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Lower Cretaceous stage durations combining radiometric data and orbital chronology: Towards a more stable relative time scale?

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Abstract

We propose an alternative calibration of Lower Cretaceous stage durations constrained by direct absolute dating of each stage combined with orbital chronology. Ten glauconitic horizons sampled in the Vocontian basin (SE, France) from the base of the Lower Hauterivian to Upper Albian, yielded K–Ar ages from 123.3 ± 1.7 Ma to 96.9 ± 1.4 Ma, respectively. The relative duration of each stage has been derived by cyclostratigraphy previously obtained in the south-east France and central and south Italy basins. Using the GL-O standard from the Albian–Cenomanian boundary at 95.3 Ma as the anchor point, a cyclostratigraphic age for each stage boundaries has been extrapolated and thus compared with the K–Ar ages. This shows a very well-defined linear correlation which demonstrates the robustness of the proposed durations of the Lower Cretaceous stages. The estimated durations are 5.3 ± 0.4 my, 5.1 ± 0.3 my, 6.8 ± 0.4 my and 11.6 ± 0.2 my for the Hauterivian, Barremian, Aptian and Albian stages, respectively. It also shows that glauconite minerals are powerful radiochronometric tools, when precisely stratigraphically defined and carefully selected. Moreover, the large discrepancy of the estimated Aptian duration of more than 6 my between the most recent published time scale and this study highlights the problem of the radiometric calibration of the M-0 magnetic chron. Finally, the stage durations and boundary ages proposed here bring strong constraints towards the calibration of the Lower Cretaceous time scale. Such accurate temporal calibration is required before any relationship between major biological crises and magmatic emplacement, for instance, could be further investigated.

Keywords: Lower Cretaceous; K–Ar; Geochronology; Cyclostratigraphy; Glaucony; Geologic time scale

1. Introduction

The Lower Cretaceous, considered as the period of the warmest climate of the Phanerozoic, undergoes several major crises, such as strong perturbations of the carbon cycle, important accumulation of organic matter, the so-called oceanic anoxic events (OAE), plankton crises in the oceans, and emplacement of large igneous provinces.

The accurate temporal calibration of this period is of major relevance to investigate a possible link between these events. Unfortunately, large discrepancies in both absolute ages and relative duration of stages are observed between proposed time scales. This is likely due to: 1) the very low number of radiometric ages available,

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2) the important variation in the nature and the precision of the stratigraphical support related to each radiometric data, 3) the selection of data and the choice of the anchor points used for the time scale calibration and, 4) the use of fundamentally different approaches, including graphical extrapolation between radiometric points in the Hawaiian seafloor spreading magnetic profile [1], maximum likelihood estimation applied to a radiometric database of high temperature minerals (K-feldspar or biotite) [2,3], and selected radiometric data for both low temperature (glauconite mineral) and high temperature minerals (K-feldspars and biotites) [4,5].

Each of these approaches has limitations, which result on large absolute and/or relative uncertainties for calibration of the Lower Cretaceous Time Scale (LCTS). The Barremian–Aptian boundary (base of the M–0 chron), for example, ranges between 113 Ma [5] and 125 Ma [2], and the duration of the Aptian between 5 and 13 Ma. Clearly, the determination of a precise and more robust chronology at the scale of the sub-stage is necessary to demonstrate any synchronicity, relationships, or interactions between the different geological events of the Lower Cretaceous. Our integrated approach is based on the combination of radiochronological dating of condensed sedimentary horizons, which provides an absolute time frame of each stage, with cyclostratigraphy (Milankovitch cyclicities) performed on continuous sedimentary basin successions and providing a relative measure of time. Here, we determined the duration of the stages and related substages of the Hauterivian–Albian interval from the Tethyan pelagic sedimentary successions using K–Ar analyses on glauconite minerals from the Vocontian basin (SE of France), combined with cyclostratigraphic data supported by a well-constrained biostratigraphic framework (ammonite zones or sub-zones) from both the Umbria–Marche (central Italy) and the Vocontian basins.

2. Geological setting and sampling of glauconitic horizons

The Vocontian basin has been investigated in detail for stratigraphy and sedimentology [6,7], and represents a stratigraphic key area relative to the location of international reference sections for the Lower Cretaceous (Fig. 1). Glauconite minerals have been collected throughout this interval in condensed sedimentary deposits, which are stratigraphically well-constrained by ammonite fauna (Table 1). Except two of them (for which precise stratigraphic positions were available, see Table 1), most of them are located at the base of biozones. The ten selected glauconitic-rich horizons follow rigorous criteria for K–Ar dating (e.g. [8]). The sections are located far from thrust belts or main faults zones. Burial depth did not exceed 1600 m [6,9]. The sedimentary deposits are not affected by pedogenetic alteration and are constituted of moderately welded marls and, in one case, of stylolite-free limestones, which argues for the lack of diagenetic effects on the glauconite minerals. These clay minerals are authigenic to rarely perigenic (no apparent reworking). The grains have been selected by hand picking following washing, sieving, magnetic separation, and ultrasonic treatment with 10% acetic acid. X-ray diffractometry shows well-crystallized closed minerals in the analyzed size fraction (125–300 μm). The selected glauconitic minerals are evolved to highly evolved (K values between 5.4% and 6.9%). Moreover this selection rules out the possible contribution of the inherited substratum of glauconitization, which could yield significant excess radiogenic argon (e.g. [10]).

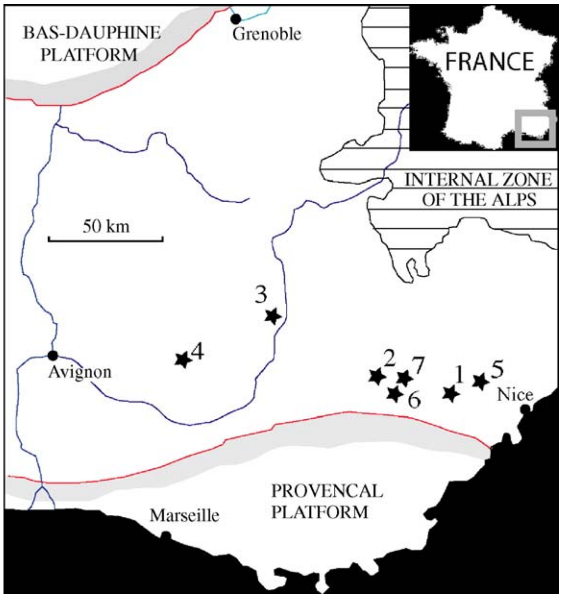

Fig. 1. Location map of sampled sections (Lambert coordinates). 1: Escragnolles (955.5–3169.95); 2: La Palud (924.2–3172.75); 3: Jas de Coeur (889.48–3206.28); 4: Gargas (843.35–3181.85); 5: Les Ferres (982.60–3182.50); 6: Rougon (925.8–3174.3); 7: La Colle (934.1–3179.1). Insert: Location of area in France.

3. K–Ar radiometric dating of glauconite minerals

Table 1 lists the K–Ar ages obtained using the Cassignol–Gillot technique [11]. They have been duplicated in most cases to better than 0.2%, which attests to the homogeneity of the glauconite minerals separation. Note that all uncertainties mentioned in this paper are given at the 1σ level.