

# A review of magnetostratigraphic results from the Tithonian–Berriasian of Nordvik (Siberia) and possible biostratigraphic constraints

PETR SCHNABL<sup>1</sup>, PETR PRUNER<sup>1</sup> and WILLIAM A.P. WIMBLEDON<sup>2</sup>

<sup>1</sup>Institute of Geology of the Czech Academy of Sciences, v.v.i., Rozvojová 269, 165 02 Praha 6, Czech Republic; schnabl@gli.cas.cz; pruner@gli.cas.cz

<sup>2</sup>School of Earth Sciences, University of Bristol, Wills Memorial Building, Queens Road, Bristol BS8 1RJ, United Kingdom; mishenka1@yahoo.co.uk

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**Abstract:** In this contribution we examine and discuss recently published magnetostratigraphic data from the Nordvik section (north Siberia) around the Tithonian–Berriasian (J/K) boundary, with a special emphasis on calibration with biostratigraphy and the reliability of both the fossil and magnetic records, as well as sedimentation rates. Specifically, we discuss original new interpretations by Bragin et al. (2013) and the commentary on that work by Guzhikov (2013). We consider some limitations of the Nordvik section, and conclude that the base of M18r, because it is in a condensed part of the sequence, makes a poor contender for precise long-range correlation. We discuss the lack of ammonites at several magnetozone boundaries, and whether the bases of the local zones of *Craspedites taimyrensis* and *Arctoteuthis tehamaensis* can be used to bracket the correlative horizon of *Calpionella alpina*, a widespread marker in the middle of M19n.2n in Tethys.

**Key words:** review, magnetostratigraphy, magnetozones M20–M16, Tithonian–Berriasian boundary, biostratigraphy, biotic markers, calibration, Cretaceous, Jurassic, boreal.

## Introduction

The magnetostratigraphy of the Tithonian/Berriasian sequence at Nordvik (NE Siberia) was first described by Houša et al. (2007), the first paleomagnetic study of any marine arctic sequence. Bragin et al.'s (2013) revision of that study is very interesting and it presents new and important results in the Tithonian–Berriasian (M20–M16r) interval, including new interpretations of M17r. We would like to suggest some additional interpretations of Bragin et al.'s (2013) results relative to the account of Houša et al. (2007). We also make observations on Guzhikov's (2013) commentary, which contains several significant remarks that merit discussion. These three cited works and Dzyuba (2012) give all necessary data on geography, location and the details of the local succession.

Thirty years ago, the name Tithonian was selected by the International Jurassic Subcommittee of the ISC as the global term for the final stage of the Jurassic, and all other stage names (even d'Orbigny's senior name of Portlandian) were suppressed (Sarjeant & Wimbledon 2000). This decision was implemented in all countries, and inside Russia (Zhamoida & Prozorovskaya 1997) the name "Volgian" was dropped. In terms of international stage nomenclature, it seems that the "Volgian" spans two periods/systems and perhaps three standard ages/stages: the topmost Kimmeridgian (Scherzinger & Mitta 2006; but see Rogov 2010), the Tithonian and the lowest Berriasian. Here we only employ global standard age/stage names and use local biozones in discussing the vital contribution that magnetostratigraphy makes at Nordvik.

Promotion of magnetostratigraphy in the J/K (Tithonian/Berriasian) interval was first undertaken thirty years ago, and today it is universally accepted that it is an essential tool when integrated with biostratigraphic markers (e.g. Lowrie & Channell 1983; Ogg et al. 1984, 1991, 1994; Galbrun 1985; Ogg & Lowrie 1986; Houša et al. 1999, 2004; Speranza et al. 2005; Grabowski & Pszczółkowski 2006; Channell et al. 2010; Pruner et al. 2010; Wimbledon et al. 2011). Use of magnetostratigraphy at the J/K boundary without biostratigraphic control was advocated by Man (2008); however, this view has not been taken up by other workers (Grabowski et al. 2010a,b, 2013; Pruner et al. 2010). As the sole Russian site in the Tithonian/Berriasian interval with described magnetostratigraphy, Nordvik uniquely fits with the stratigraphic pattern determined in Tethys. The numerous J/K sections studied in western Tethys afford a solid set of paleomagnetic data and a powerful constraint on biostratigraphy; actually, in this, the interval has a much larger data set than exists for most stratigraphic sequences and most previously selected GSSP levels. Importantly, also, magnetostratigraphy has been applied to both marine and non-marine J/K strata. But it is worth keeping our feet on the ground, remembering that magnetostratigraphic units are preserved in tangible rock intervals, subject to condensation, erosion and non-sequence, and diagenetic affects, just like the sediments themselves: this is a global 'time scale' that still may have 'minutes' and 'days' missing, or the clock reset. It is as important to try to examine the nature of magnetization, and to consider the completeness of its record, as it is for the biostratigraphic one. The definition of the mag-

netozones that straddle the Tithonian/Berriasian interval and their essential calibration with fossil markers (calpionellids, calcareous nannofossils, ammonites, palynomorphs, radiolaria, belemnites, forams, buchiiids etc.) is a task that many colleagues, including the Berriasian WG, have valuably addressed in recent years (Wimbledon 2014).

One of the main stratigraphic problems in the Tithonian-Berriasian interval is biotic endemism and limited biodiversity. Guzhikov (2013) several times mentions the need to achieve a correlation between Tethys and boreal areas (actually he refers only to Siberia) where this endemism and low diversity are prominent. But this is too narrow a focus: we are faced with a much bigger puzzle in the Tithonian-Berriasian, complicated by these two already stated biotic limitations. Defining a boundary for the base of the Berriasian involves consideration of correlations within the biotic core area of western Tethys (Morocco, Tunisia, Iberia, France, Italy, Central Europe, Turkey, Bulgaria, Ukraine, Caucasus) to western ‘Atlantic’ Tethys (Cuba, Mexico, and on to California), to eastern Tethys (Iran, Tibet, Australasia, Russian Far East, Japan), but also to Gondwana (Iraq, Yemen, Madagascar, Argentina, Chile), to the non-marine areas (USA, UK, Poland, Mongolia, China), and also to the boreal basins with their separate biozonations, including Siberia. The task with which we are concerned involves all of this and is hampered by endemism, to a greater or lesser extent, throughout. Ammonite problems are not confined to Siberia or the Russia platform: in Tethys it has never proved possible to define one ammonite zonal scheme, and in Gondwana and the Pacific mostly endemic faunas require separate zonal definition (e.g. Imlay & Jones 1970; Jeletzky 1984; Howarth 1992; Howarth & Morris 1998; references in Cantú-Chapa 2009; Zeiss & Leanza 2011; Vennari et al. 2013). All of this is the reason why in this interval fossil

groups other than ammonites are employed for correlation. Paleomagnetic techniques are vital, most certainly, in combination with the fullest range of microfossil and macrofossil elements, each calibrated against the other.

### Discussion

#### Selecting a J/K boundary

The consensus amongst researchers for generations has been that the final selection of a GSSP for the Berriasian Stage should be at a locality in Tethys (Colloquia 1963, 1973; Zakharov et al. 1996; Wimbledon et al. 2011). Tethys was the largest geographical unit in Tithonian and Berriasian times, with the clearest consistency in its biotas (notably those listed above), and it has the largest number of stratigraphically useful marker taxa in the boundary interval (Fig. 1). So the hunt has been on for the last few years to identify and fix the better markers and then the best site for a GSSP. Another task also exists, to derive better correlations with the more problematic and, biotically, sometimes more impoverished regions. Nordvik, described by Bragin et al. (2013) and discussed by Guzhikov (2013), sits in one of these, in the Siberian boreal embayment. Guzhikov (2013) refers to a “Boreal Realm”, when he, in fact, only discusses Siberia (or, at the most, Siberia plus the Russian Platform embayment), a part of the boreal far removed from Tethys where most J/K boundary studies have been focussed. Siberia has its own ammonite scale around the Tithonian/Berriasian boundary level, one different to the other boreal regions, for instance, Greenland, UK or Canada, though some individual ammonite species have wider distributions.

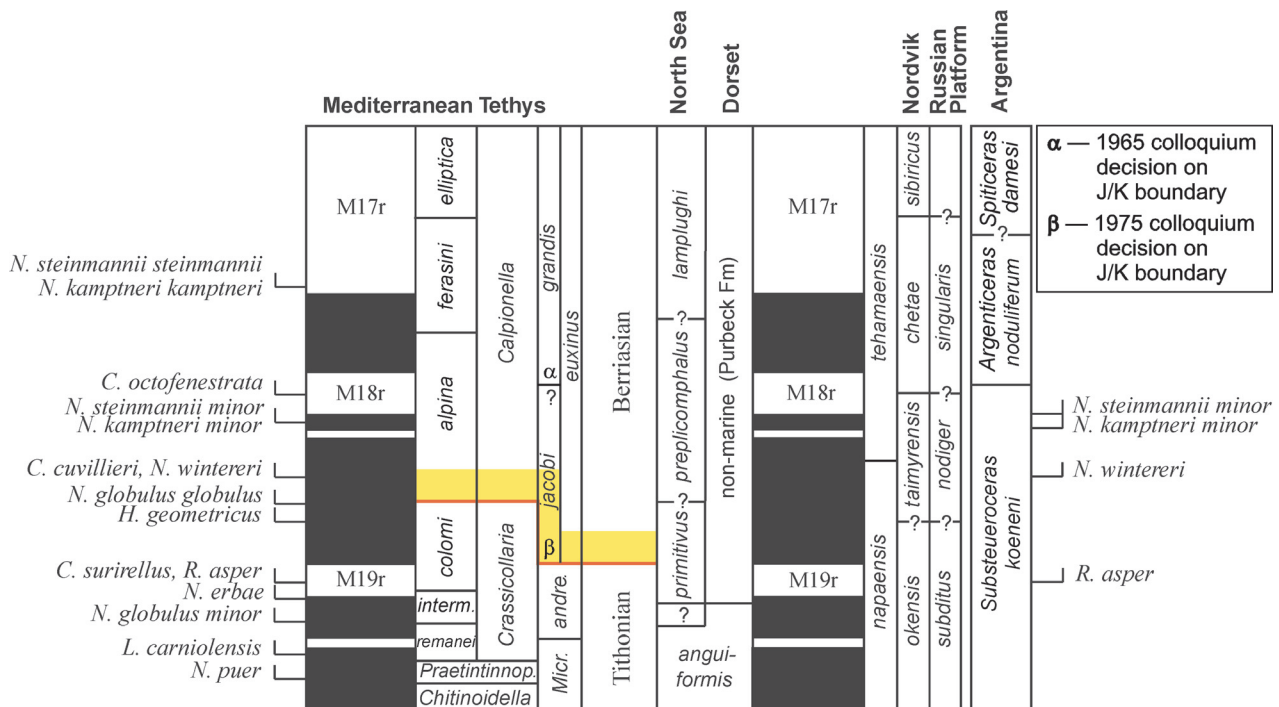


Fig. 1. Jurassic/Cretaceous (Tithonian/Berriasian) correlative framework. Argentina column after Vennari et al. (2014).

In Siberia, and elsewhere, magnetostratigraphy must certainly play a key role, as it takes no note of biotic provincialism, paleoclimate, geography, or facies. And it can help constrain correlations afforded by provincial and endemic biotas. However, Guzhikov (2013), in enthusiastically promoting the virtues of magnetostratigraphy, states several times that biostratigraphic boundaries are diachronous. This truism is, of course, a constant preoccupation for practising biostratigraphers and we agree with the International Commission on Stratigraphy (ICS) that "...the boundaries of species, are diachronous..." but also that "This fact has, however, been overstated. ...In rapidly evolving lineages this may be less than one million years, so that most biostratigraphic datings attain a higher degree of resolution than the use of radioisotopes" (Remane et al. 1996).

One correlative method with potential is that using stable isotope stratigraphy. The stable isotope record at Nordvik shows an irregular decrease in  $\delta^{18}\text{O}$  values towards the Tithonian/Berriasian boundary, which is interpreted as the result of gradual warming (Žák et al. 2011). However, correlation over wider areas using this method is complicated by differing facies and lithologies between boreal and tethyan areas, as well as the limited abundance of belemnites, noted in parts of the Nordvik sequence (Žák et al. 2011: see the more recent work of Dzyuba et al. 2013). Sadly, chemostratigraphic evidence is not very helpful in marking or bracketing a J/K boundary. Published accounts show that lower carbon isotope values characterize the latest Jurassic and the Berriasian, with no significant positive carbon isotope values seen until well into the Valanginian.

Guzhikov has recently discussed several alternative, wholly paleomagnetic, 'definitions' of a Tithonian/Berriasian boundary: at the base of M18r, even at the base of M17r (Bagaeva et al. 2011; Guzhikov et al. 2012; Guzhikov 2013). But not at levels which are constrained accurately by biostratigraphy. He also mentions the Occitanica Zone as a contender level, though this (in ?M17r) has not been seriously considered in recent years as a J/K boundary: the Occitanica Zone *per se* is, in any case, not recognizable in any part of the boreal or any Pacific/austral region (nor most of Tethys). In answer to these proposals of so many apparent alternatives, it needs to be remembered that, in fixing a boundary, we do not have a clean sheet in front of us — far from it: we are constrained by the history of research, usage, consensus and conventions, and by the decisions made in the last five years by the Berriasian Working Group of the ICS. Even if we were to suggest a magnetostratigraphic primary marker for the Tithonian/Berriasian boundary, it would need to be tightly 'sandwiched' between consistent and widespread fossil markers. Numerous widely used biostratigraphic datums cannot be ignored, and there is no merit in choosing a magnetozone boundary that is far removed from traditional levels and which has inadequate or no biostratigraphic calibration.

#### ***Biostratigraphy integrated with magnetostratigraphy***

Guzhikov (2013) states, echoing Zakharov (2011), that ammonite markers should take priority over other fossils in identifying the Tithonian/Berriasian boundary, "instead of

calpionellids and nannoconids, as recently suggested by Wimbledon et al. (2011)". This does not accurately represent what has been suggested or published: Wimbledon et al. (2011) discussed possibilities for defining the J/K boundary using *all* useful fossil markers (including ammonites) and magnetostratigraphy. Any suggestion that ammonites alone can be used overlooks the limitations of the fossil record and is untenable: in some regions ammonite distributions are disjunct, or ammonites are endemic, or there are few or no ammonites. It is clear why for decades a multiplicity of complementary or alternative fossils have been used: calpionellids, nannofossils, palynomorphs, belemnites, radiolaria, forams, bivalves etc. Thus numerous workers have in recent years tried to use such a wider range of J/K fossil groups in an integrated fashion. We can again quote Remane et al. (1996): "The use of fossils for calibrating chronostratigraphic units does not only involve tracing of biostratigraphic boundaries. It is indeed less a matter of correlation than of determining relative ages within a biochronological standard of reference. Biochronology is the reconstruction of the succession of species in time through the synthesis of local and regional biostratigraphic data ... *The chronostratigraphic reliability of biostratigraphic boundaries can thus be tested by comparing data from different species.*" — our italics. This is the approach of the ICS. And in Tethys we are fortunate that there was very considerable biodiversity and a sizable range of fossil markers is available to help bracket any Tithonian–Berriasian boundary.

For several generations, apart from occasional aberrations, definitions of a J/K boundary have focused on one interval, between the base and top of one ammonite subzone (that of *Berriasella jacobi*), and, in the last thirty years, more and more, on the widespread and more consistently recognized turnover from *Crassicollaria* assemblages to small *Calpionella* (e.g. Remane 1963, 1986; Pop 1976; Houša et al. 1999, 2004; Altiner & Özkan 1991; Lakova 1993; Benzaggagh & Atrops 1997; Pszczółkowski et al. 2005; Boughdiri et al. 2006; Michalík et al. 2009; Michalík & Reháková 2011; Benzaggagh et al. 2012; López-Martínez et al. 2013a,b). Lately this has been widely reinforced by the use of calcareous nannofossil FADs (references in Casellato 2010). The decision of a new Berriasian WG, at its first meeting, to consider the base of the Jacobi Subzone as a primary boundary contender was strongly promoted by several distinguished workers, including incidentally Russian colleagues such as Drs Sey, Kalacheva and Bogdanova. At its third workshop in Milan, the group considered the potential of various markers and levels for a GSSP, always combined with magnetostratigraphy, and still broadly in the Jacobi Subzone. This interval, the upward sequence of M19n.2n, M19n.1r and M19n.1n, in particular, provides several paleomagnetic and biotic markers in close order (Wimbledon et al. 2011; fig. 1).

The suggestion (Guzhikov 2013) that the base of M18r is a suitable contender for the J/K boundary has not been supported by biostratigraphic data. The essential task of constraining the magnetozone boundaries with calibrated fossil markers has not been addressed. The proposal of M18r goes back to the work of Ogg & Lowrie (1986): then it was based on the belief that the boundary lay "in the middle of various biostratigraphic definitions" of the boundary in Tethys. The

Berriasian Working Group decided to study approximately the same levels, in the *Berriasella jacobii* Subzone, and potential GSSP levels in key sections, in all regions, that would make it possible to calibrate the key biological markers with the magnetozones. More study has revealed that the bases of the Alpina and Jacobi biozones are not coincident (as has often been stated in the past), and neither of them is seen to lie close to the base of M18r (e.g. Wimbledon et al. 2013): in addition, study has revealed problems with definition/demarcation of the Jacobi Subzone. Examining ammonites and calpionellids, some cited by Ogg & Lowrie (1986), and nanofossils, the particular focus has therefore shifted to levels where there are more closely spaced biotic markers, that is, within and at the base of M19n.2n.

*Biostratigraphic calibration of magnetostratigraphy at Nordvik*

In discussing Bragin et al. (2013) and the calibration of Siberian and Tethyan ammonite zonations, Guzhikov (2013) suggests caution. And caution is indeed necessary, for no ammonite scheme in Tethys or any part of the boreal near the J/K boundary can really be said to be “calibrated”: they can be approximated, and then only by use of magnetostratigraphy. Therefore, in suggesting “a detailed zone-by-zone biostratigraphic correlation” of Tithonian–Berriasian rocks from the boreal to Tethys, workers really only follow some rather doubtful conventions in equating ammonite biozones. There is a practice amongst some workers of depicting correlation

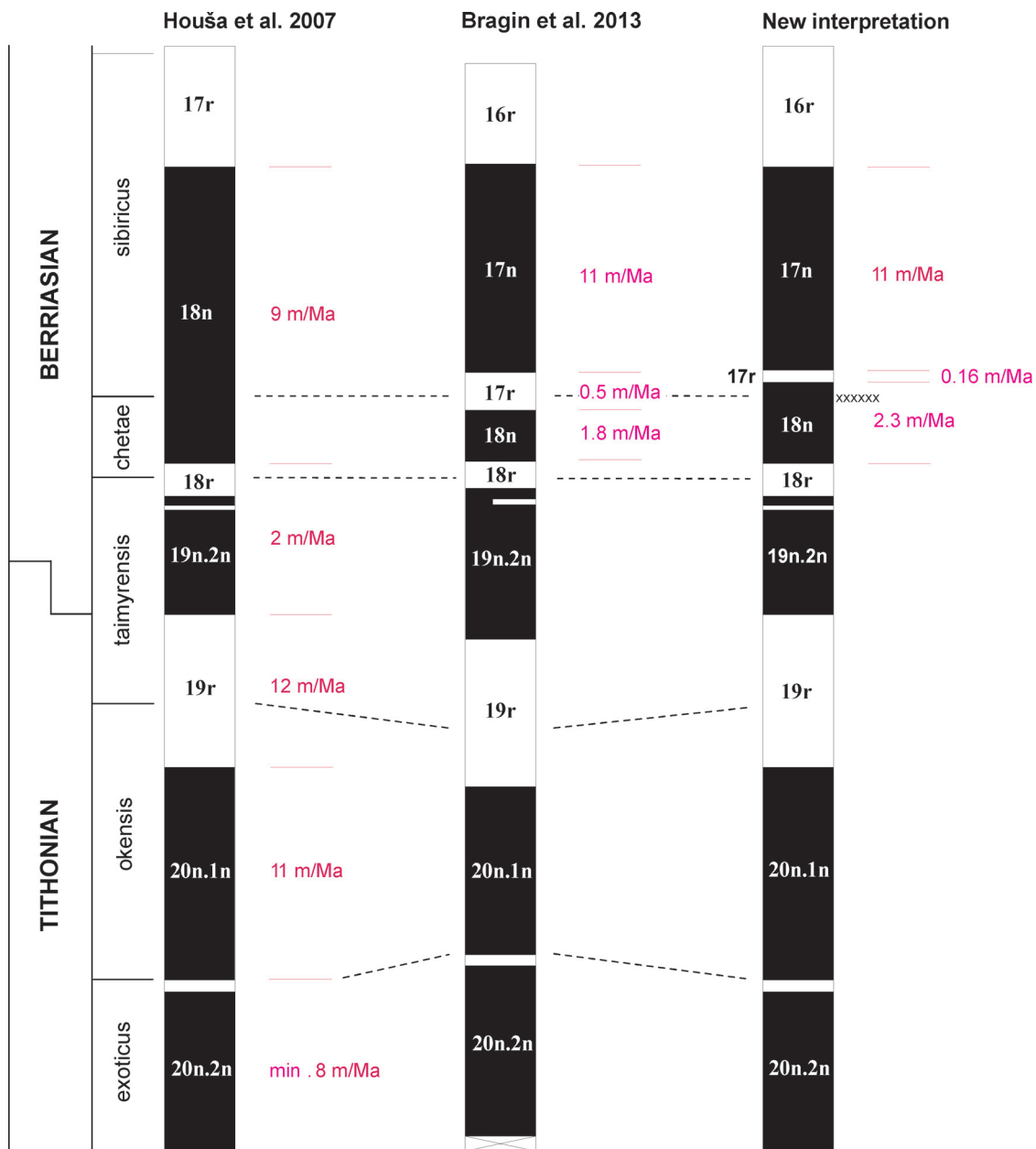


Fig. 2. Sedimentation rates in the Tithonian–Berriasian at Nordvik. xxxxxx — the level of the iridium anomaly of Houša et al. 2007.

charts with geographically distant columns of parallel biozones, zonal box neatly equalling zonal box — no gaps and no question marks: a method deplored by some senior ammonite stratigraphers, notably John Callomon. Ammonite biozones, like any other, are based on a variably imperfect fossil record. Matching of local upper Tithonian-lower Berriasian ammonite zones in Siberia to zones in Tethys, when there is not a single ammonite in common, is of course, no match at all. Correlation of the Siberian biozonal scheme to a J/K boundary in Tethys has in the past been very imprecise, straddling as much as 2.5 Ma and three local ammonite zones: base of Okensis Zone to Sibiricus Zone (Zakharov et al. 1996, 1997; Zakharov 2003; Guzhikov 2013). Bragin et al.'s (2013) results at Nordvik importantly shed light on Siberian ammonite zone durations and completeness, and heighten concerns over variable sedimentation rates and non-sequence (Fig. 2).

#### *Nordvik ammonite record*

At Nordvik, ammonite biozones (Zakharov & Rogov 2008) have been recognized, sometimes on the basis of a few species, and even sometimes with no ammonites (Fig. 3 — coloured intervals): the majority of the 14.7 m sequence (Bragin et al. 2013) between the base of M20n.1n and the top of (incomplete) M16r has none. At sites in Tethys the Tithonian/Berriasian (J/K) boundary has been identified in M19n (Fig. 1): at Nordvik M19 is placed within the *Craspedites taimyrensis* Zone (Fig. 3 — Houša et al. 2007; Bragin et al. 2013). The zone has been recognized there, though the index species is absent, and (confusingly) its lowest part only contains the index for the biozone beneath, *Craspedites okensis*. The overlying Chetae Zone has yielded one ammonite only, assigned to *Chetaites* cf. *chetae*. Igolnikov (2010) noted a similar absence of ammonites through the majority of the Kochi Zone. No doubt more finds will certainly be made, but currently at Nordvik the bases of the magnetozones which have been identified — M19r, M19n, M18r, M17r and M16r — all fall (Bragin et al. 2013) in intervals with no ammonites. This suggests the need to find accurate and repeatable biostratigraphic markers here and perhaps at alternative Siberian sites, sites that might then be considered for sampling for paleomagnetism. New work on belemnites has improved the situation (Dzyuba 2012), affording wider correlations and exciting possibilities. Importantly, the first appearance of the Californian species *Arctoteuthis tehamaensis* in Siberia provides a proxy for the base of the *Calpionella alpina* Zone (Fig. 1 and Fig. 3), and the short-ranging *Lagonibelus gustomesovi* marks the top of M19r. Further, Zanin et al.'s (2012) recent listing of calcareous nannofossils from western Siberia, including taxa found in Tethys, indicates one new line of research. *Arctoteuthis tehamaensis* in Siberia does not occur in beds that yield *Craspedites okensis* (Oksana Dzyuba, pers. comm.), and the first occurrence of *Arctoteuthis tehamaensis* at Nordvik is above the middle of M19.2n (Fig. 3). It cannot be ruled out, therefore, that the Okensis Zone extends upwards well into M19n.2n.

The scarcity of ammonites at critical levels thus leave us with some outstanding questions. If the bottom of 19n.2n

falls at the base of the Taimyrensis Zone in Siberia (Houša et al. 2007; Bragin et al. 2013), then, on the evidence of magnetostratigraphy alone, there is an improved approximation to the base of the Jacobi Subzone in Tethys. But if the Taimyrensis/Okensis zonal boundary is higher relative to the base of M19n.2n, closer to horizons with the first *A. tehamaensis*, then there could instead be an approximation to the base of the Alpina Subzone.

#### *Sedimentation rates at Nordvik*

There is some misunderstanding in the Guzhikov commentary (2013, p. 350) relative to the conclusions of Grabowski on sedimentation rates (2011, p. 124). Grabowski, using the Nordvik data of Houša et al. (2007), notes the rate of sedimentation to be quite uniform in M20n.1n and M19r (ca. 11–12 m/Ma), M18n (ca. 9 m/Ma) and at least 8 m/Ma in M20n.2n. In magnetozones M19n and M18r, the sedimentation rate seems to fall dramatically, to 1.5–2.0 m/Ma, similar to the rate in condensed *rosso ammonitico* sections (Fig. 3). In the lithological log of Houša et al. (2007, fig. 2), there is no sedimentation change which could indicate such condensation; however, changes in sedimentation rate were mentioned by Man (2011). It cannot be excluded that some of the changes in condensation and sedimentation rate might be related to the Mjølner impact in the Barents Sea, which is thought to have occurred close to the start of the late Berriasian (Zakharov et al. 1993; Smelror et al. 2001; Dypvik et al. 2006; Grabowski 2011; Wierzbowski et al. 2011; Wierzbowski & Grabowski 2013).

#### *Rock-magnetic results applied to magnetostratigraphy*

As to technical issues, Chadima et al. (2006) and Houša et al. (2007) used anisotropy of magnetic susceptibility (AMS) as a main rock-magnetic method to discriminate oblate and prolate magnetic fabrics. AMS in the group of oblate-fabric samples is predominantly controlled by the preferred orientation of iron-bearing chlorites or micas, and, to a minor extent, by the ferromagnetic fraction. The oblate, bedding-controlled, magnetic fabric, and the low remanent magnetization (RM) suggest that these samples may provide a good record of the ancient field. On the contrary, in the samples with prolate (rod like) AMS structure the dominant paramagnetic mineral is siderite, which was formed during diagenesis. During siderite formation the original magnetic signal is changed in the rock around the newly formed minerals, and new magnetite is derived from weathering of the siderite.

It is worth comparing Houša et al.'s (2007) fig. 2 and fig. 9 with Bragin et al.'s (2013) fig. 2. Bragin et al. (2013) have identified a new reversed magnetozone, defined by 5 samples, which they have referred to M17r (between the Chetae and Sibiricus ammonite zones). However, the lowest of their samples has an anomalous Q-ratio, very low magnetic susceptibility and low coercivity of remanence. Conversely, the next sample above has high coercivity of remanence, which is seen from the  $B_{cr}$  and S-ratio. This means that both samples should be omitted from any evaluation.

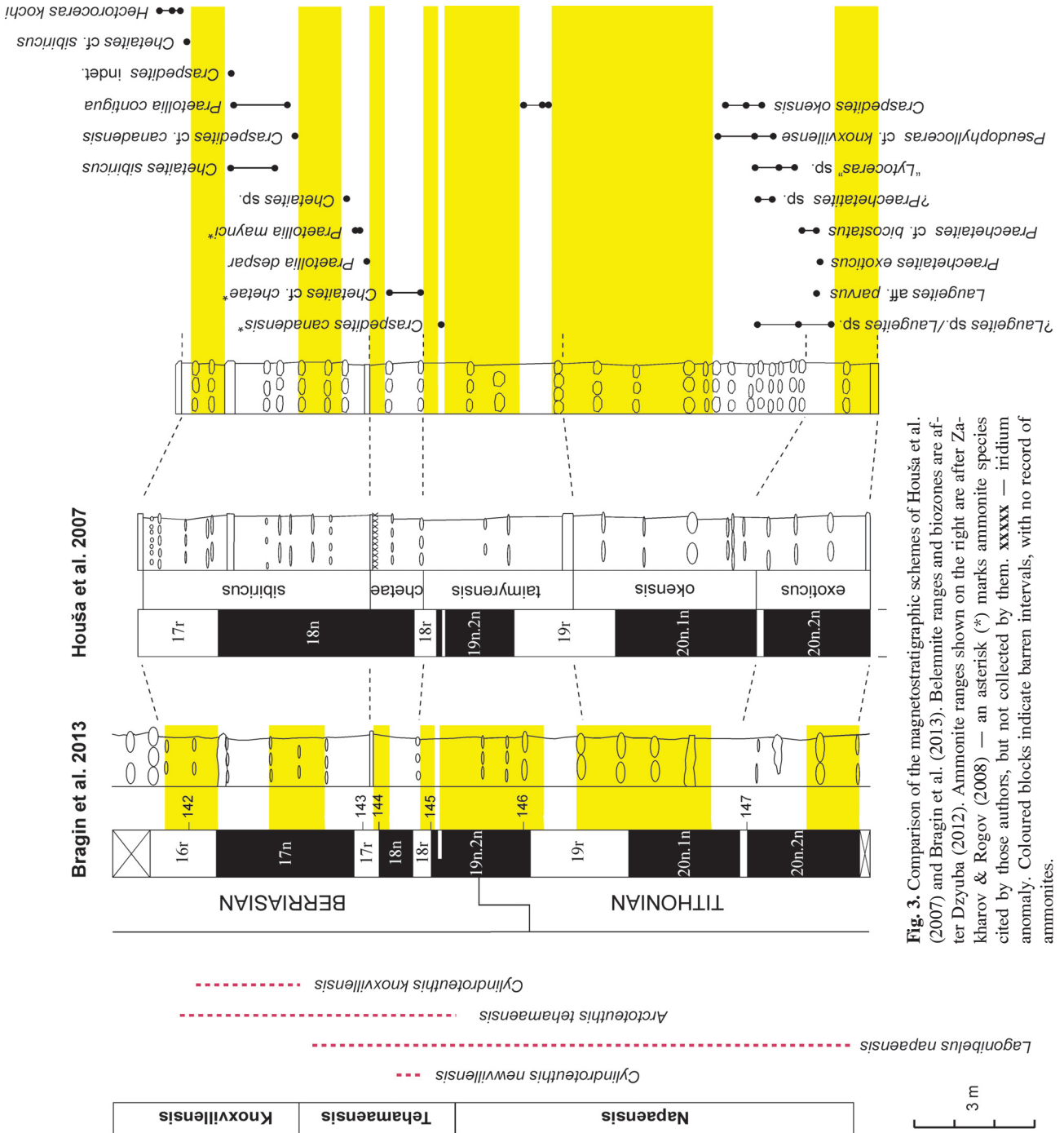
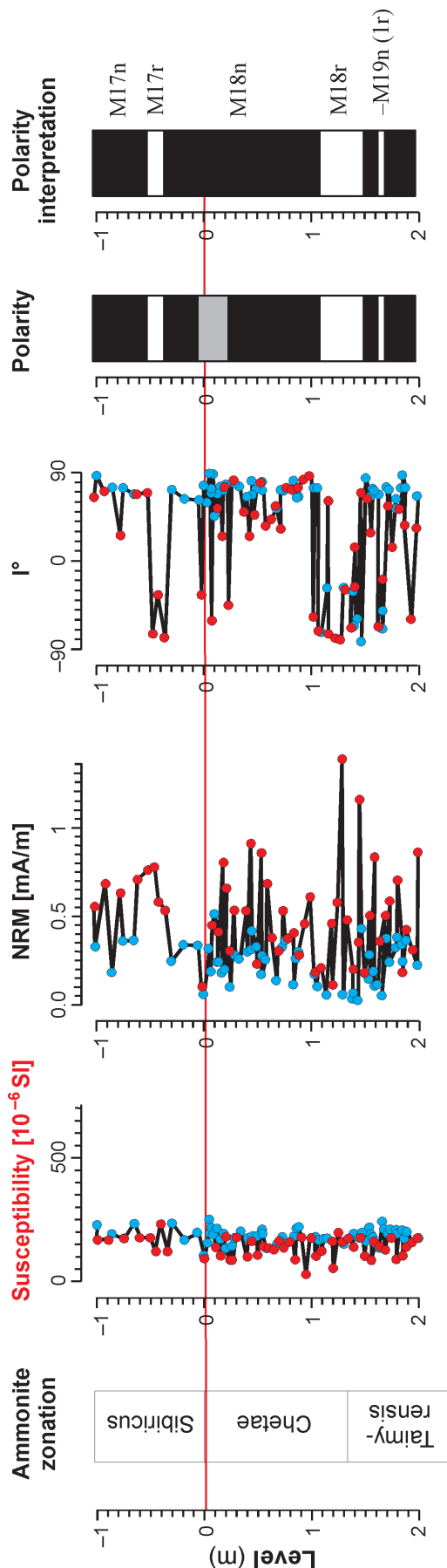


Fig. 3. Comparison of the magnetostratigraphic schemes of Houša et al. (2007) and Bragin et al. (2013). Belemnite ranges and biozones are after Dzyuba & Rogov (2008) — an asterisk (\*) marks ammonite species cited by those authors, but not collected by them. xxxxxx — iridium anomaly. Coloured blocks indicate barren intervals, with no record of ammonites.

The Houša et al. (2007) interpretation of normal polarity zone in the interval from 10 cm below and 30 cm above the Nordvik iridium anomaly is based on results from 10 samples. The two reversed samples shown by Bragin et al. (2013) show anomalous rock magnetic properties, similar to the samples of Houša et al. (2007) in this part of the section. One could be partially demagnetized and the second one probably contains siderite, which has destroyed the original magnetization. The last-mentioned authors could not obtain samples between 31 cm and 54 cm above the iridium anomaly. The sample 55 cm above the anomaly contained

no primary magnetic component due to mineralogical alteration. This means that equivalents of the three reversely polarized samples found by Bragin et al. (2013) were not sampled by Houša et al. (2007). Combining the paleomagnetic data from the 2007 and 2013 publications, the reverse polarity zone “M17r” lies in the interval from 31 cm to ~50 cm above the iridium anomaly (Figs. 2, 4). Even so, the anomalous samples suggest that there have been changes in magnetic mineralogy, and the samples mentioned should be omitted from further evaluation — we show them in the detailed Fig. 4.

**Fig. 4.** Detailed view of paleomagnetic parameters around the Jurassic/Cretaceous boundary. Red line represents the iridium anomaly (as in Houša et al. 2007). Samples with high magnetic susceptibility and high content of siderite are not plotted in the diagram. In the magnetostratigraphic column, black denotes normal polarity, white reversed polarity, and grey mostly normal. This is the authors' new interpretation.



● Houša et al. 2007  
● Bragin et al. 2013

### Speculation about the M16n.1r subzone

Guzhikov (2013, fig. 1, p. 351), interpreting Bragin et al.'s (2013) results, labels a subzone as M16n.1r. This thin subzone is rare: Tominaga & Sager (2010) found it in one third of their profiles. The Guzhikov interpretation is not at all compelling, as in the Nordvik section the supposed "M16n.1r" (called the "Feodosiya" by Guzhikov, after a reversal identified in southern Ukraine) is isolated, with no samples below or above. It is worth examining Bragin et al.'s original figure (2013, fig. 9) and the discrepancy in Guzhikov's (2013, fig. 1) positioning of "M16n.1r". We have tried to clarify the problem in Fig. 4, by combining Houša et al.'s (2007) and Bragin et al.'s (2013) sample data. We cannot agree with Guzhikov's interpretation, and the reasons for our interpretation are described above.

### Magnetostratigraphic niceties

We agree totally with Guzhikov's statement that magnetostratigraphy done without statistical and field tests (e.g. reversal test, fold test, conglomerate test etc.) is not sufficiently reliable. It is true, but there are not enough sections that exhibit folds or conglomerates. Sections showing the J/K boundary usually do not contain enough reversed polarity samples to pass the reversal test. In many cases, there are not enough normal and reversed polarity zones to enable a comparison with the GPTS using the method proposed by Man (2008), even though the sequence of the magnetozones around the J/K boundary is quite unique. The Kysuca and Brodno subzones in M20n and M19n, respectively, are often found in Tethys, and they were found also at Nordvik. In contradiction to Guzhikov (2013), we believe that these subzones should be common in boreal areas as well, and this could be investigated in other sections in Siberia, and Russia in general, to prove that they are laterally consistent.

### Limitations on long-range biostratigraphy imposed by endemic biotas

Guzhikov's diffident quotation of Zakharov's assertion that an ammonite taxon can afford a global scale and provide correlation at the J/K boundary deserves careful examination. No ammonite species, or other alternative single fossil, provides a marker that has anything remotely approaching a global distribution. There are no ammonites in Siberia (or other boreal areas — the Russian platform, UK or Greenland) that make possible a correlation with any section in any part of the lowest Berriasian, or with the traditional J/K boundary interval in Tethys. Since study started, it is a correlation that no-one has been able to make: over-concentration on ammonites in this situation has not been the solution to the correlative problem, but perhaps the cause. Our inability to correlate these J/K intervals in Siberia (which uniquely in the Russian boreal has magnetostratigraphy) with the rest of the world prompted correspondence in 2010 between the ICS Berriasian WG and the Russian Cretaceous Commission, inviting collaboration and wider application of magnetostratigraphy (as at Nordvik), and more efforts to identify

new biological markers that might improve correlations: that is, non-ammonite taxa, and non-endemic taxa that extend outside Siberia, or the Russian platform.

## Conclusions

Berriasian belemnite records at Nordvik open new prospects for correlation, for instance with California, and thus via North America with Tethys. But there appears to be a need for greater refinement of Nordvik ammonite records relative to magnetozone boundaries. The exact stratigraphic position of the base of the *Craspedites taimyrensis* Zone must be higher than previously published, and perhaps even within M19n.2n, closer to a putative Tithonian/Berriasian boundary, and nearer the base of the *Calpionella alpina* Subzone.

The newly interpreted sedimentation rate is seen to be much lower than previously assumed: in M17r it equals 0.16 m/Ma. However, the rate at the level of the iridium anomaly might have been even lower, though a figure can only be approximated. The evidence of Bragin et al. (2013) that slower sedimentation/condensation commenced in M18r tells against its proposal by Guzhikov (2013) as a marker for the J/K boundary. Though several Tethyan sections exist with uncondensed M18r, its thinned presence at Nordvik (the only published Russian section with J/K magnetostratigraphy to date), means that Guzhikov's (2013) reasoning, that this is a preferred global marker that can be identified in Siberia, is undermined. This, in particular, leads us to urge that additional Tithonian/Berriasian sections suitable for paleomagnetic and biostratigraphic calibration be sought in Siberia (and other Russian areas).

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