



Elusive Golden Spikes: When stratigraphers face the technical impossibility of specifying a GSSP in the field

Bruno R.C. GRANIER ¹

Abstract: This publication explores challenges in defining Global Boundary Stratotype Sections and Points (GSSPs) and Standard Auxiliary Boundary Stratotypes (SABSs). It identifies issues with recent practices that undermine the principles of uniqueness and accessibility fundamental to these boundaries. Examples include the controversial use of cores to designate GSSPs for the Quaternary Period, the disregard for essential geological requirements, the failure to ensure field accessibility, and the lack of protection for key sites. These concerns, exemplified by the Cenomanian GSSP for the Cretaceous Period, which remains unprotected after more than 20 years, highlight the need for stricter adherence to guidelines and a reevaluation of current practices, advocating for the mandatory enforcement of certain rules. Other examples discussed specifically relate to the author's personal experience with Lower Cretaceous GSSPs and SABSs.

Keywords:

- Global Boundary Stratotype Section and Point;
- Standard Auxiliary Boundary Stratotype;
- Quaternary;
- Cretaceous;
- International Commission on Stratigraphy;
- recommendations;
- rules

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Résumé : Les clous d'or insaisissables : Quand les stratigraphes font face à l'impossibilité technique de définir un GSSP sur le terrain.- Cet article explore les défis liés à la définition des Sites et Points Stratotypiques Mondiaux (PSM) et des Sections Stratotypiques Auxiliaires Standards (SSAS). Il met en lumière les problèmes posés par certaines pratiques récentes, comme l'utilisation de carottes, qui compromettent les principes fondamentaux d'unicité et d'accessibilité propres à ces limites. Des exemples incluent l'utilisation controversée de carottes pour désigner les GSSP de la Période Quaternaire. L'article critique également le non-respect d'exigences géologiques essentielles, l'absence d'accessibilité sur le terrain et le manque de protection des sites clés. Ces préoccupations, illustrées par le cas du GSSP du Cénomanien pour le Crétacé, resté non protégé depuis plus de 20 ans, soulignent la nécessité d'une stricte adhésion aux directives, ainsi qu'une réévaluation des pratiques actuelles, en plaidant pour l'application obligatoire de certaines règles. Les autres exemples discutés dans le texte se rapportent spécifiquement à l'expérience personnelle de l'auteur avec des GSSP et SABS du Crétacé inférieur.

Mots-clefs :

- Point stratotypique mondial ;
- Section Stratotypique Auxiliaire Standard ;
- Quaternaire ;
- Crétacé ;
- Commission Internationale de Stratigraphie ;
- recommandations ;
- règles

This publication is dedicated to the late Dr Amos SALVADOR (14/04/1923 - 02/12/2007), whose major contributions to the field of stratigraphy served as a guiding reference for the author during his early career as an oil and gas explorationist, and later as a university professor.

¹ Membre correspondant, Muséum d'histoire naturelle (MHN), Route de Malagnou 1, 1208 Genève (Switzerland); Association Carnets de Géologie, 2 impasse Charles Martel, F-29217 Plougonvelin (France) brcgranier@free.fr [ORCID: 0000-0001-9468-2353]





1. Introduction

The geologic time scale is a human construct imposed upon the natural world. The direct correspondence between rock successions and time categories is neither precise nor entirely accurate. It is now accepted that each time-scale unit should be defined by its base, referenced to a specific stratigraphic section in which this lower boundary is characterized by distinctive biostratigraphic, lithostratigraphic, biomagnetostratigraphic, and/or biochemostratigraphic properties (see GRANIER *et al.*, 2024, regarding the use of the prefix 'bio-').

By definition, a Global Boundary Stratotype Section and Point (GSSP) 'is essentially a unique and specific point in a specific sequence of sedimentary rock strata at a unique and specific geographical location' (COWIE *et al.*, 1986). It serves as the reference point for defining the base of the corresponding stage on the International Chronostratigraphic Chart.

Rules for definition of GSSPs are listed on the ICS website (ICS-International Commission on Stratigraphy, <https://stratigraphy.org/gssps/>) and summarized here (Table 1).

Table 1. Summary of the ICS rules for defining chronostratigraphic boundary proposals (modified from <https://stratigraphy.org/gssps/> as of 21/01/2025)

1. **MUST** contain a stratigraphic marker;
2. **MUST** be observable, unambiguous change in the physical or fossil properties;
3. **MUST** be adequately thick for global correlation;
4. **MUST** be continuous without facies changes;
5. **SHOULD** be unaffected by other geological processes;
6. **MUST** be accessible to research;
7. Fossil content **SHOULD** be reproducible and widespread (*i.e.*, abundant, distinctive, well preserved, and cosmopolitan);
8. **SHOULD** contain other marker horizons or attributes.

REMANE's use of 'should' indicates that these guidelines are recommendations, not rules. The word 'must' appears six times, while 'should' appears seven times (REMANE *et al.*, 1996). However, it is suggested here that these guidelines ought to be mandatory rather than remaining optional.

Additionally, REMANE *et al.* (1996) stated that the International Commission on Stratigraphy (ICS) 'should attempt to finalize, within three years after the International Union of Geological Sciences (IUGS) ratification, any remaining official steps for the protection of the site with the authorities of the country in which the GSSP is located'. Furthermore, the point 'should be indicated by a permanently fixed marker' (REMANE *et al.*, 1996), commonly represented in the field by a 'Golden Spike' in the form of a large nail made of brass (Fig. 1.A-B).

Unfortunately, enforcing such rules is not always effective. For example, the Cenomanian GSSP (KENNEDY *et al.*, 2004) at Mont Risou (Hautes-Alpes, SE France) remains unprotected more than 20 years after its ratification because the Cenomanian Working Group was unable to secure the site. This GSSP faces more than just this issue, as

will be demonstrated in this paper. Except for the Quaternary Period and the Cenomanian, the examples discussed primarily come from the Lower Cretaceous, for which the author has direct personal field experience.

Moreover, some other aspects of the ICS Guidelines require clarification to avoid ambiguity. For instance, it should be clearly stated that designating a GSSP or its Standard Auxiliary Boundary Stratotype (SABS) based on a subsurface core interval is incompatible with both the uniqueness of the point at its geographical location ^[*] and the accessibility to the site (which is necessarily located at some depth in the subsurface). In fact, such an option (well location and core material) is inadequate and common sense suggests that it must be rejected.

Finally, because some currently ratified GSSPs do not meet all of the requirements, the author recommends that certain GSSPs should be reevaluated to determine whether any should be revised or replaced.

2. Wells and cores are unsuitable as boundary stratotypes

Members of the Aptian Working Group of the International Subcommission on Cretaceous Stratigraphy (ISCS), including the author, recently commented on a candidate section for its GSSP or its SABS based on core from the APTICORE Cismone well (ERBA *et al.*, 1999). The chief reason for using this core was the existence of precedents of cores used by other GSSPs, namely (the bases of) the Northgrippian Stage (WALKER *et al.*, 2018) and the Greenlandian Stage (WALKER *et al.*, 2018). Nevertheless, there are several other important reasons to argue against the appropriateness of the selection of this core as a candidate (*e.g.*, its estimated rate of 'compacted' sedimentation at the critical interval is less than 3.5 mm/ka, which is an ultracondensed section),

A core is a cylindrical piece of rock taken from the subsurface by a special drill bit and brought to the surface for examination. Accordingly, a core taken from sedimentary rocks is merely a continuous sampling of a given interval. When on May 5, 2016, the author collected samples below, at, and above the Aptian/Albian boundary at the GSSP site (Fig. 2.B-C) near Pré Guittard pass (Fig. 2.A) to provide a second opinion (GRANIER, ed., 2017; ARAI, 2017; ANTUNES, 2017), he did not take away the GSSP, but only duly referenced rock samples. Similarly, ice cores from the NGRIP holes, 11 cm in diameter, stored in the facilities of the University of Copenhagen do not represent the boundary stratotype, but merely a continuous sampling around it.

^[*] To put it simply, both the section and the point cannot be located in two different places (uniqueness rule).



Figure 1: A) The Golden Spike (of the base) of the Maastrichtian at Tercis-les-Bains (ODIN & LAMAURELLE, 2001), Les Landes (SW France). Photo courtesy of Gilles Serge ODIN; **B)** The Golden Spike (of the base) of the Hauterivian at La Charce (MUTTERLOSE *et al.*, 2021), La Drôme (SE France). Photo courtesy of Stéphane REBOULET (30/08/2024).

However, selecting a core as a GSSP represents a disruption to the global boundary-stratotype concept, as first outlined by HEDBERG *et al.* (1976) and further developed by subsequent stratigraphers (COWIE *et al.*, 1986; SALVADOR, ed., 1994; REMANE *et al.*, 1996). Additionally, it infringes on several requirements or recommendations of the International Commission on Stratigraphy (ICS).

It is noteworthy that WALKER *et al.* (2008) highlighted the 'appropriateness of defining a global geological stratotype in an ice-core sequence.' However, while there are indeed advantages, such as the precise dating of the boundary through annual ice-layer counting and the detailed isotopic records, they are few and negligible compared to the disadvantages. As noted below, these Quaternary GSSPs based on cores do not meet important criteria required for validity.

The GSSPs for (the bases of) the Northgrippian and Greenlandian stages (WALKER *et al.*, 2018) are located in the NGRIP1 and NGRIP2 holes, respectively. They share the same Global Positioning System (GPS) coordinates, [75°06'00.0"N, 42°19'12.0"W](#), which is the location of the drilling site, not those of the points (see Fig. 3). Besides, the given depths of these GSSPs are 1228.67 m for the NGRIP1 well and 1492.45 m for the NGRIP2 well (WALKER *et al.*, 2018). Because conversion tables for the measured core depths (MD) versus the true vertical depths (TVD) are not available, the exact locations (latitude, longitude, elevation) of both points are not known.

Contrary to the assurances by WALKER *et al.* (2008), the GSSPs for (the bases of) the Northgrippian and Greenlandian stages fail to meet the accessibility requirement. Regarding accessibility, REMANE *et al.* (1996) wrote: 'Candidate sections in remote regions which can only be visited by organising costly expeditions should normally be excluded from the selection.' Clearly, Greenland sites do not meet this criterion. The chief accessibility issue is that new sampling of the location to facilitate the supplementation of information (for example, by including new paleontological groups or analyzing new chemical elements) is not straightforward although it should be. Thus, this requirement should be made mandatory. Easy access is crucial for replicating previous analyses and verifying their reproducibility. To achieve this, the material should be sufficiently abundant.

The two proposals by WALKER *et al.* (2018) do not meet either key biostratigraphic requirements at their polar localities, such as the 'abundance and diversity of well-preserved fossils' (COWIE *et al.*, 1986) 'throughout the critical interval' (REMANE *et al.*, 1996). In fact, they did not report any microfossil finds from there. Spores and pollen grains may be present, as biostratigraphy is required for Phanerozoic GSSP candidates, but this has never been tested in the ice cores. The reason for this is that, given the low concentration of microfossils in ice cores, sampling for spores and pollen grains would necessitate a significant and irreversible consumption of the initial ice-core volume.

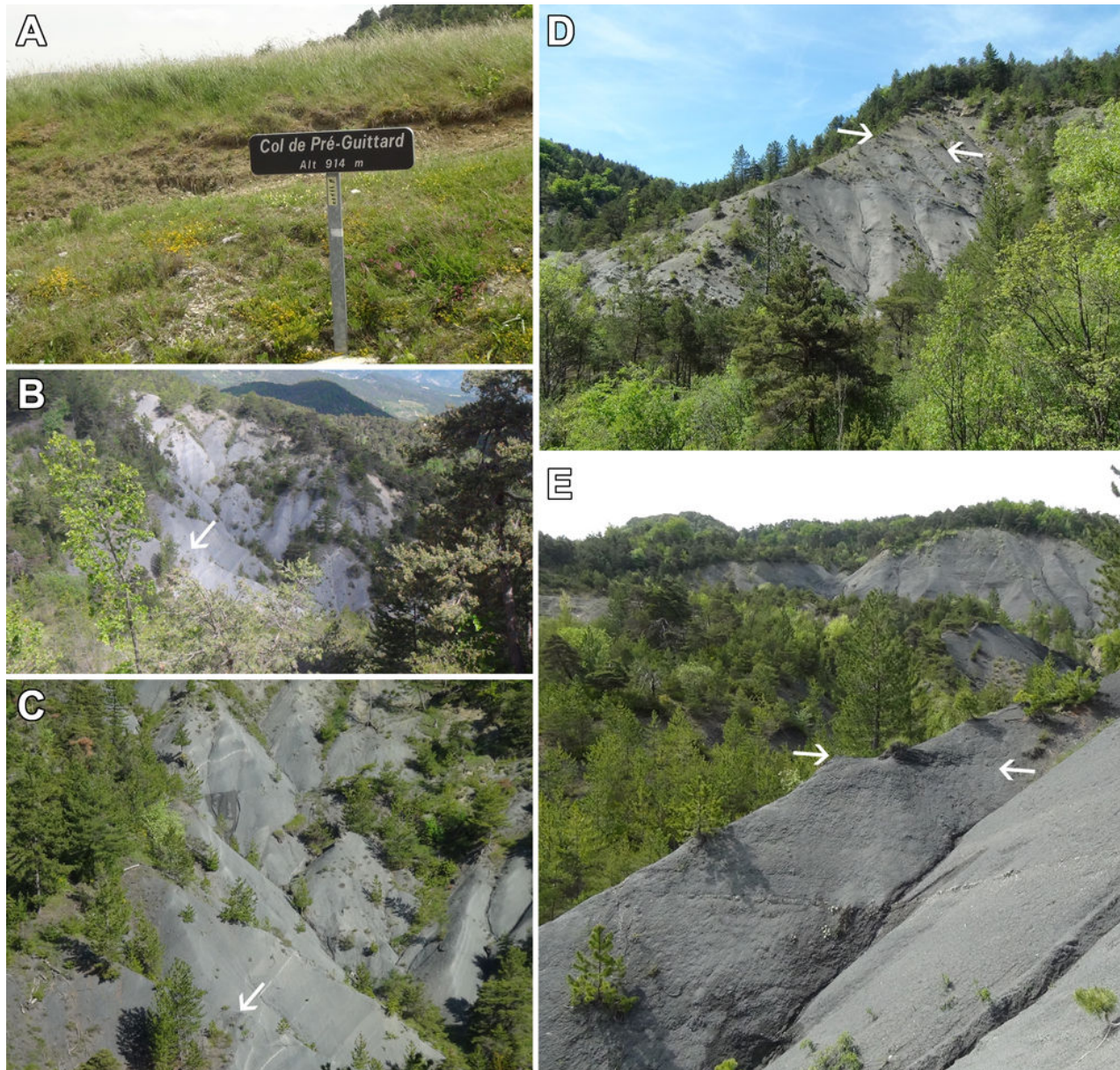
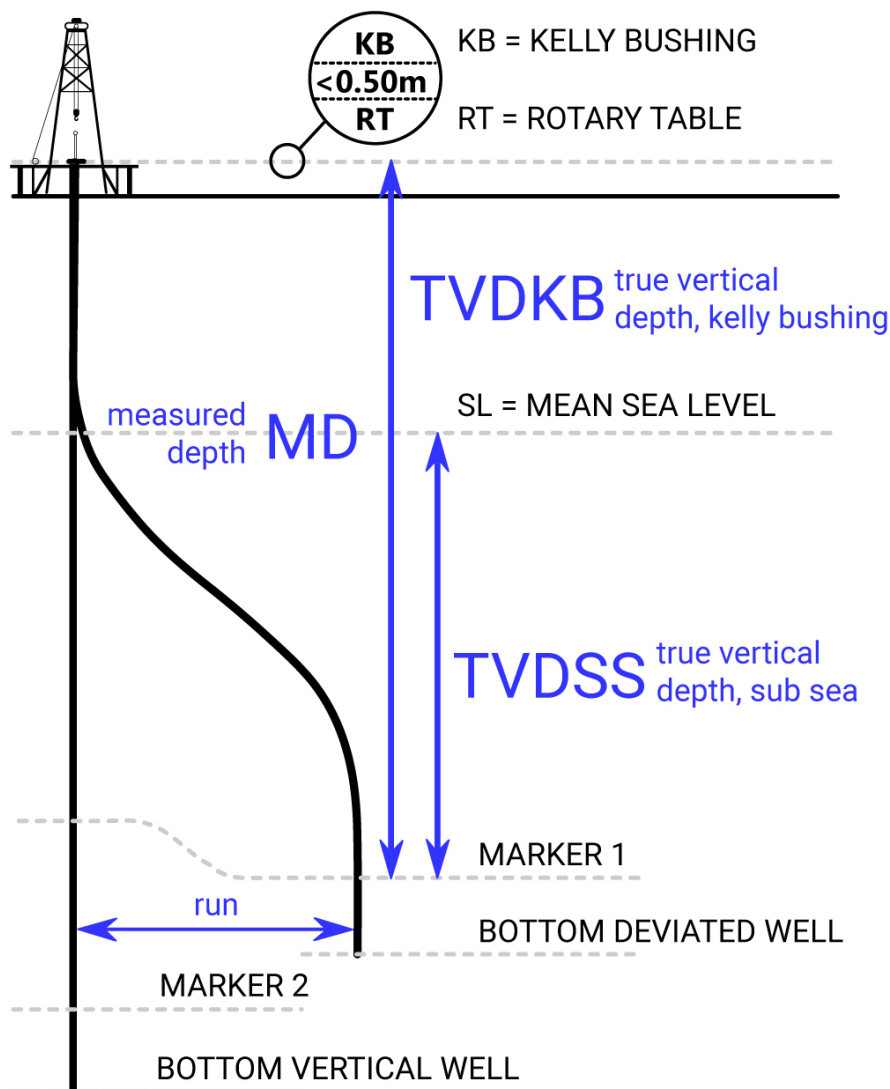


Figure 2: B-E) The Aptian/Albian boundary (Albian GSSP arrowed) in the Trébou valley, west of the Pré Guitard pass (A), La Drôme (SE France). A: 23/05/2015; B: 26/05/2015; C, E: 25/05/2013; D: 21/05/2017.

Among the biostratigraphic requirements, it is stated that '[coastal and continental settings](#) *'should' be avoided*' (REMANE *et al.*, 1996). The author suggests replacing '*should*' with '*must*', making it a mandatory requirement rather than an optional suggestion. Subaqueous sections such as open marine environments, with their diversified biotas, offer the most '[favourable facies for long-range biostratigraphic correlations](#)' (REMANE *et al.*, 1996).

Furthermore, because geochemical peaks repeat over time, correlating with any other ice core requires it to be long enough to allow for barcode correlation of the dust layers. Correlation with a sedimentary column, excluding an ice core, ne-

cessitates either biostratigraphic control or accurate numerical dating. The author '[has warned of stratigraphical misuse of geochemical curves](#)' (GRANIER, 2012, 2014; GRANIER & BUSNARDO, 2013; GRANIER *et al.*, 2024). This warning is valid for any purely physical or chemical data (e.g., barcodes of dust or polarity reversals of the Earth's magnetic field, peaks on geochemical curves). SCOTT *et al.* (2020, 2023) state that '[Chemostratigraphic Units](#)' (...) '[may be associated with or bracketed by independent stratigraphic markers such as](#)' (...) '[biostratigraphic zones, which aid in their identification](#)'. GRANIER *et al.* (2024) supported this statement and even suggest referring to biochemostratigraphy rather than chemostratigraphy.



◀ **Figure 3:** Schematic representation of vertical and deviated wells at the same location, showing the relationship between measured depth (MD), true vertical depth referenced to Kelly Bushing (TVDKB), true vertical depth referenced to the rotary table (TVDRT), and true vertical depth below mean sea level (TVDSS). The diagram also illustrates the GPS locations at the level markers, with the projections of the marker locations on a horizontal plane separated by a distance referred to as the run.

3. Field geologists should be able to identify the GSSP or SABS

REMANE *et al.* (1996) listed the 'absence of vertical facies changes at or near the boundary' under the 'Biostratigraphic requirements', not under the 'Geological requirements'. They justified this by stating that 'A change of litho- or biofacies reflects a change of ecologic conditions, which may have controlled the appearance of a given species at the boundary level.' What exactly is behind the definition of lithofacies? The author's experience suggests that this sedimentological issue requires further clarification and better documentation, as shown by the GSSPs for several Cretaceous stages.

Hauterivian Stage

The Hauterivian GSSP (MUTTERLOSE *et al.*, 2021) at La Charce (Drôme, SE France) is located at the boundary between two types of marl and argillaceous limestone alternations: thin beds and interbeds below the boundary, and thick beds and interbeds above it. There are two contrasting lithologies - marls and limestones - and two closely related but distinct stratigraphic styles. However, it

is important to note that the interbedded lithologies are considered as a single facies type: hemipelagic calcareous sedimentation. This boundary fulfills the sedimentological requirements and, moreover, is easy to map in the area. For instance, it is clearly identified (Fig. 4.A) along the D173 road in the Arnayon valley (GPS coordinates 44°28'54.2"N, 5°20'43.6"E) located approximately 8 km westward of the La Charce site (Fig. 4.B-C; GPS coordinates 44°28'09.5"N, 5°26'37.5"E).

Cenomanian Stage

KENNEDY *et al.* (2004) reported the GPS coordinates of the Cenomanian GSSP at Mont Risou, Saint-André-de-Rosans (Hautes-Alpes, SE France), to be 44°23'33"N, 5°30'43"E. However, during a visit on May 23, 2024, the GPS coordinates recorded were 44°23'28"N, 5°30'39"E, some 170 meters to the SSW of the supposed location. This is not an isolated case; the Albian GSSP at Arnayon (Drôme, SE France) had GPS coordinates 44°30'28.3"N, 5°17'50.1"E on May 25, 2016 (GRANIER, 2017), some 1,700 meters to the SE of the reported location at 44°29'47.78"N, 5°15'42.36"E (KENNEDY *et al.*, 2017).

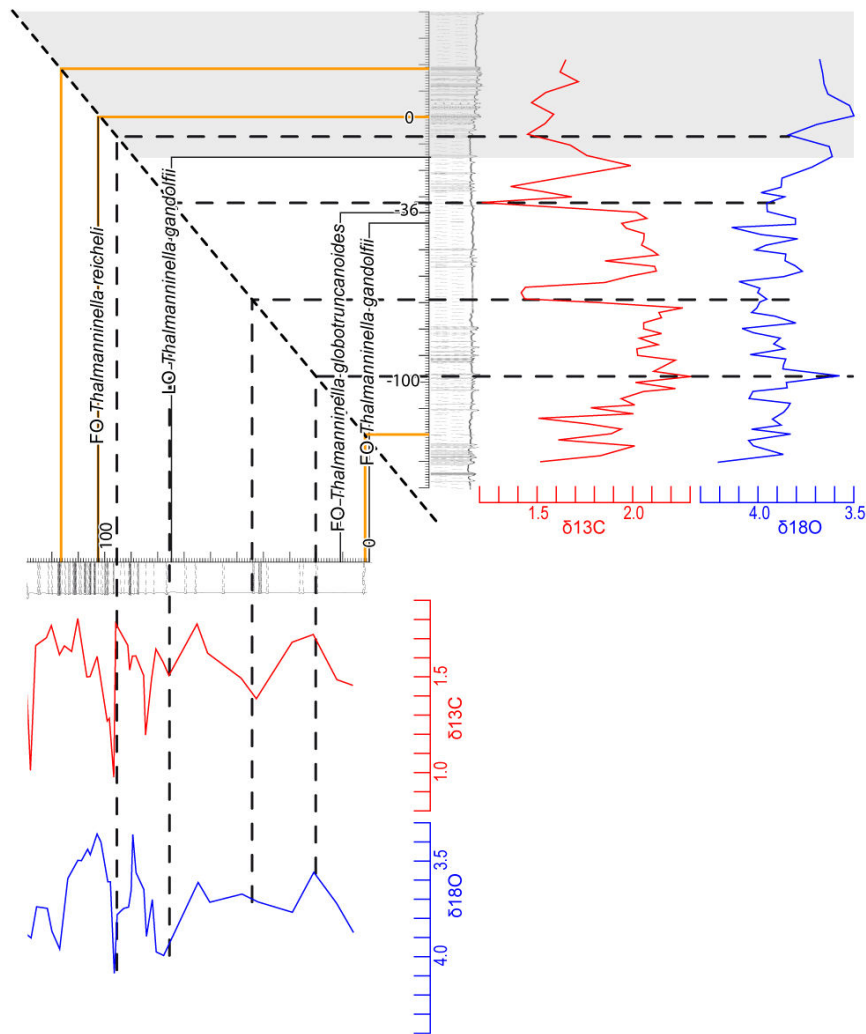


Figure 4: **A)** The Valanginian/Hauterivian boundary (arrowed) in the Arnavon valley, east of the Pré Guitard pass, La Drôme, SE France (22/05/2024). **B)** The author and a visiting group of third year students from the Université de Bretagne occidentale (Brest, Finistère) at the Hauterivian GSSP in La Charce, La Drôme, SE France (22/05/2016). **C)** The Hauterivian GSSP (arrowed) at La Charce (12/05/2020).

In both cases, the facies is rather homogeneous, consisting of the blue-grey marls or calcareous clays of the 'Marnes bleues' Formation. This facies is characteristic of pelagic sedimentation, having been deposited mostly below the Aragonite Compensation Depth, which explains the scarcity and even the absence of ammonite shells. Although some layering is visible at Arnavon, with a few marlstone layers and the organic-rich KILIAN marker bed allowing the accurate identification of the base of the Albian in the middle of this KILIAN level, the same is not true for the Mont Risou section. There, the base of the Cenomanian is located approximately 36 m below a prominent limestone bed, identified as the 'zero datum.' The GSSP is situated roughly one-third of the way down from the top of a 22-meter-thick, homogeneous marl interval, bounded by two 'bet-

ter cemented, weathering-resistant intervals in marls' (located at -28 m and -50 m below the zero datum). However, due to the lack of distinct layering in the marl, the base of the Cenomanian is not straightforwardly visible in the field. The homogeneous facies, with no visible bedding and spanning at least 22 m, and more likely up to 120 m in thickness, suggests that this section was unsuitable for selection as a GSSP. Additionally, implanting a permanent 'Golden Spike' is impractical in an unconsolidated clayey substrate.

A nearby section (GPS coordinates $44^{\circ}23'12.4''\text{N}$, $5^{\circ}30'45.9''\text{E}$), approximately 500 meters South of the GSSP, was studied by MOONS-OUDET (2013). *Thalmaninella reicheli* (MORNOD) is not reported in the log shown in KENNEDY *et al.* (2004) because no information on planktonic foraminifers is available above -15 m (indicated by a grey interval on



◀ **Figure 5:** Graphical correlation of MOONS-OUDET's (2013) and KENNEDY's (2004) logs, represented on the X and Y axes, respectively. Caption: Grey patch = lack of planktonic foraminifer analyses; orange lines = key lithologic layers; thin black lines = key biostratigraphic markers; thin dashed blue lines = selected peaks on the geochemical curves; thick dashed black line = line of correlation.

Fig. 5). There are no records of *Th. subticinensis* (GANDOLFI), *Th. tehagensis* (MARIANOS et ZINGULA) and *Th. ticinensis* (GANDOLFI) in MOONS-OUDET's log. Based on graphical correlations of key levels - such as a layer with calcareous concretions in the lowermost part of both sections, and the base and top of an alternation (orange lines on Fig. 5) - as well as tentative biogeochemical correlations of some peaks in the $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ curves (dashed lines on Fig. 5), the First Occurrence (FO) of *Th. globotruncanoides* (SIGAL), and both the First (FO) and Last (LO) occurrences of *Th. gandolfii* (LUTERBACHER et PREMOLI SILVA) appear lower in MOONS-OUDET's section than in KENNEDY's section, by approximately 65 m, 75 m, and 20 m, respectively. It is noteworthy that the primary proxy is reported approximately 65 m below the boundary it is supposed to define at a site located just 500 m from the GSSP.

Finally, access to the GSSP site is compromised (Fig. 6.A-D): the track is blocked by a large steel gate bearing a sign that prohibits entry to this private property, and the land is enclosed by a barbed wire fence. It is likely that the original investigators excavated a trench without obtaining prior permission from the landowners or the farmer.

Berriasian Stage

The former candidate site and point for the Berriasian (WIMBLEDON *et al.*, 2020) did not meet at least four 'geological requirements for a GSSP' (GRANIER *et al.*, 2020).

Following the presentation of the Berriasian GSSP candidate section (GPS coordinates [44°28'00.1"N](#), [5°49'40.7"E](#)) at a meeting of the Berriasian Working Group (BWG) in Bratislava on June 23, 2019, the author visited the Tré Maroua site (Fig. 7.A) at Le Saix (Hautes-Alpes, France) on July 24, 2019, to make field observations and collect samples for subsequent microscopic investigation. These were shared with the voting members of the ISCS before the vote took place and were published immediately afterward on February 22, 2020 (GRANIER *et al.*, 2020).

In the aftermath of this public disclosure, the BWG team leader did not fully accept the negative outcome of the poll, despite the fact that 'Of the twenty-two persons in the Subcommittee, eight (32%) voted against the proposal, eight voted "Yes", four did not vote, and two abstained' (WIMBLEDON *et al.*, 2020, p. 160). However, the ICS statutes make it clear that approval requires that the votes in favour to equal or exceed 60% of the



Figure 6: Issues with the Cenomanian GSSP at Mont Risou, Saint-André-de-Rosans (Hautes-Alpes, SE France), 23/05/2024. **A)** the steel gate; **B)** the warning sign; **C)** the 'typical outcrop' (KENNEDY *et al.*, 2004); **D)** the GSSP is hidden somewhere on the hillside.

delivered votes, provided that a quorum of 60% has been attained. He also complained that the early version of their proposal 'received some negative comments produced by three members of the Subcommittee' (WIMBLEDON *et al.*, 2020, p. 160).

Although four of the five 'geological requirements for a GSSP' were not met, eight of the ICSC voting members disregarded this significant problem and cast positive votes. It is assumed that most voting members of any subcommittee may not have visited the candidate sections before participating in the poll. It is also noteworthy that some authors of proposals never visited the candidate sections and points they studied, as their analyses were based on material collected by another team member. For instance, at least two coauthors of the (base) Albian GSSP (KENNEDY *et al.*, 2017), did not visit the site until June 10, 2017, during an excursion organized by the author (GRANIER, ed., 2017). The author himself, who is a co-author of the proposal for the (base) Barremian GSSP (COMPANY *et al.*, 2024), has not yet visited the Río Argos site (Caravaca, SE Spain). However, as a co-author of the (base) Valanginian GSSP (REBOULET *et al.*, submitted), he has visited the site of Vergol at Montbrun-les-Bains (Drôme, SE France) on several occasions (Fig. 7.B). It is understood that each contributor to a GSSP, from the specialist in the dedicated working group to the voting member in the relevant subcommis-

sion, may not have had direct access to the site and point. For this reason, the author suggests that they should be provided with a comprehensive set of imagery to ensure the suitability of the exposure.

According to WIMBLEDON *et al.* (2020), the primary proxy for the base of the Berriasian is the onset of the acme of *Calpionella alpina*. This point was supposedly located approximately 8 m above the base of their measured log (Fig. 7.A). However, GRANIER *et al.* (2020) argued that the proposed primary proxy should be placed about 3 m lower, at the base of a debris flow. Additional samples (GRANIER *et al.*, 2023a) even revealed that the boundary coincides with a fault, approximately 4 m below the proposed level. Moreover, the critical interval surrounding this boundary is riddled with calciturbidites and debris flows (GRANIER *et al.*, 2020, 2023a). A nearby outcrop of the Tithonian/Berriasian boundary is the Le Chouet section at Les Près (La Drôme, France; GPS coordinates 44°32'31.3"N, 5°33'35.7"E), approximately 23 km to the WNW of Tré Maroua. According to GRANIER *et al.* (2020), most 'bases of calpionellid zones and subzones', including the Tithonian/Berriasian boundary (Fig. 8), 'are located at basal erosional surfaces of turbidites or debris flows.' The bases of turbidites or debris flows tend to be channelized and laterally discontinuous, making them neither synchronous nor suitable as GSSPs or SABSS.



Figure 7: **A)** The former candidate site and point for the Berriasian of Tré Maroua site at Le Saix (Hautes-Alpes, France). Photo courtesy of David HARPER, 21/05/2023; **B)** The Valanginian GSSP (arrowed) of Vergol at Montbrun-les-Bains (Drôme, SE France). Photo courtesy of David HARPER, 22/05/2023.

As documented by GRANIER *et al.* (2020), the former (base) Berriasian GSSP candidate does not meet the rule of 'absence of synsedimentary and tectonic disturbances' (REMANE *et al.*, 1996) as it suffers from both issues. Although, the bases of some turbidites and debris flows may appear conformable with strata below and above, and show no apparent sign of basal erosion in the vertical section, it should be demonstrated that conformable bases are laterally extensive beyond a short distance from the reference section. If this requirement is not met, candidate sections and points in a turbiditic setting should be rejected. If such conditions are present in a current GSSP or SABS, it should be considered as a 'violation of accepted stratigraphic principles' (REMANE *et al.*, 1996), and an *ad hoc* working group should be established to review the situation.

Remark: Regardless of the results of the Berriasian Working Group, in the absence of a significant biological crisis during the transitional interval between the Tithonian and Berriasian stages, the GSSP of the Berriasian stage should not be considered *de facto* as the GSSP for the Cretaceous System. On the contrary, the Berriasian/

Valanginian boundary, which corresponds to a major crisis impacting multiple groups of organisms (see GRANIER, 2019), should regain its status as the boundary between the Jurassic and Cretaceous systems. The author does not consider the Berriasian as the first stage of the Cretaceous System, but rather as the last stage of the Jurassic System.

Aptian Stage

Like the Berriasian Working Group, the Aptian Working Group is still determining where to place the point and locate the section. Currently, their preferences are focused on the negative carbon isotope excursion (CIE) identified at the C2/C3 boundary - *i.e.*, the boundary between the second and third segments of the $\delta^{13}\text{C}$ curve for Oceanic Anoxic Event (OAE) 1a (MENEGATTI *et al.*, 1998) - as the primary proxy. They proposed the Cau section (Fig. 9.A, Province of Alicante, SE Spain; GPS coordinates: $38^{\circ}42'13.4''\text{N}$, $0^{\circ}00'16.2''\text{W}$) with its set of cores (D1 to D4), as the candidate for the GSSP, and the Cismon site (NE Italy; GPS coordinates: $46^{\circ}02'43.46''\text{N}$, $11^{\circ}45'46.85''\text{E}$) with its Apti-Core set (Fig. 10), as the candidate for the SABS.



Figure 8: The Tithonian/Berriasian boundary (arrowed) of Le Chouet (GRANIER *et al.*, 2023b) at Les Près (Hautes-Alpes, France), 08/05/2018.

Although the geological significance of the event is clear, OAE1a (specifically its segments C3-C6) was historically regarded as an intra-lower Aptian OAE, more precisely within the *Deshayesites forbesi* Zone. The new boundary criterion, however, redefines the C2/C3 segment boundary as the base of the Aptian stage. This redefinition represents a significant upward shift, estimated at approximately 60 m in the historical La Bédoule section (Fig. 9.B) of MOULLADE *et al.* (1998), and will complicate the use of past publications. Such a change implies that the Aptian would lose about one-fourth of its total time range, along with the transfer of at least one ammonite zone, the *Deshayesites oglanlensis* Zone, into the Barremian. This alternative should not be validated, given the long-standing historical precedent and the existence of suitable candidate sites and points, including those near historical localities (e.g., BERT *et al.*, 2025).

Furthermore, the correlation criterion for the C2/C3 boundary is not necessarily as robust as believed. For instance, VAHRENKAMP (1996) purportedly identified the OAE1a in the shallow-water Shu'aiba Formation of the United Arab Emirates based on a $\delta^{13}\text{C}$ curve and poorly constrained biostratigraphic data, placing the negative CIE at the base of his 'Sequence Apt 2'. Later, similar features were reported in Oman (VAHRENKAMP, 2010).

However, these chemostratigraphic interpretations conflict with ammonite records (BUSNARDO & GRANIER, 2011; GRANIER & BUSNARDO, 2013). Specifically, the identification of the *Epicheloniceras martini* Zone within the maximum flooding interval (MFI) of 'Sequence Apt 2' (VAHRENKAMP, 2010) is inconsistent with this interpretation. This interval corresponds to a condensed section equivalent to the Highstand System Tract (HST) of the Shu'aiba Formation, as described by GRANIER (2008: Fig. 9). According to VAHRENKAMP (1996, 2010), his purported equivalent of the OAE1a C3-C4 segments is assigned to the '*Deshayesites deshayesi* Zone.' However, the author (GRANIER (2012, 2014) noted that this interval cannot be older than the *Dufrenoyia furcata* Zone, thereby precluding its assignment to the OAE1a. YAMAMOTO *et al.* (2013) repeated the same error as VAHRENKAMP (2010) when analyzing similar wells from the same region (GRANIER, 2014). In conclusion, chemostratigraphy should not be applied without a robust biostratigraphic context. Instead, the concept of biochemostratigraphy (GRANIER *et al.*, 2024) should be employed, wherein the primary marker is a biostratigraphic proxy and the secondary marker is a chemostratigraphic proxy used to refine the information provided by the primary marker.



Figure 9: **A)** the candidate boundary on the side of a trail at Cau, arrowed, 25/04/2024; **B)** the uppermost Barremian behind Moteurs BAUDOUIN factory (former Villeneuve quarry) in Cassis, 24/09/2024. **C)** the lowermost Aptian in the Brigadan candidate section for the Aptian GSSP in Cassis (BERT *et al.*, 2025). Photo courtesy of Didier BERT, 16/08/2025.

Mathieu MARTINEZ (personal communication, 14/05/2024) provided the author with estimates for the duration of the C3-C4 segments, ranging from 470 to 747 ka. This interval measures 880 mm at Gorgo a Cerbara, 1,580 mm in the AptiCore (1,500 mm, considering that the cores are cut at an angle of 20°; Fig. 10), 11,090 mm at La Bé-

doule, and 11,670 mm at Cau. According to BARABOSHKIN (2009), condensed sections *sensu stricto* are characterized by sedimentation rates (after compaction) ranging from 5 to 10 mm/ka, while ultracondensed sections exhibit rates below this range. With sedimentation rates of 1.2 to 1.9 mm/ka and 2.0 to 3.2 mm/ka, respectively, both Gorgo a



Cerbara and Cismon record ultracondensed sedimentation and should not be considered valid candidates for a GSSP or a SABs. In contrast, sedimentation rates at La Bédoule and Cau range from 14.8 to 23.6 mm/ka and 15.6 to 24.8 mm/ka, respectively. These rates place both Cau and La Bédoule sections outside the condensed section category.

Besides their sedimentation rates, the Gorgo a Cerbara and Cismon sites are unsuitable for other reasons. For example, the facies change abruptly at 25.03 m in core 15, which is the boundary between units 4 and 5 (ERBA & LARSON, 1998: Fig. 5), as seen in archival photographs of the Apti-Core (Fig. 10). The vertical facies change at the boundary, occurring on a firmground, indicates a hiatus, another characteristic that should have disqualified this site from consideration.

4. Conclusions

Inconsistencies in the approaches to establish Global Stratotype Sections and Points and Standard Auxiliary Boundary Stratotypes indicate the need to elevate some existing recommendations to rules, introduce new recommendations ('should') and rules ('must'), and enforce stricter adherence to both current and future guidelines in the selection and definition of GSSPs and SABs.

1) Any candidate based on subsurface material such as a core from a drill hole or well is inherently unsuitable as a boundary stratotype or auxiliary boundary because it violates the principle of geographical (latitude and longitude) and topographical (elevation) uniqueness. The location of such a site is necessarily defined by its position within the hole at depth, with the reference point located in the subsurface, which, by nature, impedes any easy and unrestricted access. Additionally, the ice record in the critical interval for the lower boundaries of the Northgrippian and Greenlandian stages lacks biostratigraphic information, which would have otherwise resulted in irreversible destruction of the material concerned. Furthermore, the reproducibility of measurements in ice cores is either very limited or impossible. Therefore, it is suggested that existing well and coreGSSPs be abandoned, and new *ad hoc* working groups to identify better candidates for the same GSSPs be selected. More broadly, any new GSSP or SABs candidate based on a well and sedimentary core must be ruled out from the outset, as a unique site and point cannot be ubiquitous.

2) Astronomically controlled deposits, such as the marl and argillaceous limestone alternations of the Valanginian-Hauterivian in the La Drôme department (SE France), should be treated as a single hemipelagic facies, even though they exhibit two lithologies and various stratinomic styles. In contrast, non-cyclical alternations related to turbiditic deposits within pelagic sedimentation, such

as the debris flows and turbidites found at the former Berriasian GSSP candidate site in the Les Hautes-Alpes department (SE France), are unsuitable intervals for identifying GSSPs or SABs because the 'sharp lithofacial change' at the bottom of each debris flow or turbidite marks an erosional surface, indicating a hiatus that may be more or less significantly developed laterally. Therefore, it is suggested that if any past GSSP or SABs coincides with an erosional surface at the bottom of a debris flow or turbidite, it must be abandoned, and a new *ad hoc* working group should be appointed. More broadly, any new GSSP or SABs candidate in a turbiditic setting must be ruled out from the start.

3) Homogeneous critical intervals lacking visible layering must be considered unsuitable for the location of GSSPs or SABs because the boundary cannot be immediately and easily identified. Additionally, it may not be feasible to place a permanent 'Golden Spike' at some clayey or marly sites. This issue is exemplified by the Cenomanian GSSP at Mont Risou, which must be abandoned for these reasons, among others.

4) Finally, the action on the Berriasian proposal (GRANIER *et al.*, 2020, versus WIMBLEDON *et al.*, 2020) demonstrates the importance that voting member have first-hand field-work knowledge of the candidate sections. To a lesser degree, the same concern applies to members of the working groups. It is suggested that proposals should include a comprehensive set of field photographs, videos, or Digital Terrain Model (DTM) and Digital Surface Model (DST) derived from drone imagery to ensure the suitability of candidate GSSP or SABs exposures.

In conclusion, several examples of approved and candidate Phanerozoic GSSPs and/or SABs reviewed here do not meet the recommended criteria (HEDBERG *et al.*, 1976; COWIE *et al.*, 1986; SALVADOR, ed., 1994; REMANE *et al.*, 1996). The author proposes that all well-established criteria of future Phanerozoic GSSPs and SABs be thoroughly documented before a proposal is submitted. Furthermore, it is recommended that already approved GSSPs and SABs be reassessed to ensure that documentation is complete, and that each site, as a potential World Heritage Site, is protected and **accessible to both researchers and the general public**, in accordance with the philosophy of the GSSP. Aside from the issue of accessibility, although the identification of a boundary may appear more photogenic on core material than in most field outcrops, the location of the section (*i.e.*, the drill hole) and the specific point on the core are, by nature, not unique, an aspect that also contradicts the general philosophy of the GSSP.

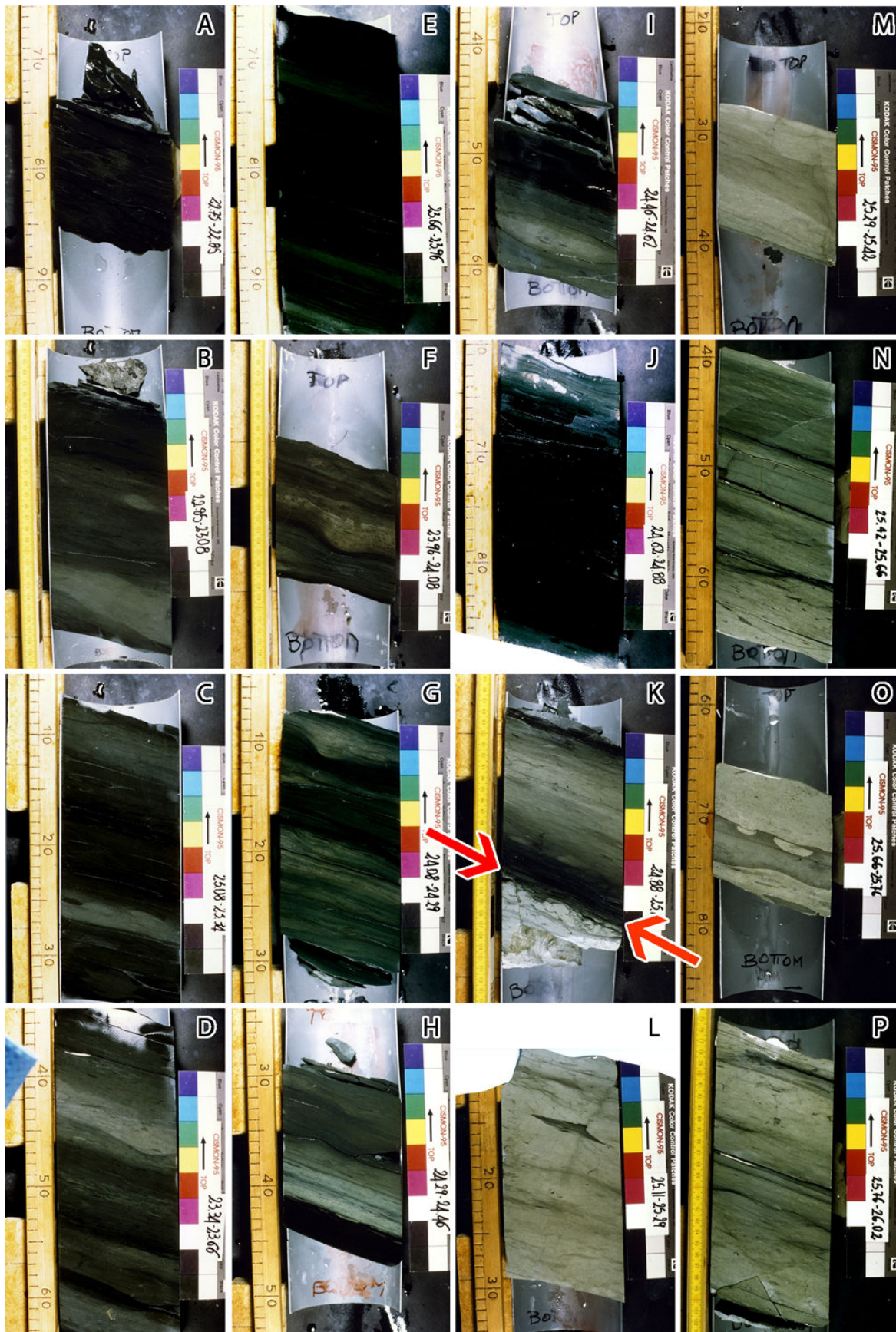


Figure 10: Core photographs from the AptiCore drilling at Cismon (excerpts from https://mlp.ideo.columbia.edu/data/cismon/core_photos/). ERBA's and LARSON's 4/5 unit boundary (*i.e.*, MENEGATTI's C2-C3 segment boundary) is arrowed in red on K. A-F: core 14 pars, A) 22.75-22.85 m; B) 22.85-23.08 m; C) 23.08-23.34 m; D) 23.34-23.66 m; E) 23.66-23.96 m; F) 23.96-24.08. G-P: core 15 pars, G) 24.08-24.29 m; H) 24.29-24.46 m; I) 24.46-24.62 m; J) 24.62-24.88 m; K) 24.88-25.11 m; L) 25.11-25.29 m; M) 25.29-25.42; N) 25.42-25.66 m; O) 25.66-25.76 m; P) 25.76-26.02 m.



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