level, which is insistently recommended as the primary marker of the Jurassic-Cretaceous boundary (Schnabl et al. 2015; Wimbledon 2016, 2017)], and the paleontological "muteness" of the deposits and impossibility of using the same faunal groups for substantiating the stratigraphic boundary in different regions. At the same time, the paleomagnetic chrons, irrespective of the relatively complicated alternated paleomagnetic zonality of the Jurassic-Cretaceous boundary interval, are basically identifiable even with the minimum paleontological description of the rock. The case of the Feodosiya section (Crimea) may be cited as the prime example. Scarce ammonite finds and meagre calpionella assemblages prevent one from determining the boundary level, but allow reliable identifications of magnetic chrons in the examined deposits (Guzhikov et al. 2012). The choice of geomagnetic reversal as the primary feature for substantiating the Jurassic-Cretaceous boundary [which was actually proposed in GTS-2012 (Gradstein et al. 2012)] would make it possible to solve this problem (Guzhikov 2013; Baraboshkin et al. 2013; Arkadiev et al. 2014).

Similar tendencies are characteristic of other GSS intervals, as well, since using a paleomagnetic feature as the leading criterion for boundary selection allows to abate the disputable matters arising from mismatch of stratigraphic boundaries recognized from different flora and fauna assemblages in real sections. For example, the bottom of the M0 chron was recommended by the international working group on the Aptian stage as one of the principal markers of the Barremian-Aptian boundary (Erba et al. 1996). Outlining the Santonian-Campanian boundary along the bottom of the C33r chron has been repeatedly proposed by the authors of the Geological Time scale (Ogg et al. 2016); expediency of matching the Campanian-Maastrichtian boundary with the top of the C32n2 chron has been stated at the X Cretaceous System Symposium in Vienna (Baraboshkin et al. 2017). The C27n bottom has already been officially chosen as the primary marker of the Thanetian stage base (Schmitz et al. 2011).

The importance of paleomagnetic features for the GSS structuring constitutes a separate aspect in discussing their stratigraphic role. The relations of deep geodynamic events, responsible for transformation of the polarity regime in a geomagnetic field, with the geologic events, inclusive of biotic changes that serve as the criteria for ranging stratons into series, stages and substages, predetermine the theoretical possibility of involving the paleomagnetic criteria into solving the problems of the GSS structuring. It has been repeatedly noted, that clear division of the Cretaceous interval of the magnetostratigraphic scale into three parts: that of alternating sign (Berriasian—lowermost Barremian), of dominant direct polarity (uppermost Barremian—lowermost Santonian) and another part of alternating sign, though with fewer reversals (uppermost Santonian—Maastrichtian) may be regarded as an argument in favor of tripartition of the Cretaceous system (Molostovskii and Fomin 2004). With all its disputability, the idea of using the features that determine the paleomagnetic scale structure for the GSS ranging deserves serious consideration and meticulous elaboration. It is not improbable, that the results of such approach will contribute to solving the urgent problems associated with choosing between dividing certain GSS systems and stages into two or three components.

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