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# The Kalaat Senan section in central Tunisia: A potential reference section for the Danian/Selandian boundary

ETIENNE STEURBAUT, CHRISTIAN DUPUIS, IGNACIO ARENILLAS, EUSTOQUIO MOLINA, and M. FAOUZI MATMATI

During most of the early and middle Paleocene, from c. 63 to 60 Ma, sedimentation conditions remained fairly uniform at Kalaat Senan, located within the proximal part of the Tunisian Trough, about 50 km south of the well-known El Kef section (Fig. 1). The area was marked by a marly deposition regime (average carbonate content around 35%), with high sedimentation rates (average 6 cm/k.y.), normal carbon contents (TOC fluctuating between 0.5 and 1.5%) and abundant planktonic activity. These marls, informally known as the Aïn Settara marls, form part of the El Haria Formation (Burollet 1956) (Fig. 2). They are characterised by a high content of smectite (between 80 and 98% of the total clay fraction) and variable quantities of kaolinite (up to 15%). This uniform marly sedimentation pattern lasted for about 3 m.y. at Kalaat Senan (from about 95 m to 285 m above the K/T boundary). It was only interrupted during a short period, as evidenced by the presence of complex channel systems abruptly occurring at Sidi Nasseur (NSF section) at approximately 250 m above the K/T boundary (Fig. 2).

Two conspicuous thin glauconite concentrations, representing the earliest authigenic glauconite occurrence in the Paleocene of the Kalaat Senan area, occur at respectively 5.3 and 4.3 m below the 1 m thick glauconitic marker bed. The presence of glauconite, of submarine erosion channels, and the strongly fluctuating quantities of kaolinite (from 0 to 4% in the glauconitic interval to 8–15% immediately above and below) is interpreted as a major basinward shift of the depocentre. The 3 m thick marly package below the base of the lowermost and most prominent channel, including the two thin glauconite beds, presents high carbonate contents (>50%, up to 84%) (Fig. 2). It is believed to represent the late highstand of the third order depositional sequence Da 4 (Neal & Hardenbol 1998, p. 88, fig. 1). The erosional surface marking the base of the lowermost channel is interpreted as the sequence boundary Da 4/Sel 1, because it coincides or is very close to the planktonic foraminiferal zonal boundary P2/P3a, whereas the closest underlying sequence boundary Da 3/Da 4 is much older (within P1c). The base of the 1 m thick glauconitic marker bed, 2 m higher up, represents the transgressive surface of the overlying sequence Sel 1. The less carbonate rich marls (from 14 to 47%) between both surfaces, which show successive lateral channelling, might represent the lowstand systems tract of sequence Sel 1. The main glauconitic bed is overlain by dark brown marls, including several thin indurated beds. These marls present small fluctuations in carbonate content. At about 17 and 26 m above the main glauconite occur thin discrete fossiliferous horizons, consisting of large foraminifera (*Frondicularia* and *Nodosaria*) and bivalves, which indicate episodes of slowdown in sedimentation. Ten m higher up, the carbonate content is strongly decreasing and macrofossils become less frequent probably due to increasing sedimentation rates and to a deepening of the palaeoenvironment.

The c. 6 m thick, glauconitic, shallow marine package across the sequence boundary Da 4/Sel 1 entirely falls within calcareous nannofossil zone NP 4. The first *Ellipsolithus macellus*, marking the NP3/NP4 zonal boundary, were found at c. 40 m below the first entry of glauconite and the first *Fasciculithus billii* and *F. pileatus*, known to appear slightly below the base of NP 5, occur c. 30 m above the uppermost glauconite concentration (Fig. 2). A more refined biostratigraphic positioning of this level can be achieved using Varol's (1989) calcareous nannofossil zonation. The main glauconite bed and the 6 m thick overlying clayey marls, which are characterised by the presence of *Chiasmolithus edentulus* and *Fasciculithus chowii* and by the absence of *Sphenolithus primus*, belong to Varol's *Chiasmolithus edentulus* Subzone, labelled NTp7B. The 7.5 m thick underlying marls, including the two thin glauconite horizons fall within Varol's *Ellipsolithus distichus* Subzone, labelled NTp7A. The boundary between zones NTp6 and NTp7, which is marked by the last occurrence of *Neochiastozygus eosaepes*, lies at about 7.5 m below the base of the main glauconite. Zone NTp7 correlates with the middle part of Martini's (1971) NP4. The glauco-

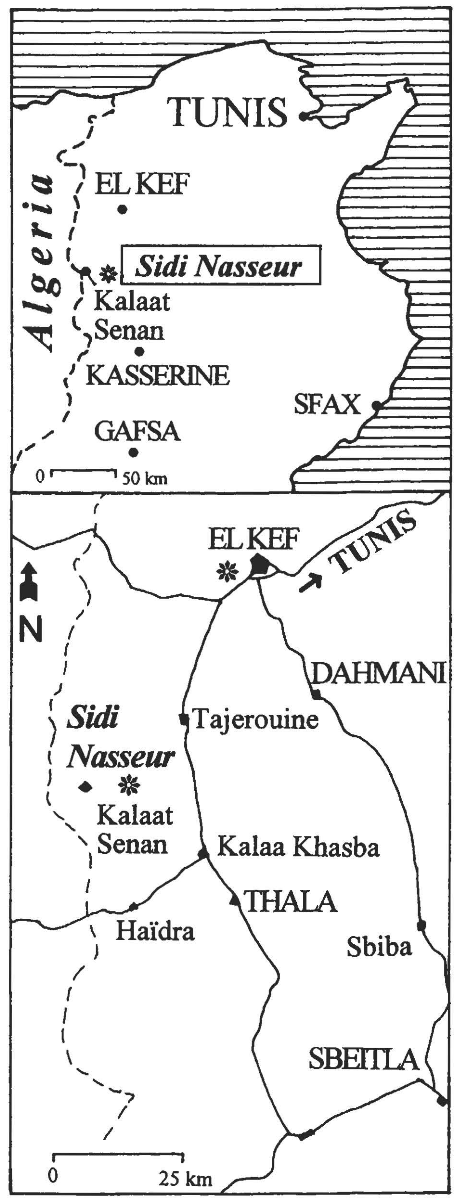

*Fig. 1.* General map of northern Tunisia and (below) close up of the area around the Kalaat Senan section at Sidi Nasseur.

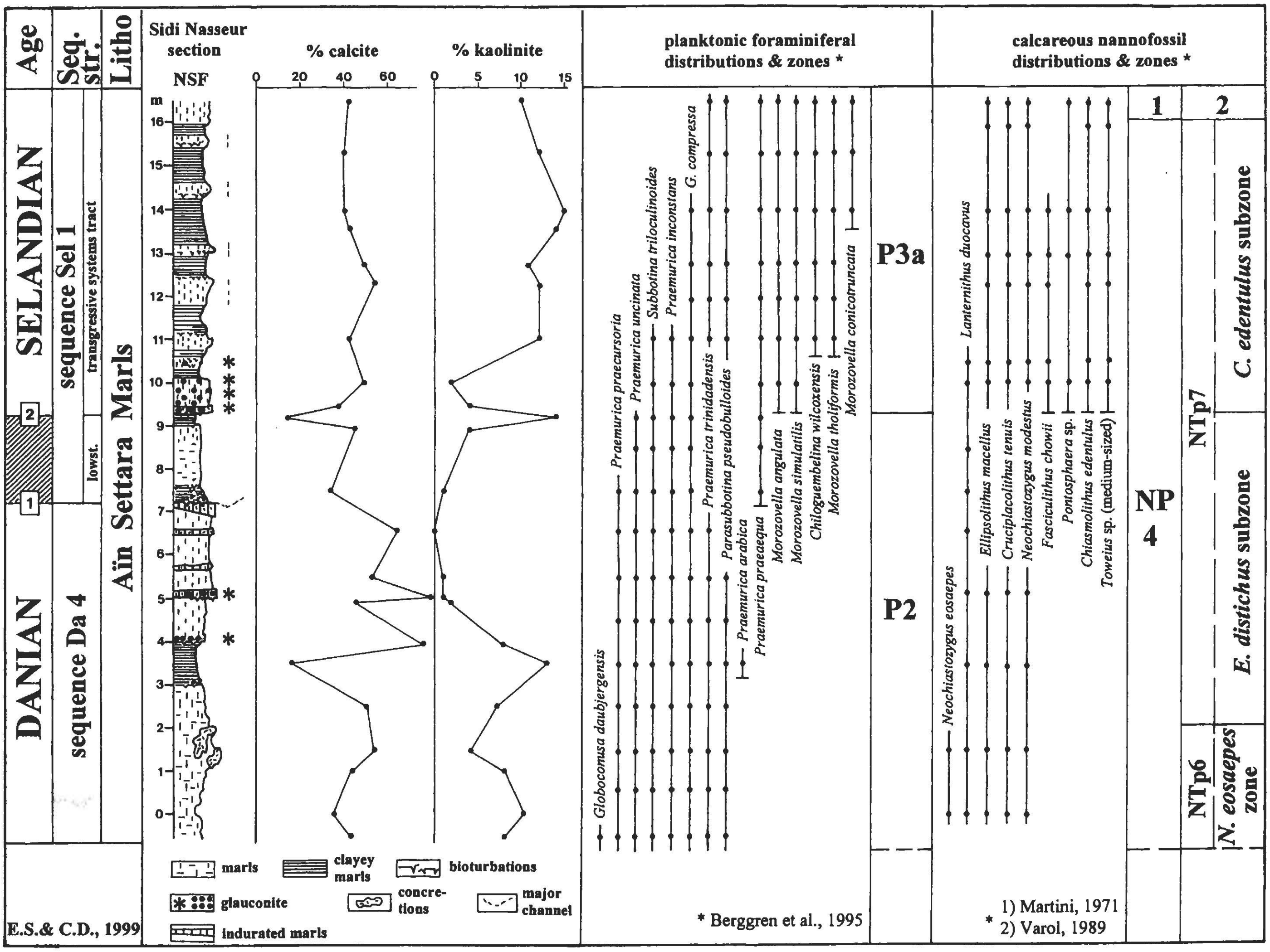


*Fig. 2.* The Danian/Selandian boundary in the Kalaat Senan section at Sidi Nasseur (central Tunisia).

nitic interval of the Kalaat Senan section can also be precisely calibrated with the standard planktonic foraminiferal zonation of Berggren et al. (1995). The lowest occurrence of *Morozovella angulata*, defining the P2/P3a zonal boundary, lies within the glauconitic marker bed, less than 0.5 m above its base (sample NSF10). Additional biostratigraphical useful foraminiferal events across this glauconitic interval are: the first occurrence (FO) of *Praemurica uncinata*, encountered at about 67 m below the first *M. angulata*, the FO of *M. crosswickensis* and the FO of *Igorina albeari* at respectively 26 and 80 m above this *M. angulata* event.

A similar sequence of bioevents has been recognised by Schmitz et al. (1998) in the Zumaya section in N. Spain. However, the stratigraphic significance given to these events by these authors differs from the interpretations presented here. The base of the red marl at about 56.6 m above the K/T boundary in the Zymaya section was proposed by Schmitz et al. (1998) as a suitable candidate for the definition of the Danian/Selandian boundary, because it is very close or coincides with major changes in planktonic foraminifera (FO of *M. crosswickensis* and the FO of *Chiloguembelina crinita*; disappearence of four taxa), with the FO of *Neochiastozygus perfectus* and with a major lithofacies change, believed to represent a sequence boundary. Reassessment of all these data suggests that these abrupt changes are due to a substantial landward shift of the depocentre (from platform to outer shelf or even deeper), as witnessed by the end of the acme of *Braarudospaera bigelowii*, and are not due to a major sea-level fall. This agrees well with the observations of Pujalte et al. (1998, table 2 and fig. 9), who demonstrated that the most prominent sea-level fall in N. Spain (= base of 3rd order sequence DS-P2; point 11 in table 2 of Pujalte et al.), occurred earlier, at c. 10 m below the base of the red marl (point 13), which according to Schmitz et al. (1998, p. 40) is very close to the FO of *M. angulata*. The FO of *N. perfectus*, *M. crosswickensis*, and *C. crinita* have also been identified at Sidi Nasseur just above the thin shell bed at about 26 m above the base of the glauconitic marked bed.

Comparison with NW Europe, where most of the internationally accepted Paleogene standard stages have been defined (see Steurbaut 1998 for a historical and stratigraphic evaluation of these stages), suggests that the abrupt shift in lithofacies and the start of the submarine channel development in the Kalaat Senan section is related to the globally well-known major sea-level fall at the Danian/Selandian boundary (Haq et al. 1988; Neal & Hardenbol 1998; Michelsen et al. 1998, fig. 23). The major hiatus identified just below the first occurrence of *Chiasmolithus edentulus* in many wells in the Central North Sea (e.g. well T-1X at 7347 feet and well E-1X at 6780 feet, see Van Heck & Prins 1987) is believed to represent sequence boundary Da 4/Sel 1 or Da 3/Sel 1, as Da 4 might be missing. The first appearance of *M. angulata* seems also to be linked with a major discontinuity, probably Da 4/Sel 1, in the El Kef section (Brinkhuis et al. 1994).

The data from Tunisia, Spain, and the Central North Sea are not entirely compatible with the observations in the Harre and Store Bælt boreholes on the Danish onshore, where the main unconformity and sequence boundary, representing the Danian/Selandian boundary, is posterior to the first occurrence of *C. edentulus* and *N. perfectus* (Thomsen & Heilmann-Clausen 1985; Thomsen 1994). The significance and causes for these discrepancies are not fully understood. However, the present study has demonstrated that sedimentation was very expanded, almost uninterrupted and carbonate-rich in the Kalaat Senan area, in contradiction to the European basins which emerged at the Danian/Selandian boundary (Berggren 1994; Knox 1996; Steurbaut 1998; Vandenberghe et al. 1998). This offers a wide range of perspectives, such as a very precise dating through planktonic microfossils, interpretable palaeomagnetic data and useful stable isotope and trace element signals. As it is furthermore well-exposed and readily accessible the Kalaat Senan section might fulfil all the recommendations for the establishment of a GSSP for the Danian/Selandian boundary. The three recommended options for this GSSP, appearing from this study, are: (1) the base of the thick major glauconitic bed (point 2 in Fig. 2), (2) the base of the main channel, 2 m below (point 1), and (3) the thin fossil bed 26 m higher up. The first proposition corresponds to a transgressive surface and coincides with the first appearances of *M. angulata*, *M. simulatilis*, *C. edentulus*, *F. chowii*, and the first *Pontosphaera*, the second represents a third order sequence boundary, resulting from a major sea-level fall, whereas the third, placed at the FO of *M. crosswickensis* and the FO of *N. perfectus*, represents a slowdown in sedimentation, which, in terms of depositional dynamics, is less important.

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*E. Steurbaut, Royal Belgian Institute of Natural Sciences, 29 Vautierstraat, BE-1000 Brussels & Katholieke Universiteit Leuven, Belgium, fax 0032-2-6274174, steurbau@kbinirsnb.be*

*C. Dupuis, Faculté Polytechnique de Mons, 9 rue de Houdain, BE-7000 Mons, Belgium, fax 0032-65-374610, christian.dupuis @fpms.ac.be*

*I. Arenillas and E. Molina (emolina@posta.unizar.es), Departamento de Ciencias de la Tierra (Paleontología), Universidad de Zaragoza, ES-50009 Zaragoza, Spain, fax 0034-976761088*

*M.F. Matmati, Service Géologique de Tunisie, O.N.M., B.P. 215, 1800 Tunis Cédex, Tunisia, fax 02161-794016*