

**CYCLIC STRATIGRAPHY OF TWO INTERVALS AT THE BOUNDARIES OF
A 3RD ORDER SEQUENCE (LOWER CRETACEOUS, BERRIASIAN) IN THE
FRENCH JURA, FRANCE AND THE DORSET COAST, ENGLAND**

A Thesis
Submitted to
the Temple University Graduate Board

in Partial Fulfillment
of the Requirements for the Degree
MASTER OF SCIENCE

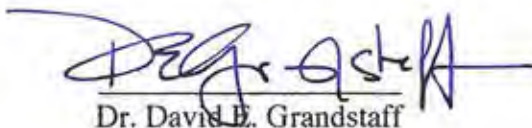
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ABSTRACT

Marked facies changes occur at and just above 3rd order boundaries in Lower Cretaceous carbonate platform deposits of the French Jura and the Dorset Coast. In contrast, the boundaries of cycles just below 3rd order boundaries show smaller facies changes and the facies are very restricted. Two studied intervals (lower and upper) in these carbonate platform deposits are near the lower and upper boundaries of a 3rd order sequence (Anderson, 2000; 2001a & b). These intervals are described in terms of facies and their cyclic stacking pattern and are correlated within each region. The studied intervals are well exposed at four localities in the French Jura: Salève, Chapeau de Gendarme, Crozet, and Yenne, and two on the Dorset coast: Durlston Bay and Stair Hole. Correlation involves using unconformities interpreted from sequence stratigraphy techniques, biostratigraphy from previous literature, distinct marker beds such as paleosols or freshwater beds, and the interpretation and matching of the hierarchic cyclic structure at each locality. The interpretation of sequences and the stacking pattern at each locality is based on the Milankovitch orbital forcing model. The degree of facies change within a sequence and at sequence boundaries is a function of the magnitude of the sea-level rise. Cycles and sequences usually are characterized by shallowing upward facies with more massive limestone, usually calcarenite, beds near the base and marl, shale, or paleosols toward the top. This pattern of facies change is seen throughout each locality and in cycles of every scale in the Milankovitch hierarchy. In each region cycles near the basin margin are missing or highly truncated, whereas in the most complete sections

(type sections) located more basinward a more complete Milankovitch stacking pattern is preserved. Paleosols tended to form near major cycle boundaries and as a consequences are associated with formational and member boundaries. Paleosols are classified using USDA (1998) and Mack et al. (1993) standards by examining macro- and microanalysis, molecular weathering ratios determined from ICP-MS data, and clay mineralogy from X-ray diffraction. Four paleosols were sampled. Two of these paleosols are from the study interval in the French Jura and two are sampled from the study interval in the Dorset coast. The analysis of the paleosols in England (samples D3-5 and D1-6) indicate moderate development and are classified as Inceptisols. Whereas the paleosols in the French Jura (samples R-2 and S-19) are poorly developed and are classified as Entisols.

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CHAPTER 1 INTRODUCTION

The cyclic structure of two stratigraphic intervals in carbonate platform deposits in the Lower Cretaceous (Berriasian Age), located in the French Jura and on the Dorset coast of England was studied (Figure 1). These sediments were deposited on the northern passive margin of the Tethys Ocean in different sub-basins (Figure 2). The purpose of this study is to describe the cyclic nature of the facies patterns at and near the boundaries of a 3rd order sequence, and also to describe four paleosols located within these study intervals. The interpreted cyclic structure is then used to correlate the studied sections within each basin (Paris sub-basin, the French Jura, and the Wessex sub-basin, England). The studied regions were chosen because they show excellent preservation of shallowing-upward sequences bounded by distinctive surfaces that are the result of relative sea-level rise events (Strasser, 1988; Allen and Wimbledon, 1991; Anderson, 2000). These carbonate deposits were also chosen because they represent depositional systems whose deposits were not interrupted or obscured by tectonic, volcanic, or geomorphic noise, but were sufficiently steady in facies accumulation to record cycles in the Croll-Milankovitch band (Strasser and Hilgärtner, 1998; Anderson 2000).

The biostratigraphic frameworks of both the French Jura and the Dorset coast indicate that the studied sections are Berriasian in age (Clements, 1993; Feist, 1995; Strasser and Hilgärtner, 1998). The biostratigraphic framework (gathered from previous literature) is mainly constructed from ammonite and foraminifera fauna of deeper water facies that are located more basinward than the carbonate platform deposits of the study intervals. The deposits on the carbonate platforms in both regions contain few of these

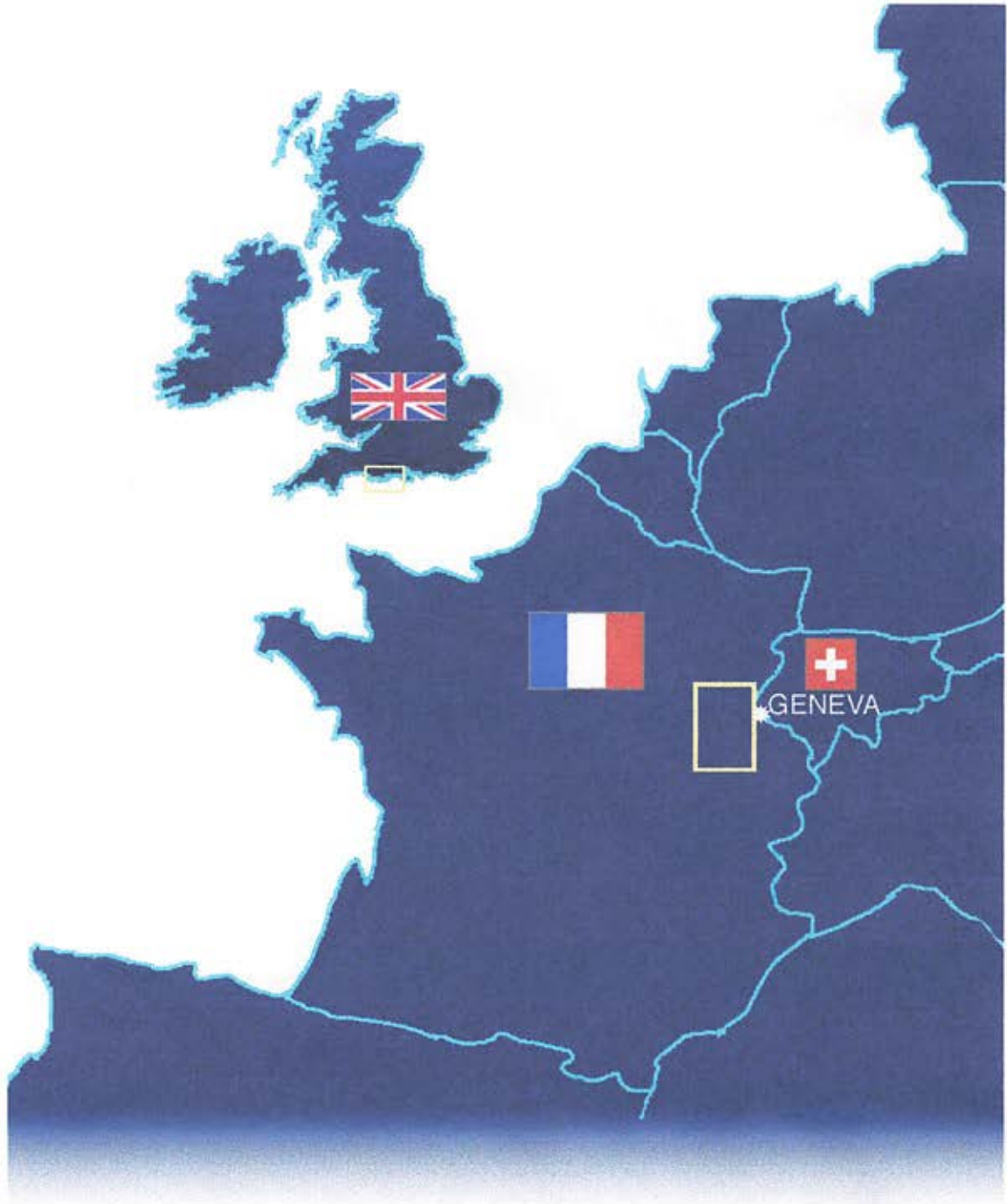


Figure 1. Locations of the two studied regions in England and France.

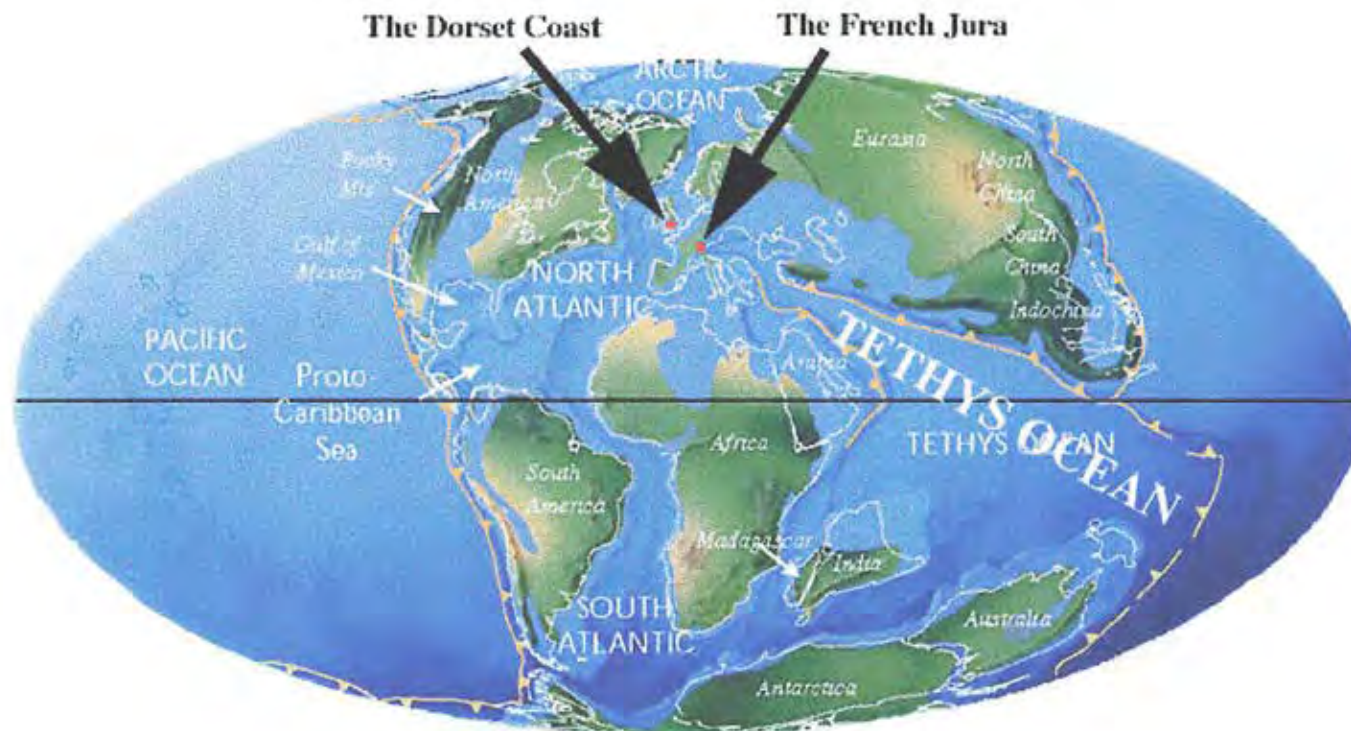


Figure 2. Paleogeographic reconstruction. Map showing the position of the French Jura and the Dorset Coast during the Early Cretaceous. .

key index fossils, and the biostratigraphy is poorly developed. The occurrence of abundant species in the more basinal localities establishes biozonation, and when certain marker species are found in the studied platform intervals, they act as biostratigraphic markers for correlation.

This study describes and interprets the cyclic structure of two stratigraphic intervals associated with the upper and lower boundaries of a 3rd order sequence in both the French Jura and the time equivalent sections on the Dorset coast (Anderson, 2000; 2001 a & b). The 3rd order sequence in the Jura extends from just below the Goldberg/Pierre Châtel Formation boundary to the upper part of the Vions Formation (Figure 3; Strasser and Hilgärtner, 1998). In Dorset, the same 3rd order sequence is comprised of the interval from the Marly Freshwater Member of the Lulworth Formation to the middle of the Chief Beef Member of the Durlston Formation (Figure 4; Clements, 1993). This 3rd order sequence (in both regions) is defined on the basis of facies asymmetry and in terms of cyclic structure. In both the French Jura and the Dorset coast, the 3rd order sequence contains portions of five 4th order sequences and a general facies pattern from more carbonate rich below to more shaley and argillaceous above. The definition of a 3rd order sequence applied in this study is a 2 million year set of five 4th order long eccentricity sequences (Goodwin and Anderson, 1997).

The definition of a 3rd order sequence in this study is distinctly different from that applied by the practitioners of sequence stratigraphy (Vail et al., 1977; Van Wagoner et al., 1988). They interpret most unconformities as 3rd order boundaries, whereas in this study such unconformities, recognized at surfaces characterized by erosion, reworked deposits, mudcracks, and palcosols are recognized as both 4th and 5th, as well as 3rd order

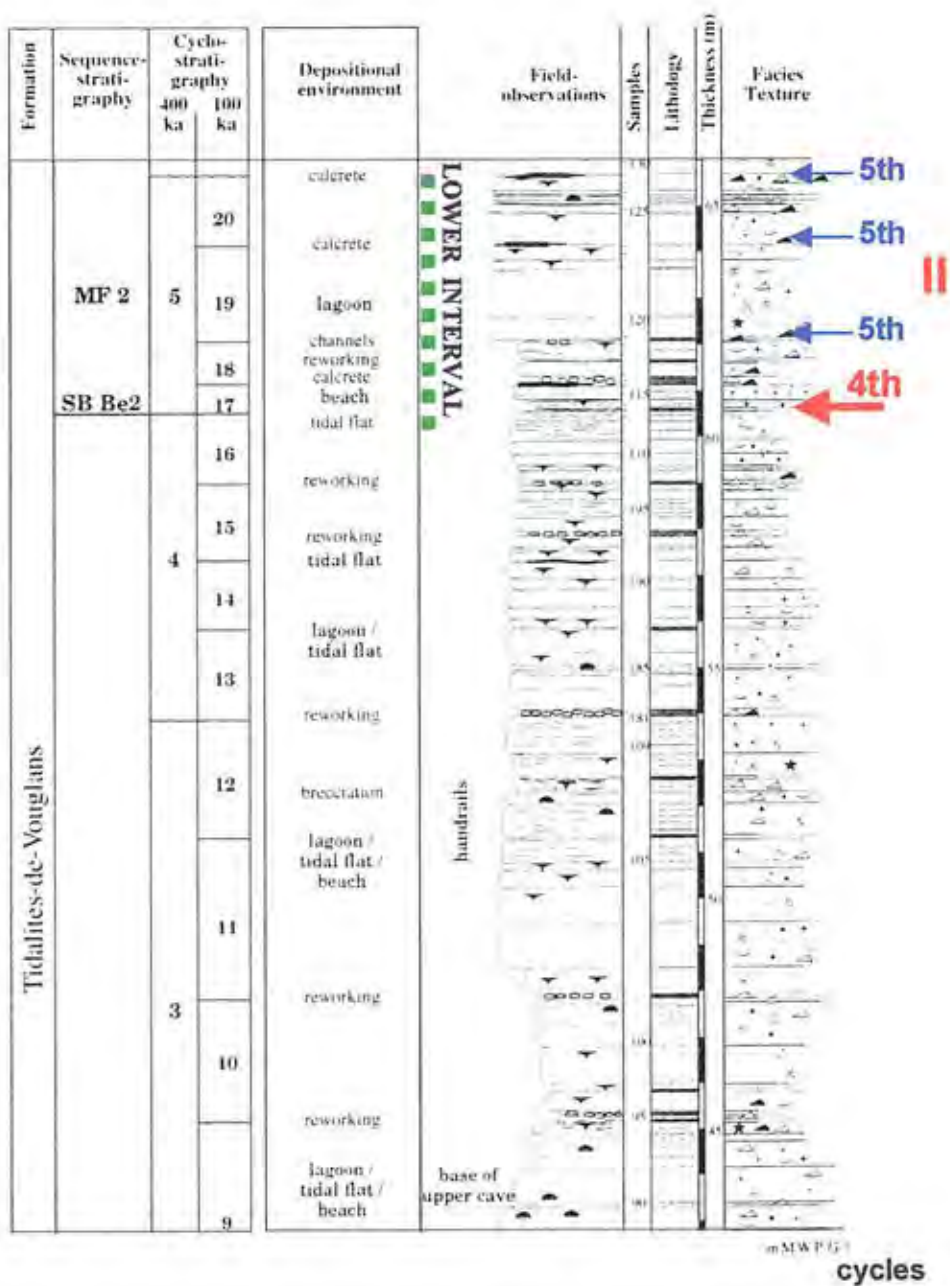


Figure 3. Stratigraphic columns from Strasser and Hillgartner (1998).

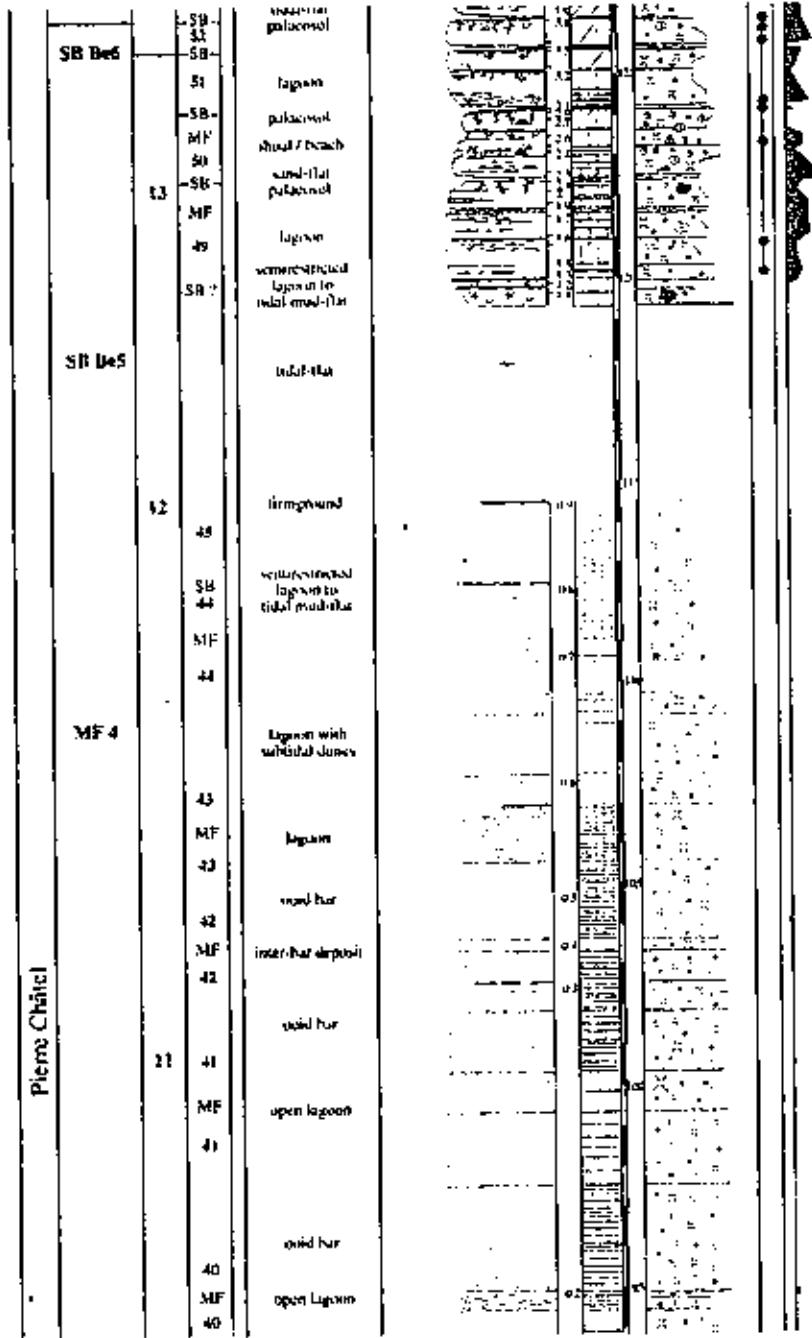


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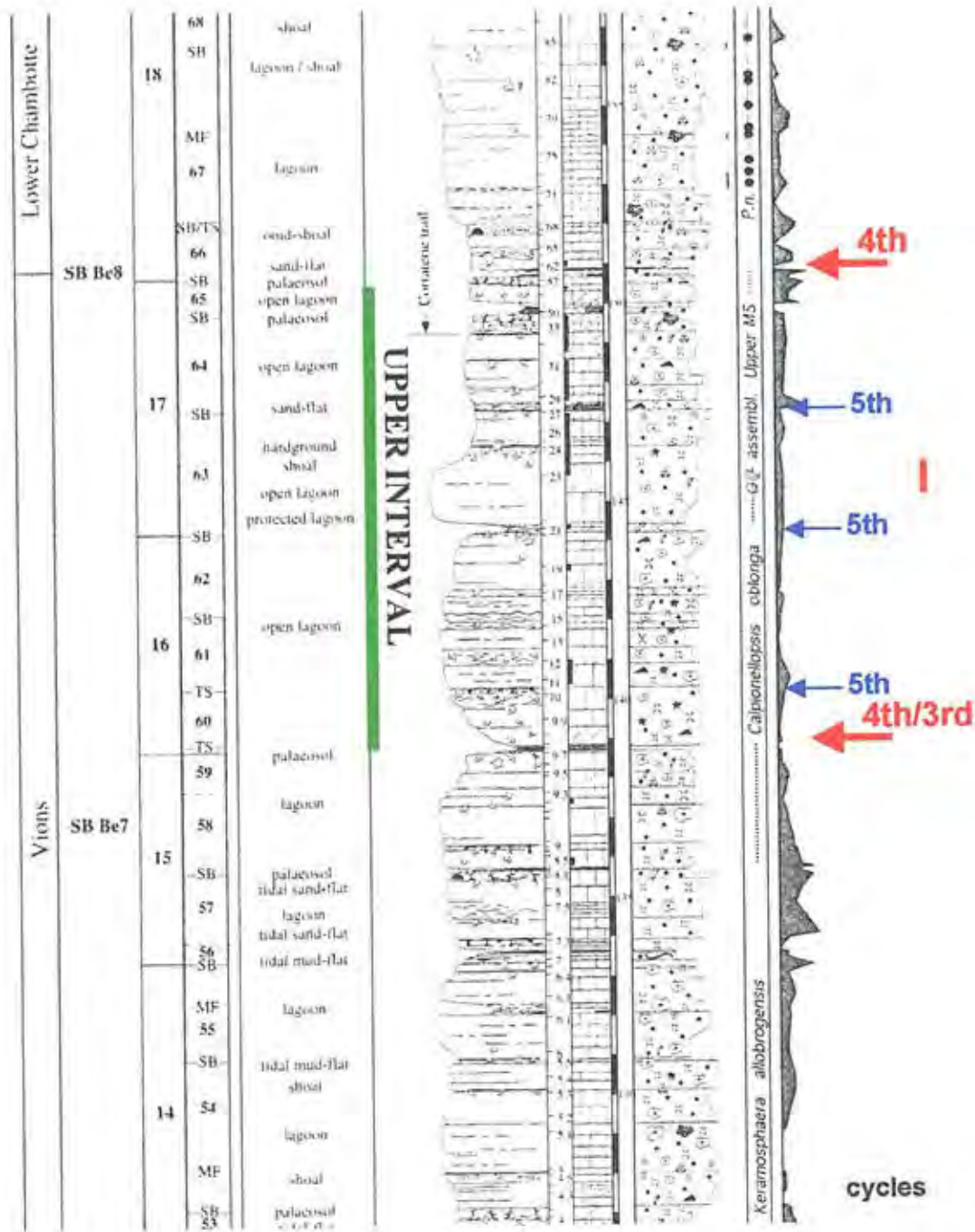


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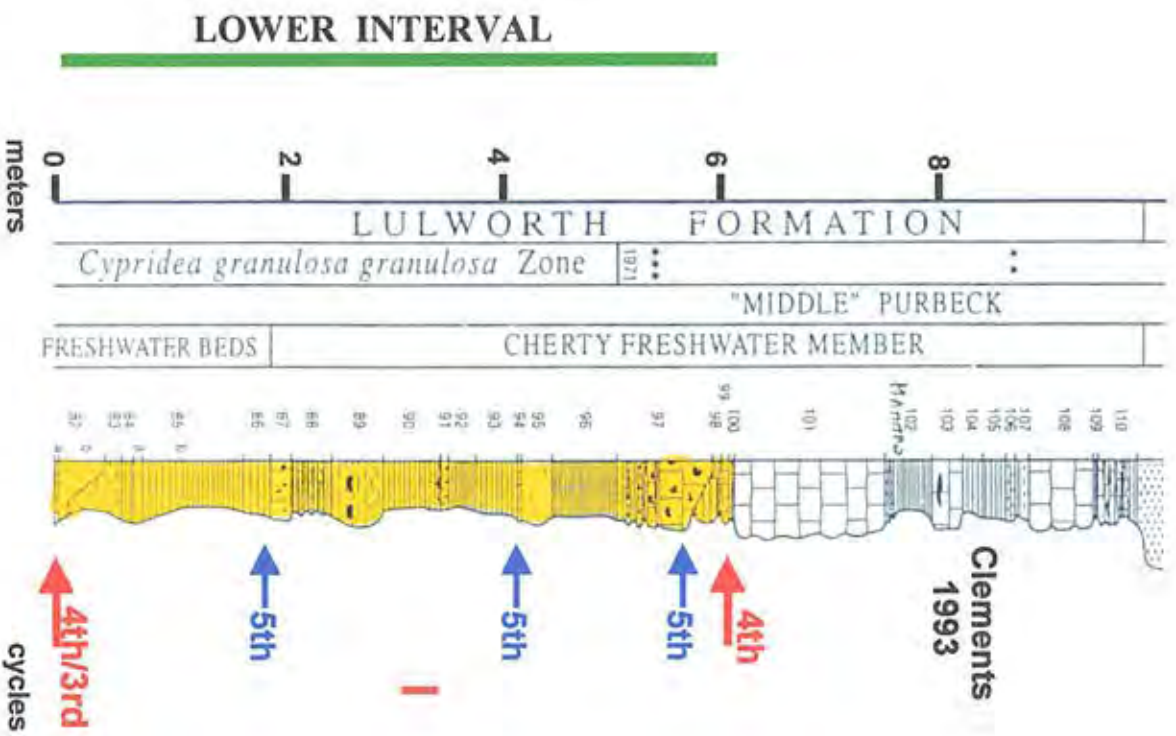


Figure 4. Stratigraphic columns from Clements (1993).

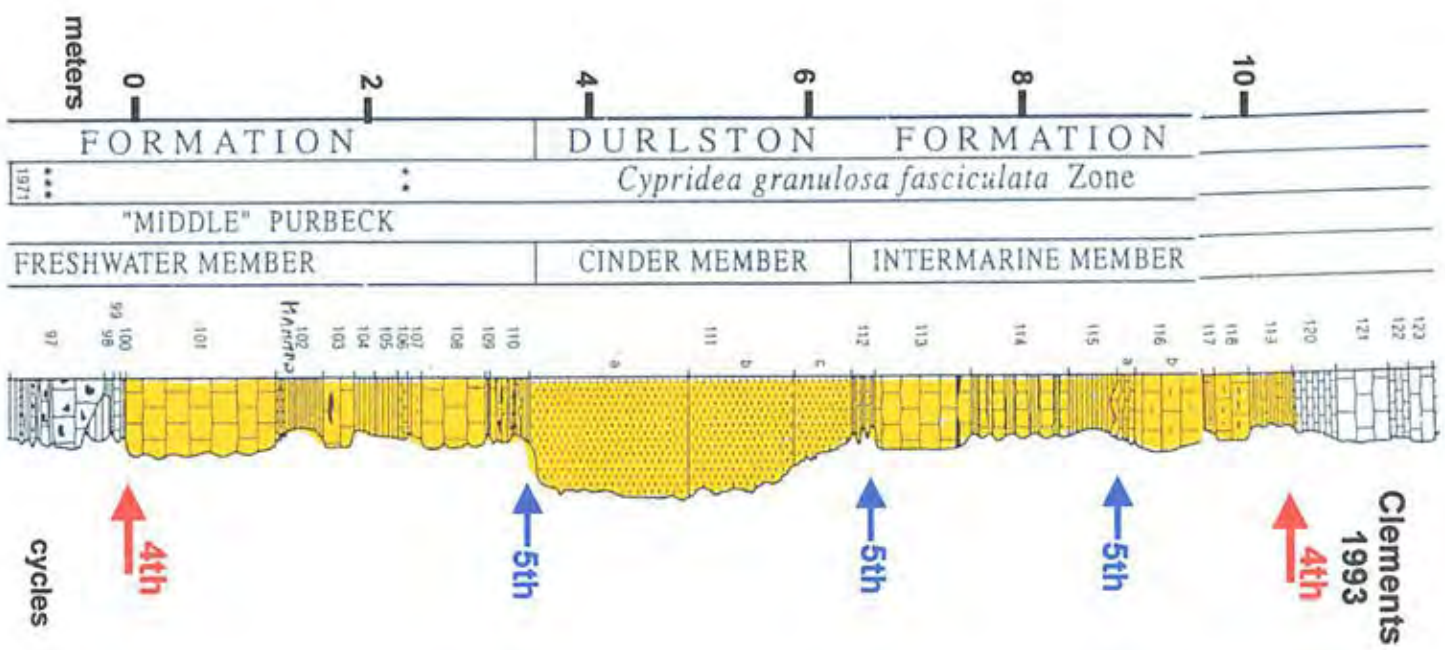


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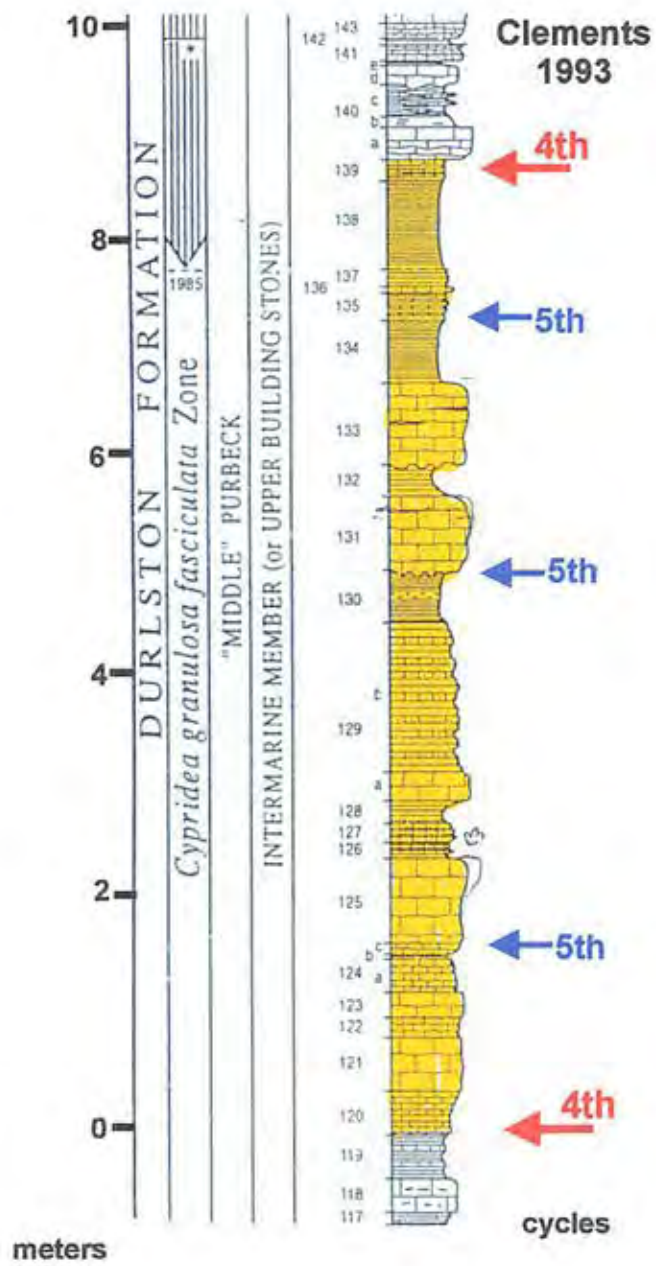


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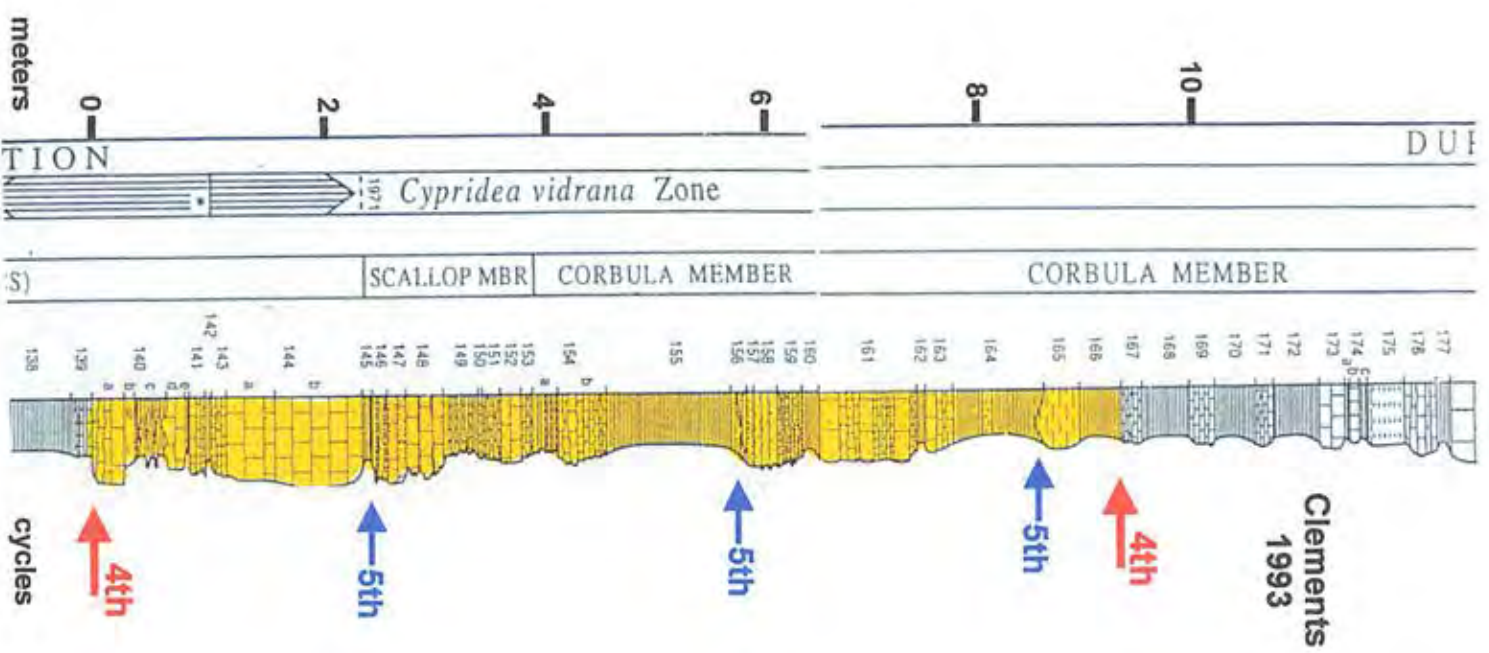


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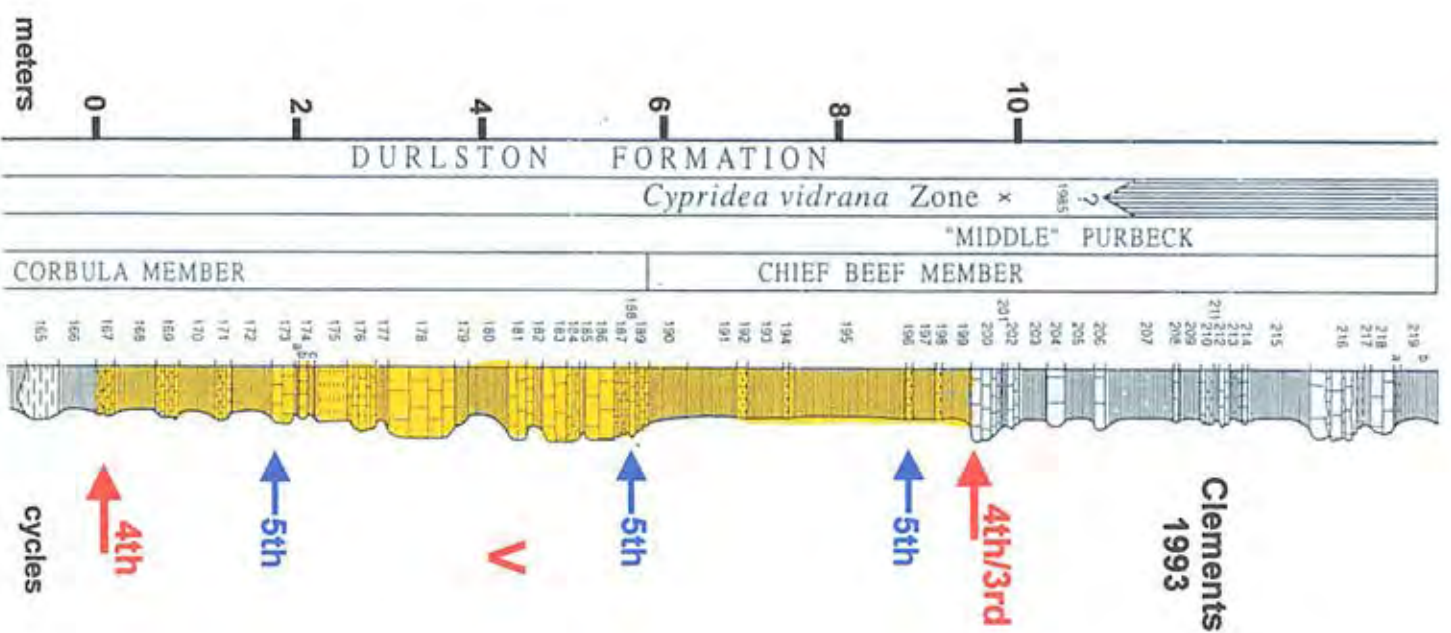


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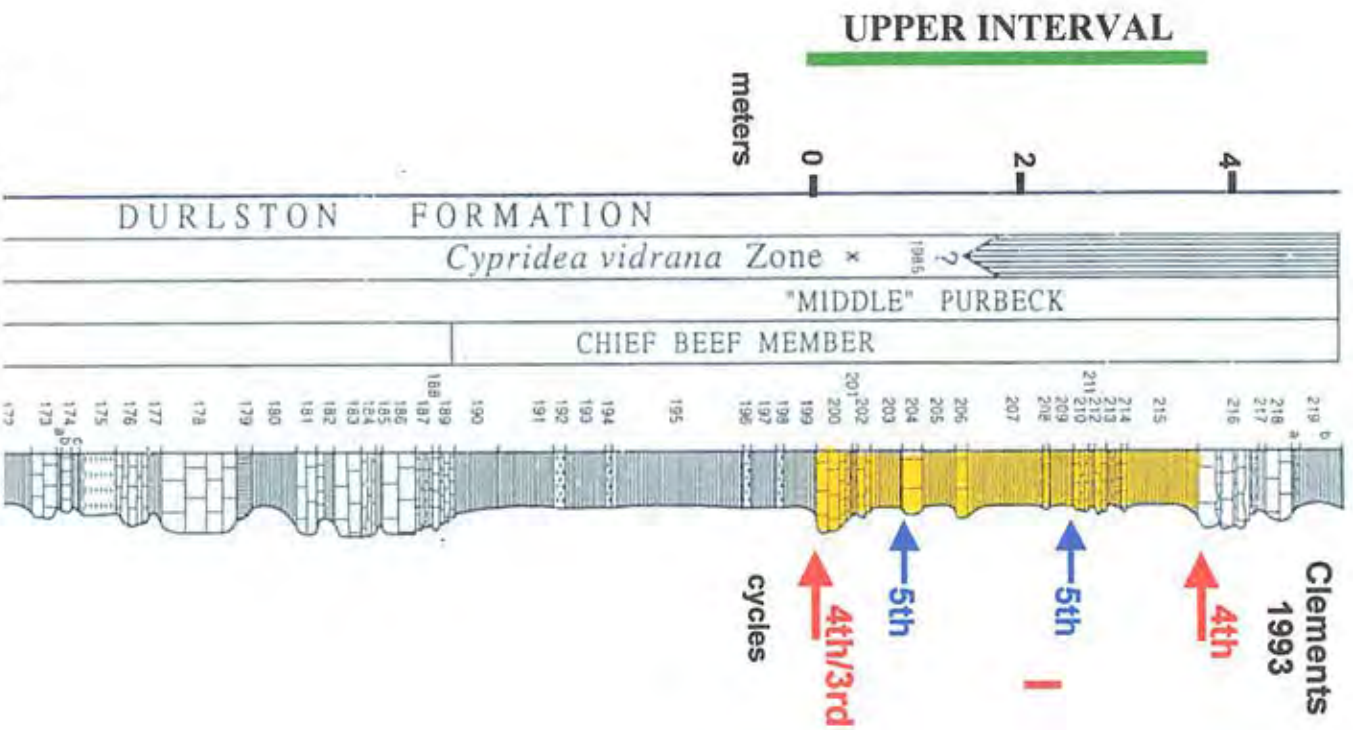


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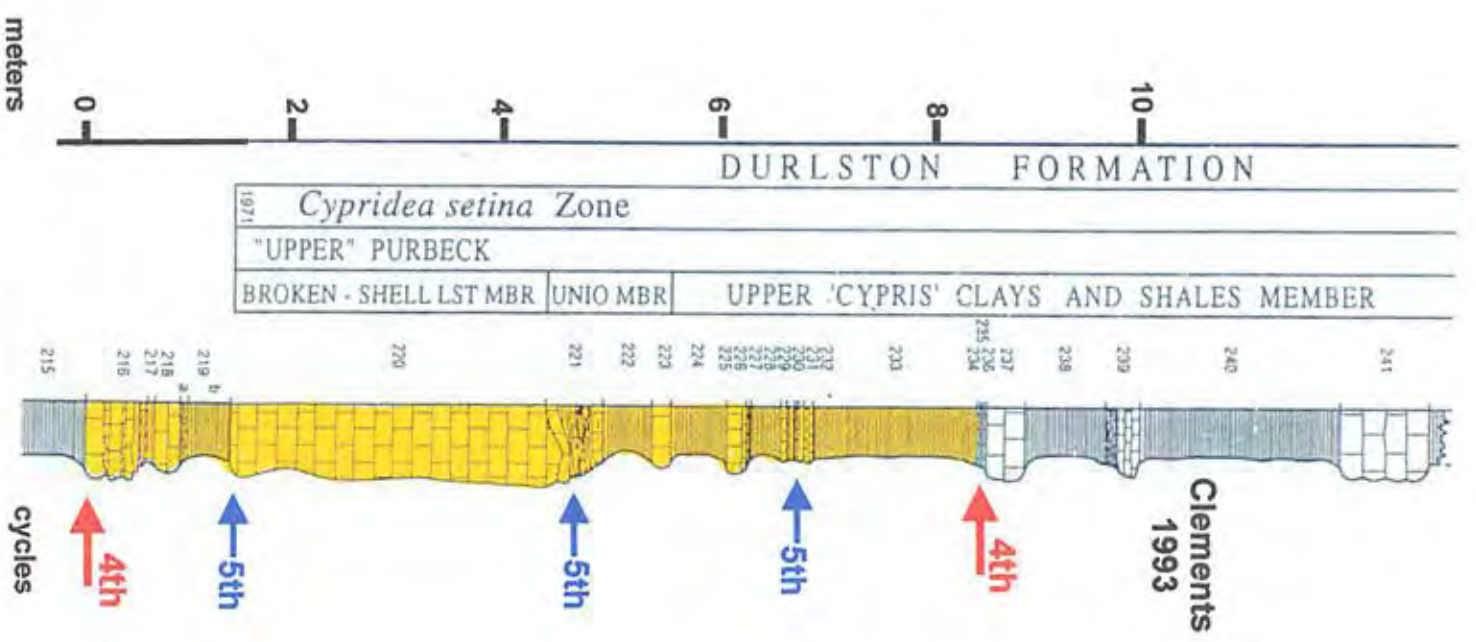


Figure 4. (continued).

boundaries based on recurring patterns of facies asymmetry. Figure 5 shows that the 3rd order sequence interpreted in this study is equal to the regressive part of a 2nd order sequence (i.e. R10) containing four 3rd order sequence boundaries (Be 4 to Be 7) boundaries as interpreted from seismic data (Jacquin et al., 1998). Jacquin et al. (1998) interprets the duration of this interval (see Figure 5) as 3 million years. These dates are estimated from absolute dates at the beginning and end of the Berriasian determined by Gradstein et al. (1994, 1995) that are 144.2 ± 2.2 and 137.0 ± 2.6 , respectively. There interpretation of R-10, the study interval, as a 2 million year long 3rd order sequence falls well within the absolute time limits estimated by Gradstein et al. in Figure 5.

The two study intervals are correlated throughout the French Jura and the Dorset coast using high-resolution cyclic stratigraphy. Small-scale correlations are based on examining the cyclic hierarchy down to the level of 20 ka cycles (6th order) or, according to Goodwin and Anderson (1985, 1986, 1997), the PAC level, and also to 100 ka (5th order) and 400 ka (4th order) bundles. The stacking pattern for a complete orbitally forced hierarchy can be seen in Figure 6. Sequence boundaries are synchronous and can be correlated over tens of kilometers. Mapping the hierarchy of 3rd, 4th, 5th, and 6th order sequences used in cyclic stratigraphy at each locality and correlation of this overall structure between closely spaced localities permits higher resolution than the usual levels used in sequence stratigraphy. Correlation from the Paris Sub-basin (France) to the Wessex basin (England) mainly relies on 3rd and 4th order sequences. These cycles can be used for accurate correlations and time-measurements within a basin and to other basins (Anderson, 2001 a,b,c,d; Cotillon, 1992).

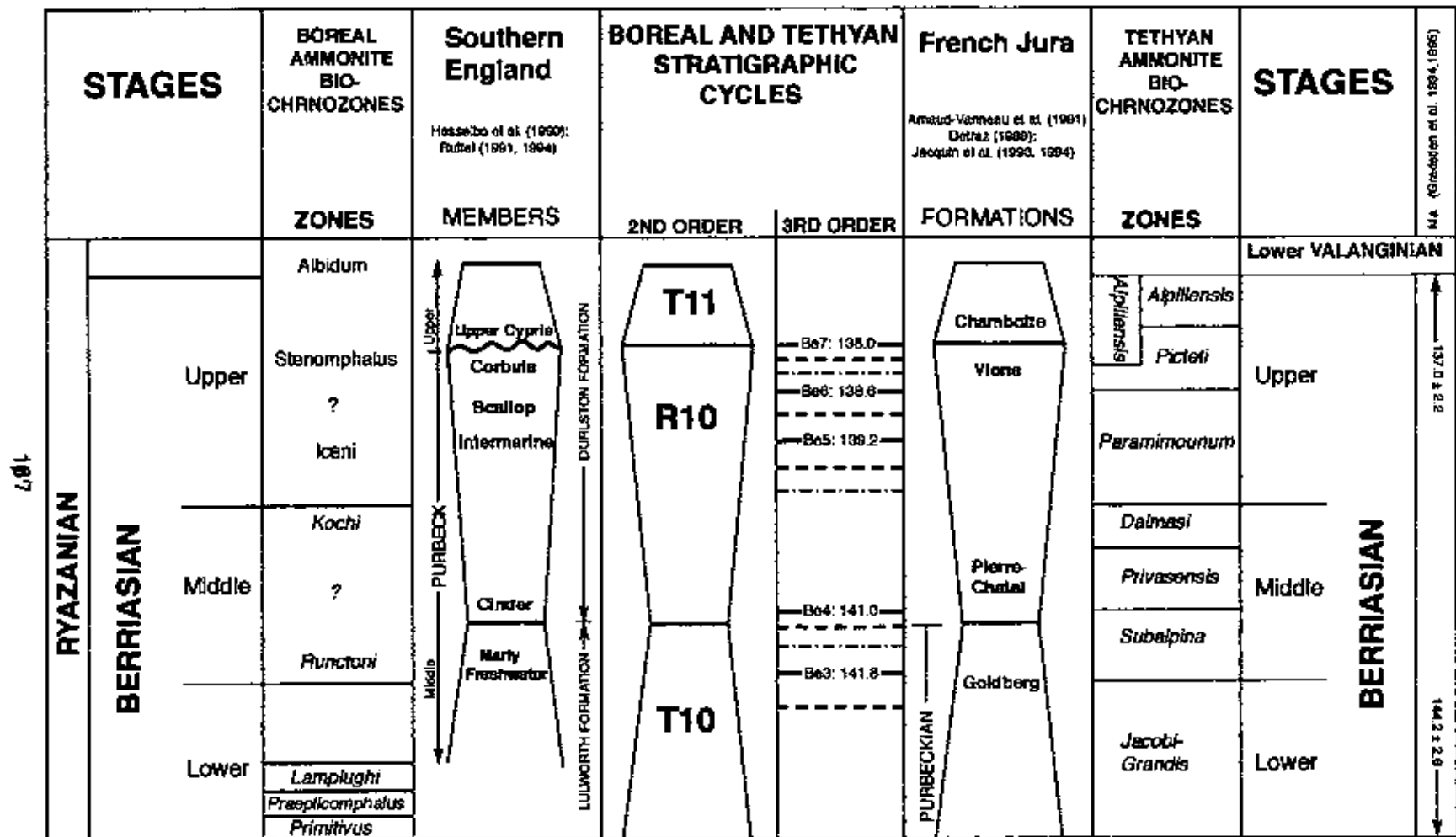


Figure 5. Correlation of 2nd order sequences and ammonite zones. Correlation from England to France during the Early Cretaceous (Berriasian age) after Jacquin et al. (1998)

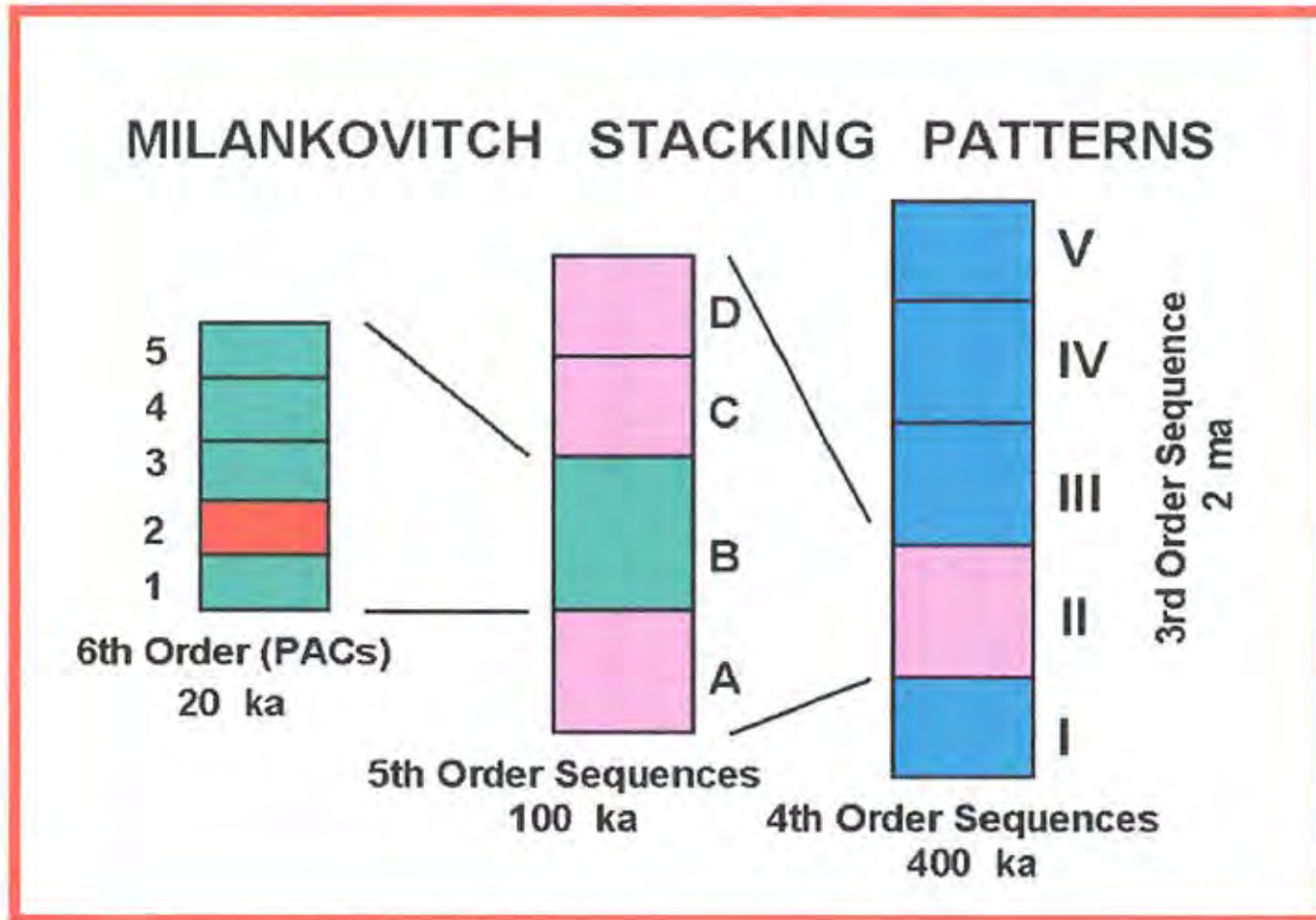


Figure 6. Milankovitch Stacking pattern (Anderson, 2000; 2001a, b, c & d).

The two stratigraphic intervals in the French Jura were measured at four localities and on the Dorset coast at three localities. They are described in terms of their distinctive cyclic structure and in reference to local formation and member boundaries. In the French Jura the upper and lower 3rd order boundaries were observed at the Salève, Yenne, Crozet, and Chapeau de Gendarme localities. The study intervals in France are located near the Goldberg/Pierre-Châtel formation boundary (lower interval) and the Vions/Chambotte formation boundary that is in the upper interval (Figure 7 & 8). The lower interval in France consists of four 4th order sequences directly below the 3rd order boundary (Sequences II, III, IV, and V). The upper interval consists of one 4th order sequence above the upper 3rd order boundary and is labeled 'Sequence I'. The localities on the Dorset coast are at Durleston Bay and Stair Hole. The lower interval in England is recognized in the upper part of the Lulworth Formation near the Marly Freshwater/Cherty Freshwater Member boundary (Figure 9). The upper interval is just below the Chief Beef/Broken Shell Limestone Member boundary in the Durleston Formation (Figure 10). In Dorset the studied lower and upper intervals both consist of one 4th order sequence located directly above the lower and upper 3rd order boundaries, respectively (both labeled as 'Sequence I'). In the French Jura the upper interval is the equivalent to that studied in England, but the lower interval is the 4th order sequence just below the lower 3rd order boundary.

This paper also describes the micro- and macrofacies that characterize sequences and facies changes at sequence boundaries at all levels of the orbitally forced cyclic hierarchy abbreviated in the study interval. At larger-scale sequence boundaries, such as

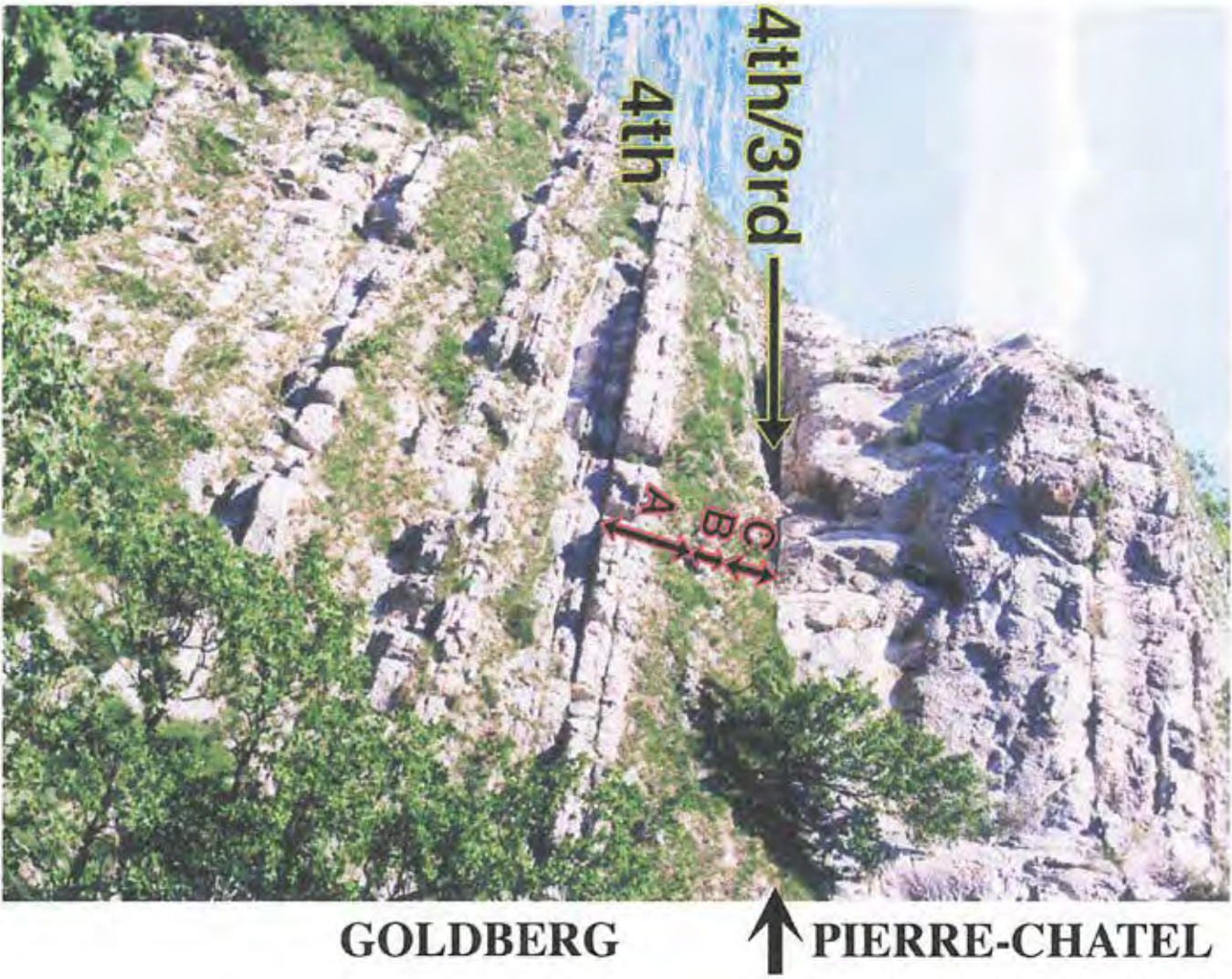


Figure 7. The lower interval at Saleve in the French Jura.

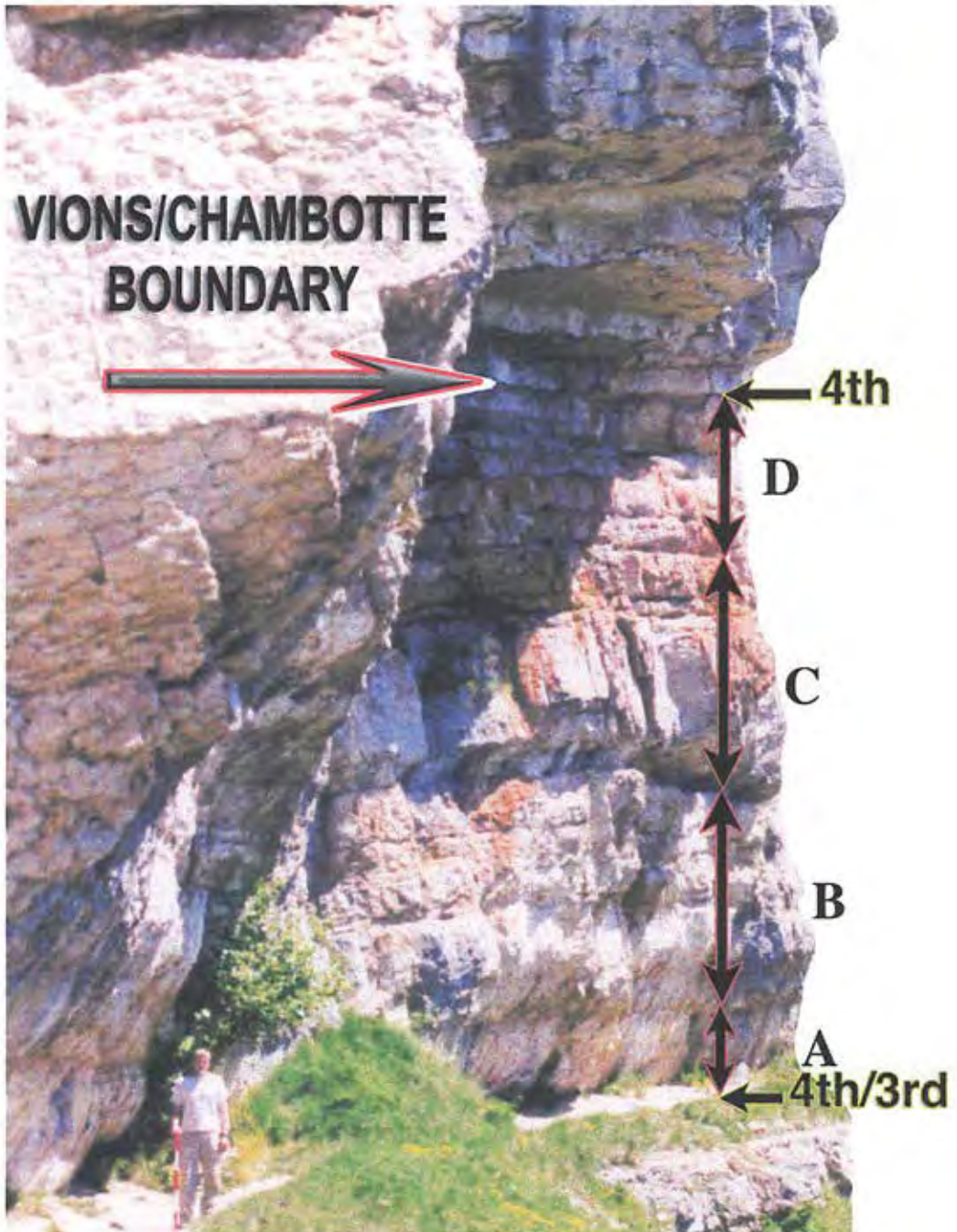


Figure 8. The upper interval at Saleve in the French Jura.

Figure 9. Lower interval at Durleston Bay (North) on the Dorset coast.

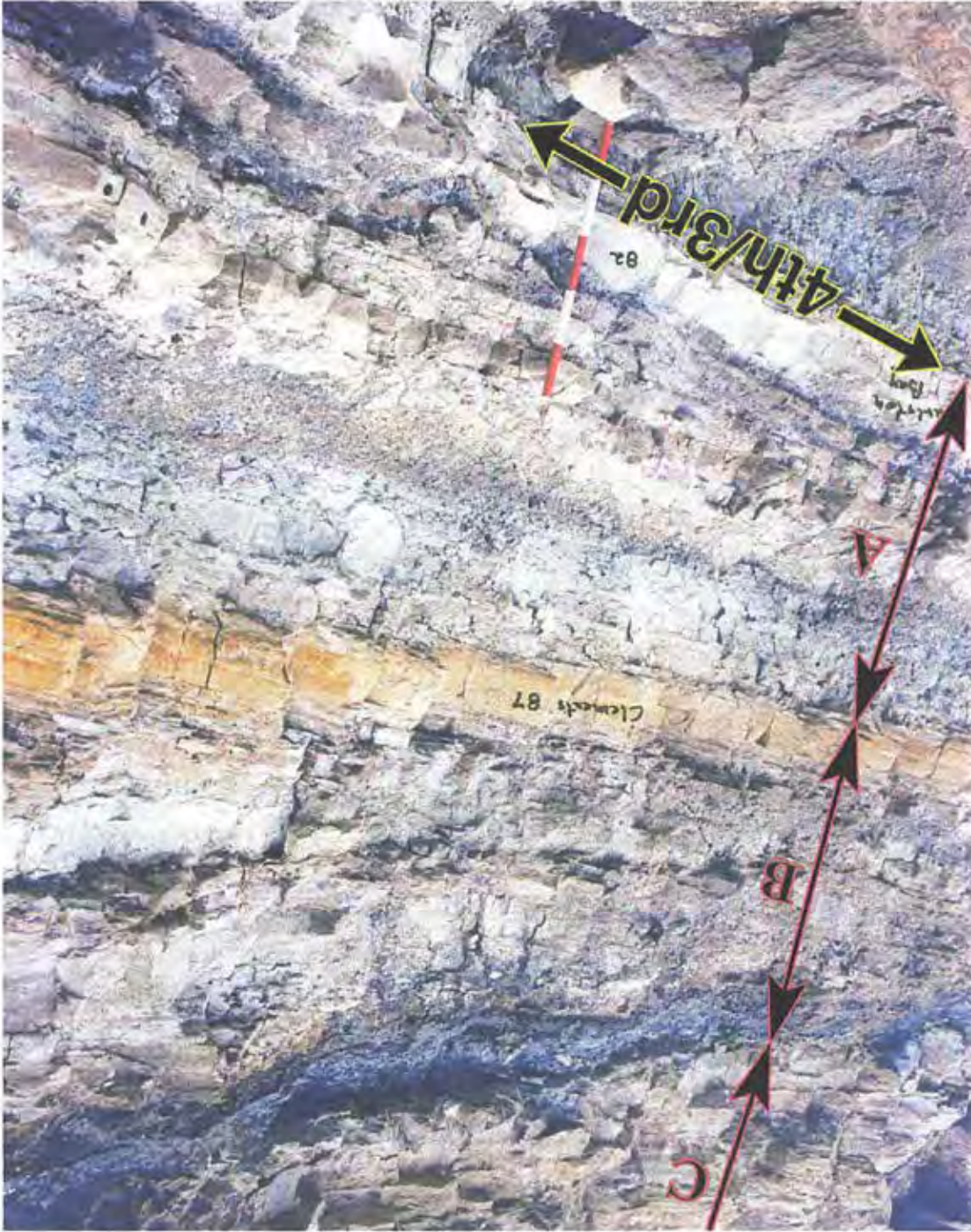




Figure 9. (continued)



Figure 10. Upper interval at Durlston Bay (North) on the Dorset coast.

in 3rd, 4th, and/or 5th order boundaries, there appears to be a larger degree of facies change. These larger-scale sequences show shallowing-upward facies trends, such as subtidal, intertidal, and supratidal facies juxtaposed in one sequence, followed by an abrupt change to deeper facies. Often, the shallowest part of the sequence has facies that indicate exposure. Exposure surfaces that undergo extensive pedogenic alterations result in soil formation. The degree of soil formation mainly depends on the amount of time the platform deposits were exposed to these processes. When exposure is long enough for horizonation, accumulation of clay, and soil structures to form, it can be preserved as a paleosol at a sequence boundary.

Potential paleosols were identified within the study intervals at 3rd, 4th, and 5th order sequence boundaries, several of which occur at formation or member boundaries. Paleosols were sampled at Crozet (sample R-2), Durlston Bay North (sample D1-6) and Durlston Bay South (sample D3-5), and Salève (sample S-19). The development of each paleosol was investigated by analysis of micro- and macroscopic pedogenic features, molecular weathering ratios, and X-ray diffraction (XRD). A greater degree of development for a paleosol that represents the shallowest part of a sequence can further indicate that a larger sea-level event occurred. Larger sea-level events produce increased exposure times during the lowstand portion of the sea-level cycle that are necessary for pedogenic development.

CHAPTER 2 MATERIALS AND METHODS

Detailed stratigraphic columns were drawn at each locality at a scale of one meter to the inch. The localities included four in the French Jura (Chapeau de Gendarme, Crozet, Salève, and Yenne) and two on the Dorset coast (Durlston Bay and Stair Hole). Columns that were drawn represented stratigraphic intervals that ranged from 6 to 32 meters. The orbital forcing model was used to define a cyclic hierarchy for each section (Figure 6). The degree of sea-level fluctuation was interpreted by the amount of facies change within a cycle and at cycle boundaries. Greater facies changes define higher order cycle boundaries, whereas at smaller-scale (lower order) cycle boundaries facies change varied less. The columns were then used for correlation between all localities in France and between the two sections in England. Distinctive marker beds, such as a paleosol or a massive cherty bed, were used as tie points for correlation within each region or basin. Oriented hand-samples were collected from limestones in nine of the study intervals for a total of 86 samples. Each sample was made into a thin section to provide lithologic and faunal detail. The Folk Classification (1974) was used to describe and identify each thin section.

Paleosols occurred at cycle boundaries throughout each study interval. Macroscopic pedogenic features were described in the field. Colors were described by using the Munsell soil color charts (Munsell, 1975). Paleosols (samples S-19, R-2, D1-6, D3-5) were sampled in orientation so that organic material, diagenetic features, minerals, soil structure, and evidence of clay accumulation could be identified in thin section. Geochemical analyses were done by XRAL Laboratories in Don Mills, Ontario, Canada

using Inductively Coupled Plasma-Mass Spectrometry (ICP-MS), with an analytical uncertainty of no more than 10% (results can be seen in Appendix C). Molecular weathering ratios include hydration [$\text{SiO}_2/\text{Al}_2\text{O}_3$], hydrolysis $[(\text{CaO}+\text{MgO}+\text{K}_2\text{O}+\text{Na}_2\text{O})/\text{Al}_2\text{O}_3]$, leaching [Ba/Sr], salinization $[(\text{K}_2\text{O}+\text{Na}_2\text{O})/\text{Al}_2\text{O}_3]$ and $(\text{Na}_2\text{O}/\text{K}_2\text{O})$, oxidation [$\text{FeO}/\text{Al}_2\text{O}_3$], and calcification $[(\text{CaO}+\text{MgO})/\text{Al}_2\text{O}_3]$. The trace elements Cu, Cr, Ni, and Zn were also used. Clays were identified on a Philips analytical X-ray generator (PW 1729) set at 40 kv/30 ma using Cu $K\alpha$ radiation with a graphite monochromatic filter equipped with a scintillation detector, located at Bryn Mawr College. The samples were mounted on glass slides by using the methods of Moore and Reynolds (1989). The samples were run from 4° to 30° 2-Theta. Samples that showed peaks for mixed-layered illite/smectite, smectite and/or kaolinite were run again after glycolation and heating to confirm the presence of these clays. The glycolation process involved placing the slides in an ethylene glycol chamber overnight. Heated samples were placed in an oven for 1 hour at 550°C . Identified clays in samples that were untreated, glycolated, and heated were compared using the techniques of Moore and Reynolds (1989). Each paleosol was classified using the United States Department of Agriculture (USDA, Soil Survey Staff, 1998) soil taxonomy to the subgroup level and also with Mack et al. (1993) standards to subordinate modifiers if necessary.

All figures were digitally drafted using Adobe Photoshop, Adobe Illustrator, Jade, and Quark Xpress. The graphs were done in Cricket Graph. Thin-section tables were done in Microsoft Excel. All written work was done using Microsoft Word.

CHAPTER 3 MODELS OF ALLOCYCLICITY

PACs

The PAC hypothesis of Goodwin and Anderson (1985 & 1986) is a model of stratigraphic accumulation that is episodic and a function of allogenic mechanisms. Goodwin and Anderson (1985) define a punctuated aggradational cycle (PAC) to be a basin-wide, time stratigraphic unit and the fundamental unit for correlation within a basin and potentially between basins. PACs are meter-scale shallowing-upward cycles that are bound by surfaces produced by sea-level rises. These surfaces are recognized by abrupt changes from shallower to deeper facies and are produced by rapid sea-level events approximately every 20 ka. PAC surfaces can be correlated over long distances because they are synchronous and are produced by allogenic mechanisms. PACs and their synchronous boundary surfaces are extremely useful for detailed correlation between the study intervals in both France and England. Detailed correlations by PACs can provide for more refined paleogeographic reconstruction and interpretations of paleoenvironments and basin dynamics.

The PAC hypothesis is different from the accepted gradualistic model that suggests small-scale stratigraphic cycles are autogenic in origin. For example, subsidence superimposed on a lateral environmental migration could produce an autogenic repetition of cycles. The migration of a meandering river channel could produce bounded surfaces within the extent of a floodplain. These surfaces could not be considered a result of an allogenic mechanism, but are the product of a sedimentation process because of the limited lateral extent of these surfaces. These surfaces are the

result of local discontinuities that have a limited extent, whereas PAC boundaries are traceable surfaces that are laterally extensive across major facies boundaries because they are allogenic in origin. Allogenic mechanisms that produce PAC surfaces occur worldwide and are potentially traceable throughout the basin and between basins (Goodwin and Anderson, 1985).

Goodwin and Anderson (1985, 1986, 1988) show the application of these concepts to strata in the Helderberg Group of New York State. They state the important characteristics PACs have that make them more useful than other correlation techniques. PACs have unique lateral persistence of lithological features that distinguish them from adjacent cycles above or below. This allows for the correlation between closely spaced sections for tens of kilometers. In addition, sequences of PACs can be correlated throughout widely spaced sections in a basin or from basin to basin.

Orbital Forcing (Croll-Milankovitch band frequency)

Much of the Earth's history has been affected by orbital forcing patterns that regulate the amount of solar energy reaching the outer atmosphere because of the Earth's tilt, and the changing distance between the Earth and the Sun. Orbital forcing is the astronomical theory that acts as a mechanism for paleoclimatic change and the cyclic stacking pattern of the stratigraphic record (Milankovitch, 1941; Berger, 1980). The results of orbital forcing are atmospheric changes that not only effect climate by the thawing and freezing of ice, but also by the subsequent changing climatic regimes that alter erosional and weathering processes (House, 1995). The varying heat budget from orbital forcing controls the deglaciation and glaciation at higher latitudes on the Earth,

resulting in fluctuations of sea-level during each event. The regular, repeating orbital cycles identified by Milankovitch (1941) include the Earth's precession, oscillation of the axial obliquity, and several orbital eccentricity cycles related to variation in the shape of the Earth's orbit. Milutin Milankovitch (1941), who also used this theory to explain the ice ages, calculated the time scale for these cycles within the range of 20 to 400 ka. These orbital cycles effectively change seasonal distribution of solar energy, or insolation. The orbital fluctuations most strongly associated with cyclic patterns in the stratigraphic record are the precessional (PACs) and eccentricity signals (Anderson and Goodwin, 1986; Goodwin and Anderson, 1986; Olsen, 1986; Goldhammer et al., 1990; Fischer and Bottjer, 1991). Cycles identified in the rock record are of major importance because they establish time in geology and record its past events (House, 1995).

Precession

The precessional cycle can be described as the rotation of the Earth's axis 360° in a cone (Figure 11). This cycle has in average a period of 26 ka, but occurs at extremes of 14 to 28 ka (Fischer and Bottjer, 1991). However, the functional precessional cycle averages approximately 20 ka and not 26 ka (Milankovitch, 1941; Berger, 1980; Fischer and Bottjer, 1991). The reason for this difference is due to the rotation of the position of the Earth's elliptical orbit (Figure 12). The long (major) axis of the Earth's orbit rotates counterclockwise in space, which decreases the average amount of time for a complete precessional cycle relative to the long axis of the Earth's elliptical orbit.

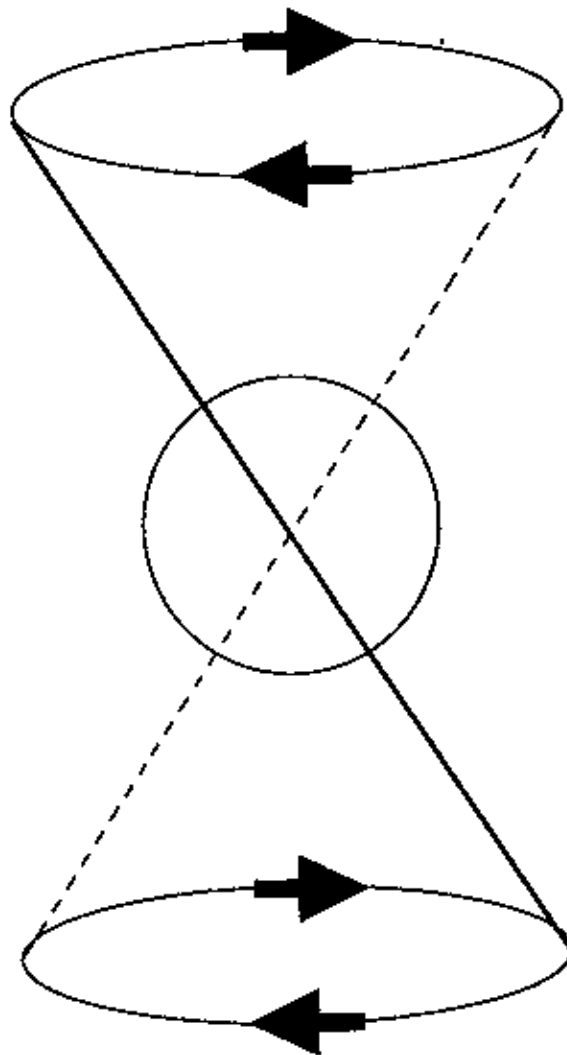


Figure 11. Precession of the Earth's axis. This cycle rotates clockwise and has a period of 26 ka in space.

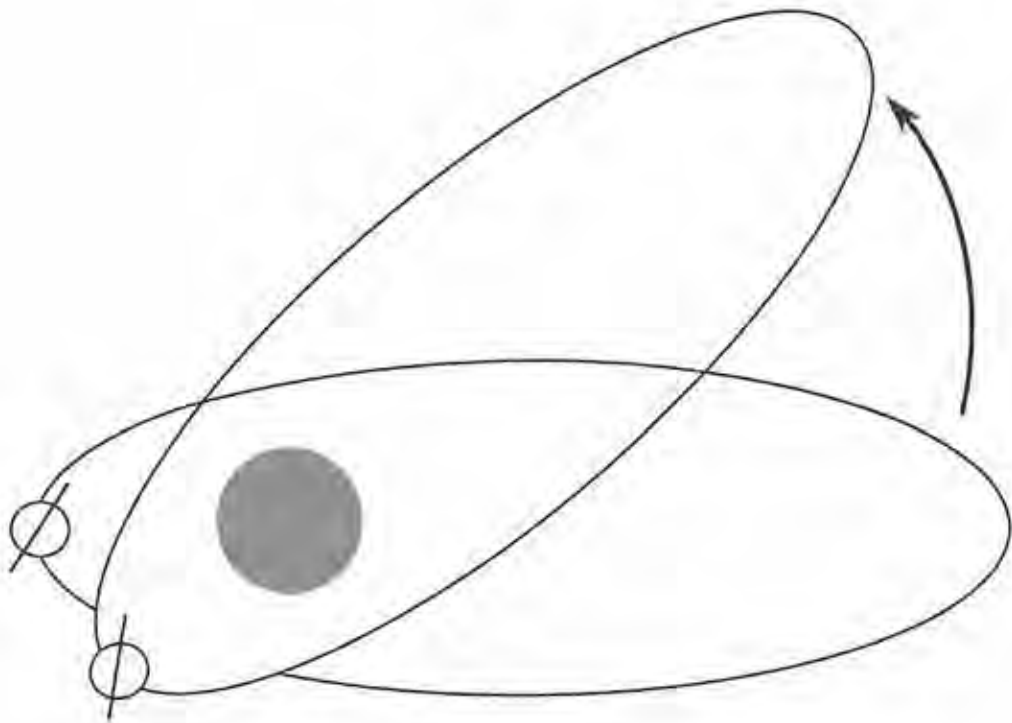


Figure 12. Rotation of the Earth's elliptical orbit around the sun. Perihelion summers are shortened from 26 ka to 20 ka due to the counter-clockwise rotation of the Earth's elliptical orbit around the sun in space.

Obliquity

The obliquity cycle is the periodic change in the degree of axial tilt between 22.1° and 24.5° with a period of around 41 ka (Figure 13; Fischer and Bottjer, 1991). Insolation the Earth receives at high latitudes increases with increasing tilt of the Earth's axis. This increases the intensity of the insolation effect caused by the precessional signal and it alters the pole to equator insolation gradient that directly affects climatic and ocean circulation (House, 1995). In a hypothetical event where the Earth has no obliquity (i.e. the Earth's axis is perpendicular to the planes of the elliptic), the sun would appear directly above the equator, the poles would be in constant twilight, and there would be no seasons. The most extreme seasonality would occur if the obliquity was at 90° , when the sun would be directly over the pole in summer and the opposite pole in winter. The result of increased insolation to the polar regions would produce maximum flooding from melting of the glaciers.

Eccentricity

Eccentricity is the change in shape of the Earth's orbit (the degree of ellipticalness) around the Sun. The shape of the Earth's orbit changes from maximal to minimal ellipticalness in 50 ka (Figure 14; Fischer and Bottjer, 1991). A complete eccentricity cycle occurs with a period of about 100 ka. In addition, bundles of eccentricity cycles occur every 400 ka and possibly 2 ma (Berger, 1988; Fisher and Bottjer, 1991). House (1995) recognized these cycles as climatic signatures of 106 and 410 ka in the 2.5 ma records of oxygen isotopes ($\delta^{18}\text{O}$) recorded from ocean cores. The

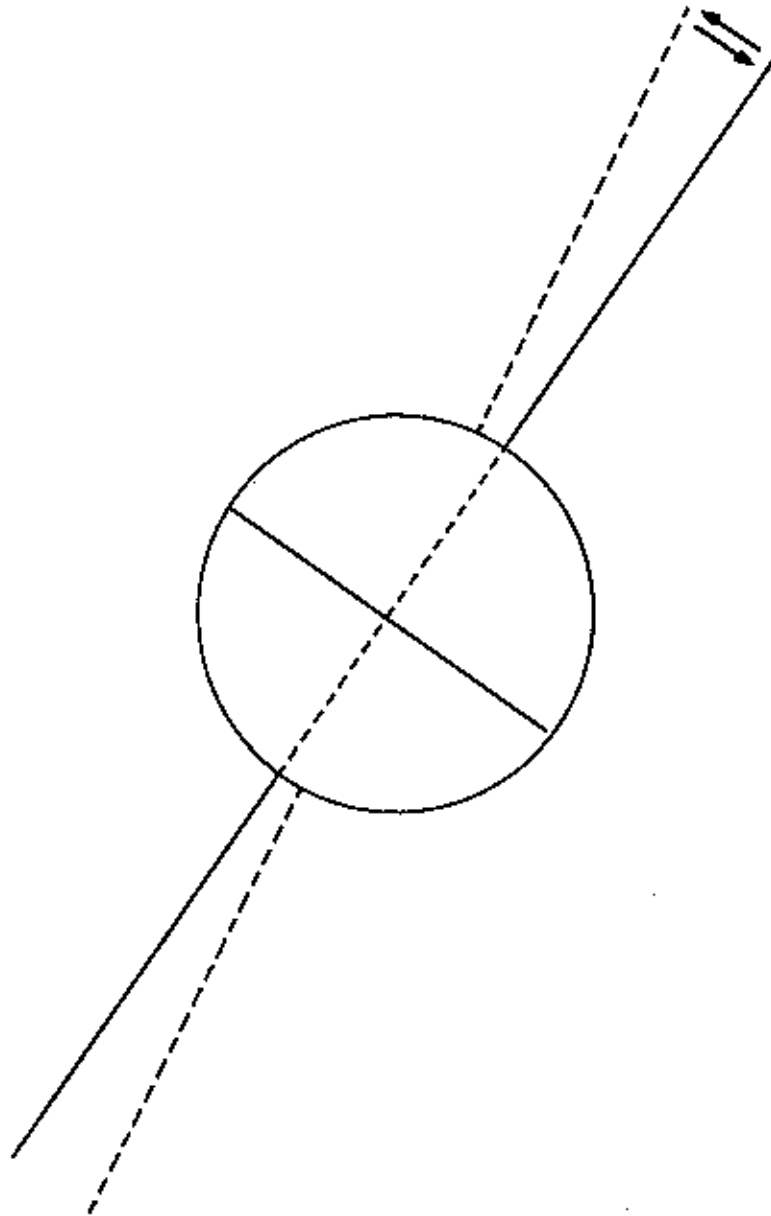


Figure 13. Obliquity of the Earth.

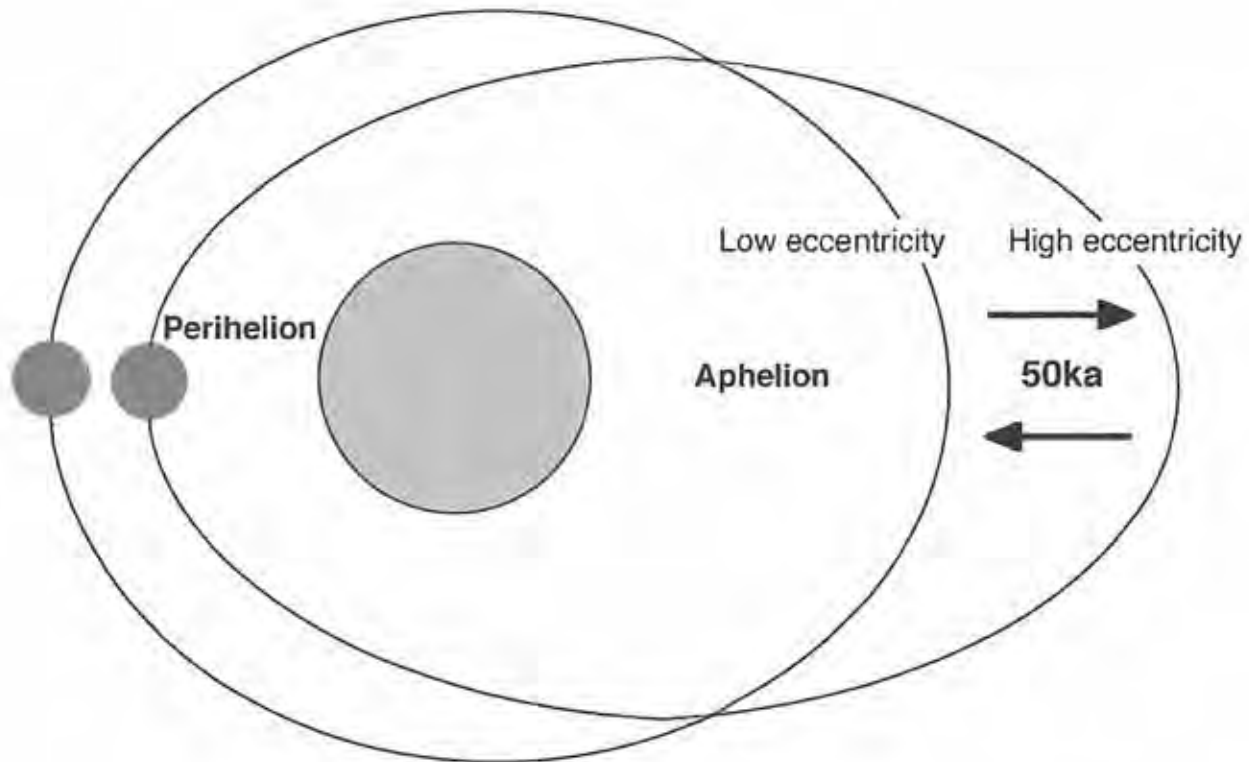


Figure 14. The Earth's eccentricity cycle. This cycle changes from high to low every 50ka. The Earth is closest to the sun during perihelion and farthest during aphelion.

magnitude of precessional effects on sea-level are determined by the degree of eccentricity.

The distance from the Earth to the Sun varies throughout the eccentricity orbit. The Earth is as much as 14 million miles closer to the sun during perihelion than at aphelion and thus receives more insolation, at perihelion. Earth's high and low eccentricity orbits introduce variations in seasonal changes. During low eccentricity, radiation is more uniform throughout the orbit and the precessional cycle results in minimal change in insolation. Whereas at times of high eccentricity the Earth's orbit is more eccentric and this causes maximum insolation to occur at perihelion. Therefore, at high eccentricity and perihelion, the Earth will receive the most insolation (the hottest summers) than in any other configuration of the orbit. If these hot summers (Figure 15) occur in a hemisphere where there are large areas of continental glacial ice accumulation, there will be a maximum amount of melting. However, glacial ice would tend to accumulate at higher latitudes during repetitive cool summers associated with aphelion.

Currently, the northern hemisphere is experiencing perihelion winters and aphelion (cool) summers (Figure 15). The southern hemisphere experiences maximum seasonality with perihelion summers and aphelion winters. In contrast, insolation at high latitudes is low during the northern hemisphere summer when the Earth is at perihelion. High northern latitudes are most important today because this is where most glaciation occurs. Therefore, an increased insolation in these regions will result in major sea-level changes (rises).

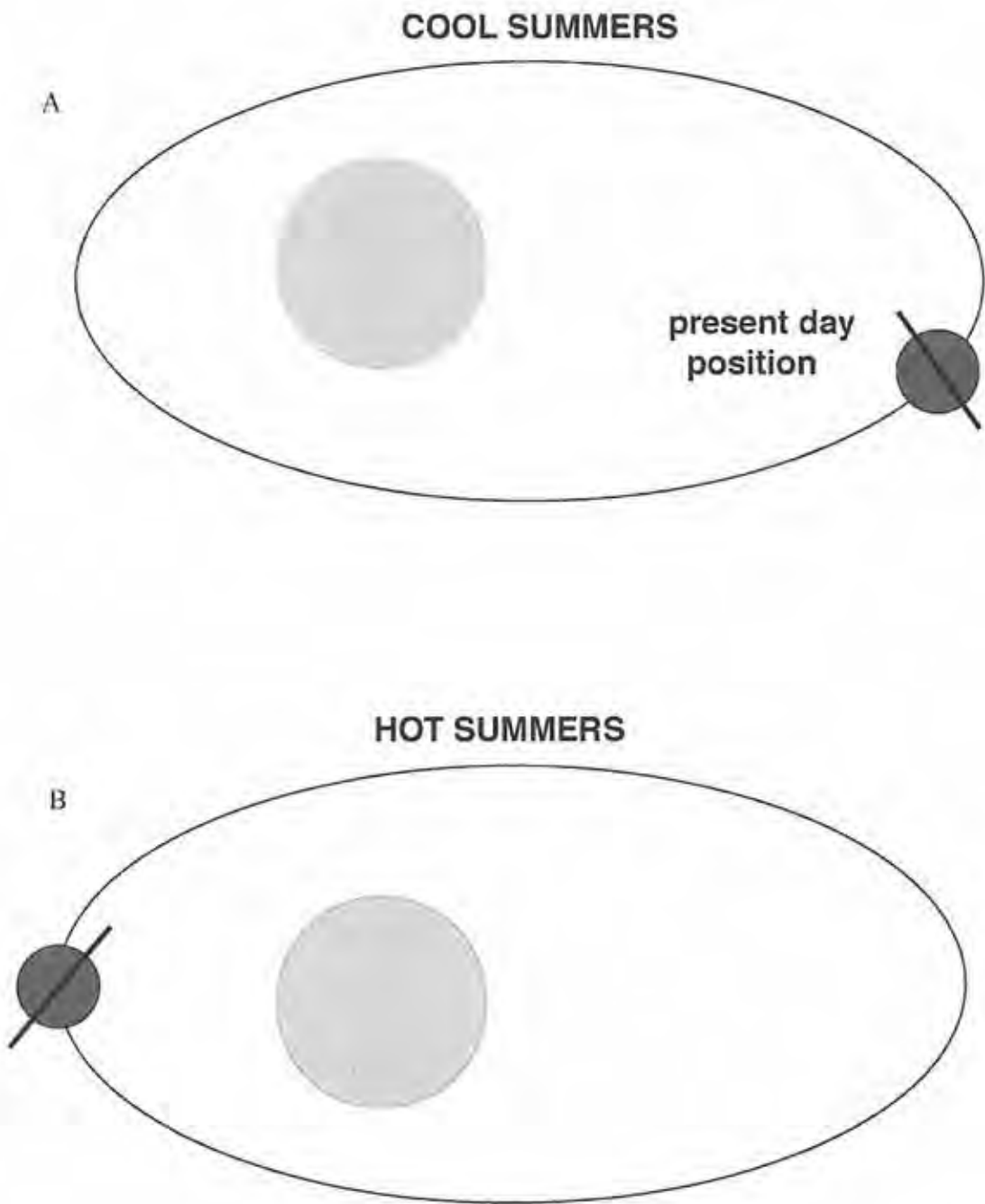


Figure 15. Earth's recent position and its position during cool and hot summers. A shows the present day position of the Earth during perihelion. B shows the position of the Earth 10 ka earlier or later during aphelion.

The study intervals in France and England show a unique hierarchic stacking pattern where small-scale, shallowing upward cycles are less than 1 meter in thickness, and these are bundled to make up much larger scale cycles. Recurring cycles throughout the study intervals indicate that sedimentation was influenced by periodic cyclical events. Small-scale cycles seen throughout the study intervals are interpreted to be the product of rapid flooding events caused by the precessional cycle (6th order or PAC). Two to six precessional cycles are seen bundled in distinct larger scale cycles that reflect a control of sea-level by the first eccentricity cycle (5th order). The second eccentricity cycle (4th order) has been observed to usually contain four first eccentricity cycles. Obliquity cycles within the sections were not identified throughout the study intervals. However, the influence of this cycle could have increased facies change from shallow to deep, and/or controlled the thickness of sequences.

CHAPTER 4 BIOSTRATIGRAPHY

Correlation of stratigraphic sections in this study relies on an established biostratigraphic framework of the French Jura and the Dorset coast (Figure 16 & 17). Biostratigraphic markers are scarce in both the French Jura and the Dorset coast. This makes precise dating and small scale correlations based on biostratigraphic data very difficult in the study intervals (Strasser, 1994; Hillgärtner, 1998,1999). Pasquier and Strasser (1994) state that in the French Jura sections, zone and subzone boundaries of fossils are not well defined because of the scarcity of fossils. However, biostratigraphically useful faunal elements for correlation in the French Jura include calpionellids, ostracod-charophyte assemblages, benthic foraminifera, and ammonites (Figure 16; Strasser, 1994; Hillgärtner, 1999). The organisms used for correlation in the Dorset coast include ostracods, charophytes, molluscs, and ammonites (Figure 17; Anderson, 1985; Feist et al., 1995; Wimbledon and Hunt, 1983; Home, 1995). Ammonites are extremely rare in the study intervals in England and are less reliable for biostratigraphic tie points than the ostracods and molluscs. In any case, when fossils are recognized and identified correctly, biostratigraphy allows for more defined zone boundaries and better correlation of formations and members throughout the Wessex basin and Paris sub-basin. Jacquin et al. (1998) showed the basin to basin correlation from the French Jura to the Dorset coast by using Berriasian ammonite zones (Figure 5). This established biostratigraphy relevant in the study intervals in the Berriasian is gathered from previous literature (Hillgärtner, 1999).

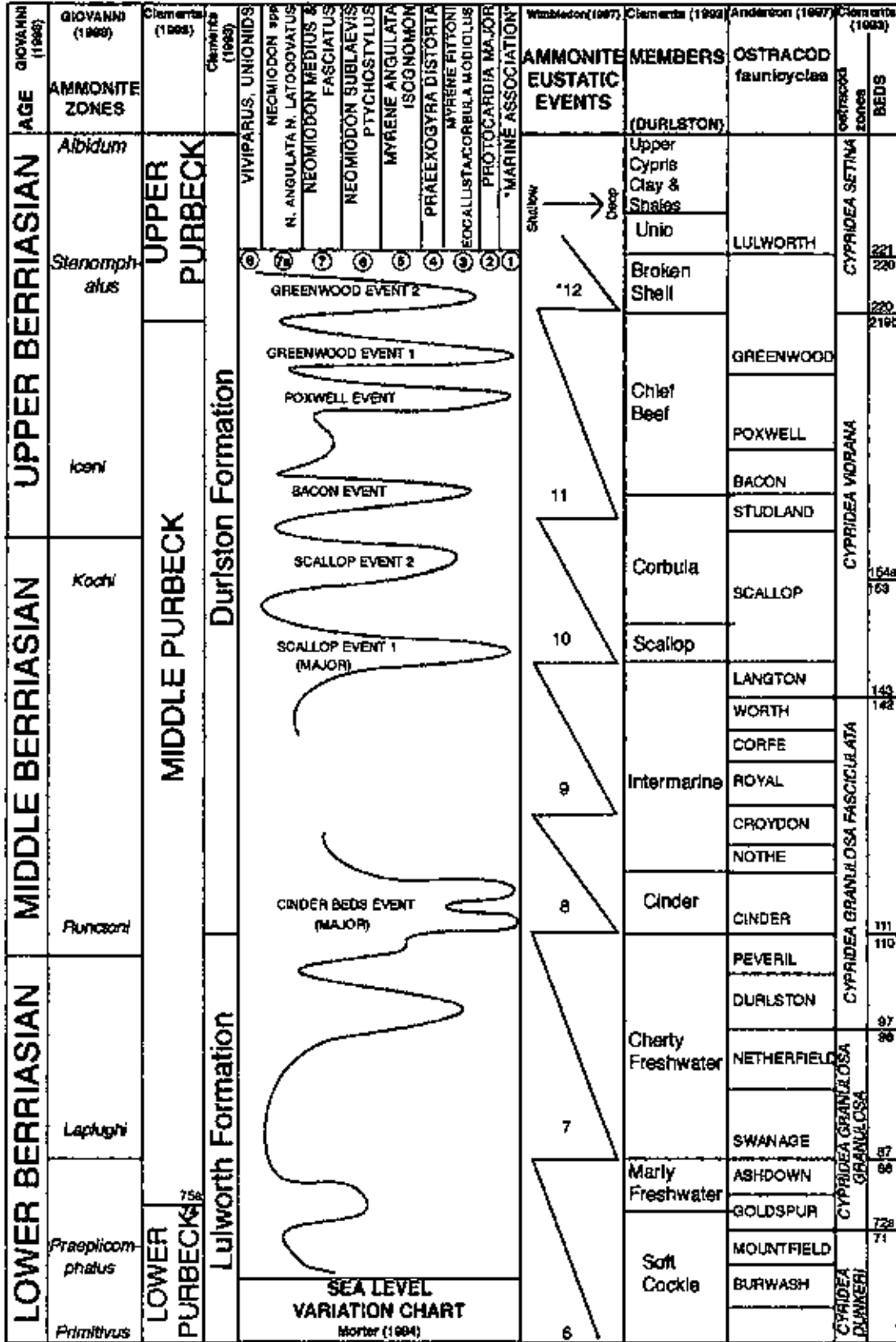


Figure 17. Biostratigraphy of the Dorset coast. Biostratigraphic charts and sea level changes.

The French Jura

Calpionellids

The Jura platform contains very few calpionellids. Hillgärtner (1999) states that even when calpionellids are collected, they are difficult to identify. Calpionellids are well established in more basinal settings, mainly in the Volcontian Trough, where they are most abundant (Hillgärtner, 1999). Calpionellids that are found in the Jura platform include *Calpionellopsis sp.* at the base of the Vions Formation that make up the D biozone, and *Calpionellopsis oblonga* that are part of zone D2 and are found in the middle of this Formation (Figure 16; Hillgärtner, 1999). The occurrence of these biozones places the Vions Formation in the Upper Berriasian (Hillgärtner, 1999).

Charophytes and Ostracods

Charophyte and ostracod assemblages are important in determining age constraints in the Middle and Upper Berriasian. These assemblages are not seen throughout the Jura platform, but only in the marly, marginal-marine sediments of the Vions and Goldberg Formations (Hillgärtner, 1999). In fact, the Goldberg Formation was defined by Häfeli (1966) in Bienne, France based on ostracod faunas. Charophyte and ostracod assemblages (e.g. M5, the *Nurensis* assemblage from Hillgärtner, 1999) found in the Vions Formation suggest it be placed in the Upper Berriasian (Figure 16; Hillgärtner, 1999). In addition, Deville (1991) also confirmed this age constraint due to an important discovery in the upper part of the Vions Formation by identifying a charophyte and ostracod assemblage to be Upper Berriasian. Other discoveries include one by Pasquier and Strasser (1997) who recognized a charophyte assemblage (M3,

Horrida) in the upper Goldberg and the base of the Pierre-Châtel, indicating an early Middle Berriasian age.

Benthic Foraminifera

Benthic foraminifera are important in this study because they serve as chronostratigraphic markers based on their limited biostratigraphic range (Hillgärtner, 1999). They are most abundant in the French Jura platform deposits (Hillgärtner, 1999). The benthic foraminifera used in this study include *Pavlovecina allobrogensis*, *Pseudotextulariella courtionensis*, and *Pfenderina neocomensis* (Figure 16). *Pavlovecina allobrogensis* occurs only in the lower parts of the Vions Formation. *Pseudotextulariella courtionensis* has a slightly larger biostratigraphic extent and appears in the middle to upper parts of the Pierre-Châtel to the lower part of the Vions Formation. *Pfenderina neocomensis* has the largest biostratigraphic extent of all three and appears in the upper Vions and extends to the upper part of the Chambotte Formation.

Ammonites

Bulot (1995) and Le Hegarat (1980) established ammonite zones for the Berriasian (Figure 5 & 16). Absolute dates at ammonite zone boundaries were determined by Gradstein et al. (1994, 1995). The ammonite zone *Jacobi-grandis* is recognized at the top of the Goldberg Formation. An ammonite of the *Jacobi-grandis* zone (Lower Berriasian) was identified by Strasser (1994) in a sequence at a locality, Cluse de Chaille, that was found approximately one meter below the Pierre-Châtel and Goldberg boundary. The research done by Pasquier and Strasser (1997) indicates a hiatus

at the boundary between the base of the Pierre-Châtel and the top of the Goldberg Formation based on the absence of at least some of the *Subalpina* zone (Deville, 1991). This hiatus at the base of the Pierre-Châtel Formation is recognized by the occurrence of a *Privasensis* zone ammonite, indicating that some of the *Subalpina* zone is missing above this unconformity (Pasquier and Strasser, 1997). The bottom of the Pierre-Châtel Formation just above the hiatus can be correlated with a large scale transgression at approximately 141.0 ma (Gradstein et al. 1995; Hillgärtner, 1999). Ammonite zones higher up in the study interval between the Vions and Chambotte Formations are not well established to distinctly show a biostratigraphic change in zones across the Formation boundary. However, Hillgärtner (1999) and Jacquin et al. (1998) show in Figures 5 and 16 that the boundary between the *Picteti* and *Alpillensis* zones is probably in the upper Vions Formation and the lower Chambotte Formation.

The Dorset Coast

Ostracods

The ostracod zonations of Clements (1993) are used to divide the Purbeck into the Lower, Middle, and Upper at the type section in Durlston Bay (Figure 17). The ostracod zone *Cypridea setina* represents the Upper Purbeck. The *Cypridea vidrana*, *Cypridea granulosa fasciculata*, and *Cypridea granulosa granulosa* zones lie in the Middle Purbeck. The Lower Purbeck is represented by the *Cypridea dunkeri* zone.

Anderson et al. (1985) recognized that ostracods alternated between high salinity tolerant species to ones that were more freshwater in a cyclic pattern they call a 'faunicycle'. They identify a faunicycle as a succession of a saline ostracod assemblage

followed by a freshwater assemblage. For example, one faunicycle in the Cinder Member is dominated with *Galliaecytherides* as the saline phase and *Cypride* as the freshwater phase. The freshwater phase in the faunicycles is not easily identifiable and most of them are incomplete. The paleosalinity interpretations of ostracods within the faunicycles of Anderson et al. (1985) are debated, but are still important for determining sea-level changes. Morter (1984) suggests that a definite salinity is not needed to interpret changing conditions to more marine or more freshwater. Therefore, each faunicycle can indicate fluctuations in sea-level. In addition, Anderson (2000c) showed that the faunicycles of Anderson et al. can be correlated with 5th order (100 ka) sequences.

Molluscs

Morter (1984) recognized the abundance of molluscan fauna in the Purbeck and created a sea-level variation chart from interpreted paleosalinities for different molluscan associations. Nine molluscan associations have been recognized and salinity tolerances were established for each association (Figure 17). Eight associations are freshwater to brackish and one is marine euhaline. For clarification of differing salinity environments, Morter (1984) adopted a scale that is numbered from 8, being the most freshwater, to 1, representing marine. The associations of molluscan faunas are used to interpret marine and brackish events that are used to construct a sea-level variation chart (Figure 17). The *Viviparus/unio* association (8) contain freshwater mollusca. Species of *Neomiodon* sp. association (7a) occupy oligohaline, brackish freshwater conditions (.5-5‰ salinity). Mollusca of association 7a are only found in the Corbula and the Chief Beef Member in

the upper interval of the Purbeck. The *Neomiodon faciatus-mediis* association (7) indicates mesohaline to oligohaline conditions (5-9‰ salinity). This association occurs in the Durlston Formation and is usually observed in shell drift facies. The *Neomiodon sublaevis-Ptychostylus* association (6) characterizes brackish marine mesohaline conditions (9-11‰ salinity). *Myrene angulata* association (5) is mainly found in the upper and middle parts of the Cinder Member and is indicative of mesohaline conditions (11-14‰ salinity). *Praeexogyra distorta* association (4) indicates mesohaline conditions (14-18‰ salinity) and occurs mainly in the Cinder Member. *Myrene fittoni-Modiolus-Corbula* association (5) is characteristic of polyhaline conditions with salinity of around 18-30‰. A specific species of *Corbula* in this association is found in the Corbula Member without any association fauna. This fauna alone can be used as a stratigraphic marker because it can be traced throughout the Dorset coast (Morter, 1984). *Protocardia major* association (2) represents euhaline marine to slightly restricted polyhaline conditions (around 30‰ salinity). The marine association (1) is not characterized by any one species, but represents euhaline conditions with salinity ranging from 14-30‰.

Ostracods and Molluscs

The occurrences of ostracod faunicycles show a distinct relationship to the mollusca associations. These minor transgressive events from ostracods and mollusca can be matched (Figure 17). For example, the ostracod faunicycles that show a correlation to sea-level events of the molluscan assemblages include the Greenwood, Poxell, Bacon, Scallop, Cinder, and Durlston. There are more than double the number of ostracod faunicycles than the number of minor sea-level transgressions indicated by

molluscan assemblages. In any case, almost every marine transgression based on the molluscan assemblages is indicated in the ostracod faunicycles. The transgressions from the molluscan assemblages not only correlate well to the ostracod faunicycles, but also to the lithostratigraphy (Morter, 1984; Wimbledon, 1987).

Ostracod faunicycles and molluscan assemblages are also connected to major transgressions that can be correlated throughout the basin (Morter, 1984). A major transgression called the Cinder Beds Event is recognized from molluscan assemblages. This flooding event occurred during the Middle Berriasian and is also recognized by the Cinder ostracod faunicycle (Figure 17). The scallop faunicycle and molluscan assemblages indicate another major transgressive event called the Scallop Event that occurred during the Upper Berriasian (Figure 17). These major sea-level events are recognized throughout the Purbeck and in the French Jura on not only salinity interpretations from faunal remains, but also from an overall change to deeper water facies.

Ammonites

Wimbledon (1987) relates ammonite zones to shallowing-upward events in the Purbeck (Figure 17). Ammonite zonation can be problematic in the study intervals because few ammonites have been collected to determine a distinct zonation (Wimbledon, 1987). The shallowing upward events are characterized by deeper facies ending with shallow marl facies, or in extreme cases with emergent surfaces (Wimbledon, 1987). The ammonite zones are approximate because there are few ammonites to distinguish boundaries in the Purbeck (Wimbledon, 1987). Therefore,

Figure 17 has few ammonite controls for the eustatic events. These eustatic events are also recognized in marine and non-marine molluscan fauna sea-level events. Four marine transgressions from molluscan assemblages (Mortier, 1984) that correlate well with the ammonite eustatic events interpreted by Wimbledon (1987) include the Greenwood Event 2, Bacon Event, Scallop Event 1, and the Cinder Beds Event (Figure 17).

The eustatic events that Wimbledon (1987) relates to ammonite zones can also be matched to members in the Purbeck and molluscan assemblages (Figure 17). Eustatic event 6 starts at the base of the Cypris Freestones and ends at the top of the Marly Freshwater Beds. This event correlates well with good ammonite controls to the ammonite zones *Primitivus* and *Praeplicomphalus*. The ammonite zone *Primitivus* is not seen in Figure 17, but is located below the *Praeplicomphalus* zone (Figure 5). Eustatic event 7 is a shallowing upward sequence of the entire Cherty Freshwater Member. The Cinder Member starts the next eustatic event (8) and also correlates well with the transgression seen in the sea-level variation chart for molluscan faunas (Figure 17). Eustatic event 8 correlates to the Cinder ostracod faunicycle and the start of the Durlston Formation and Middle Berriasian. Wimbledon (1987) suggests this event (8) most likely lies in the *Runctoni* zone that defines early Middle Berriasian age. The upper interval at the top of the Corbula Member and in the Chief Beef Member starts eustatic Event 11. Event 11 is probably related to the *Iceni* zone and terminates at the base of the Broken Shell Limestone. Wimbledon (1987) does not show data above this interval. However, Figure 4 shows that the next ammonite zone (*Stenomphalus*) could correlate to the next deepening event at the base of the Broken Shell Limestone Member (* Figure 17). The Boreal ammonite zones in the Purbeck have poorly defined boundaries, however more

research on these sections could provide better ammonite controls for members above the Cherty Freshwater Member.

CHAPTER 5 LOCALITIES

The French Jura

Chapeau de Gendarme

The Chapeau de Gendarme section can be found between the villages of St. Claude and Septmoncel along road D 436 in the French Jura (Figure 18). The outcrop is located on the same side of the road as the landmark “Chapeau de Gendarme”. This landmark is a hinge of a small fold in a limb of an anticline. The strata dip away from this landmark to the east. (coordinates 874.130/156.600, IGN map, 1:25000, St. Claude; coordinates B/3, IGN map, 1:1000000, Annecy Lausanne).



Figure 18. Map of the section at Chapeau de Gendarme.

Crozet

This section is found northwest of Geneva on the first anticlinal Jura range (Figure 20). The lower interval is found on the right hand side of a forest road next to the Reserve Naturelle de la Haute Chaîne, 9.5 kilometers SW of the town Gex (2.5km SW of Crozet). The upper interval is located in an abandoned quarry that is used as a parking lot for a hotel and the Crozet cable way. Facing the quarry, the outcrop is located on the right hand side. The strata dip toward the Crozet cable way station to the southeast (coordinates 489.580/126.820, Swiss National Topographic map, 1/25000, 1280 Gex, altitude 650m; coordinates B/3.8, IGN map, 1:1000000, Annecy Lausanne).

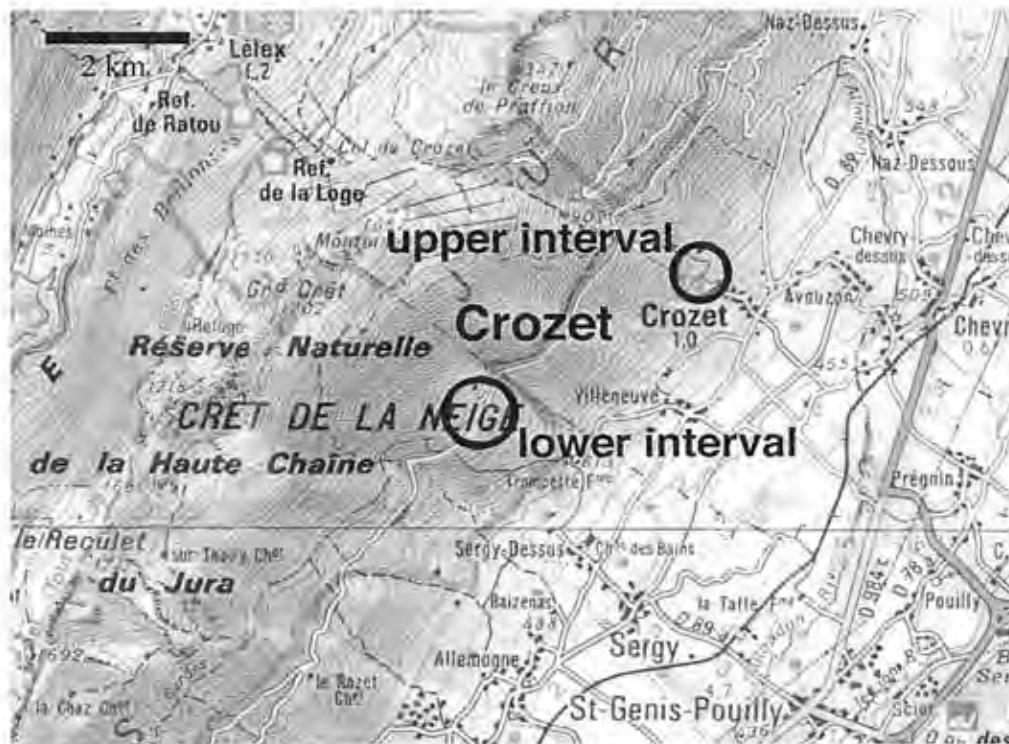


Figure 19. Map of the section at Crozet.

Salève

This section is found on the death-defying steep west face of Mount Salève in the Corraterie region (Figure 23). The outcrop is composed of well exposed horizontal strata. The base of the lower interval lies near the Etournelles trail. The upper interval is located near the Corraterie trail (coordinates 501.770/110.115, Swiss National Topographic map, 1/25000, altitude 1115m; coordinates D/2.3, IGN map, 1:25000, Mount Salève).

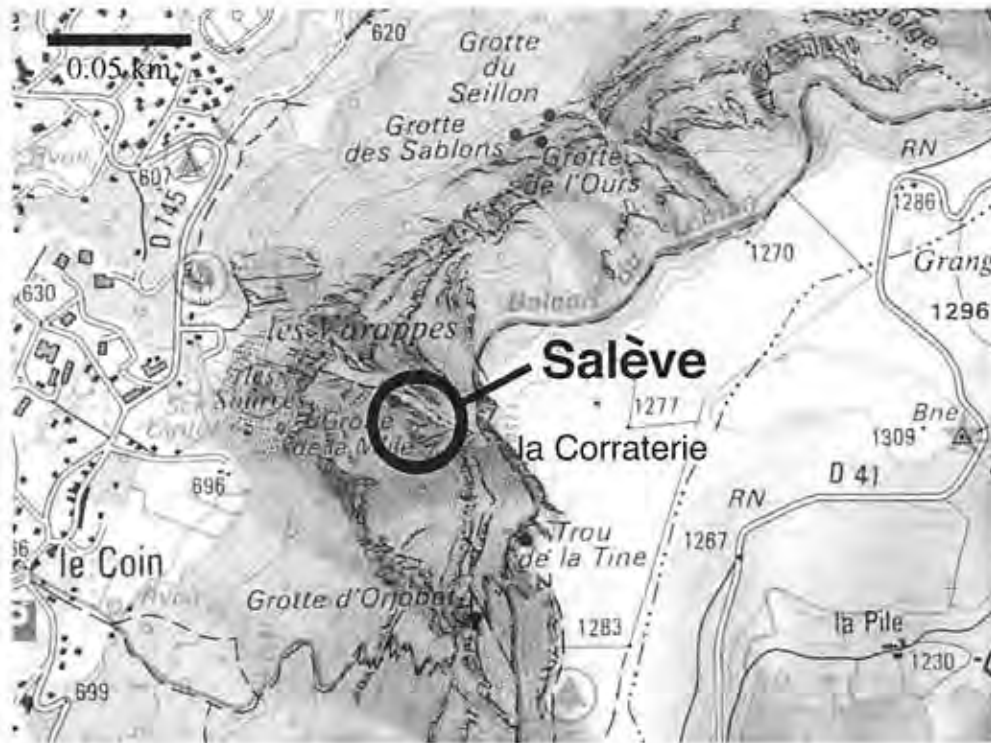


Figure 20. Map of the section at Salève.

Yenne

The section at Yenne is located 9 kilometers west of the Lac du Bourget and east of the Rhone River (Figure 26). Taking road N 504, it is 2 kilometers west of the town Yenne. It appears on the left hand side (South) of the road. The strata dip approximately 45 degrees to the east (coordinates 866/83, IGN map, 1/25000, Chambéry).

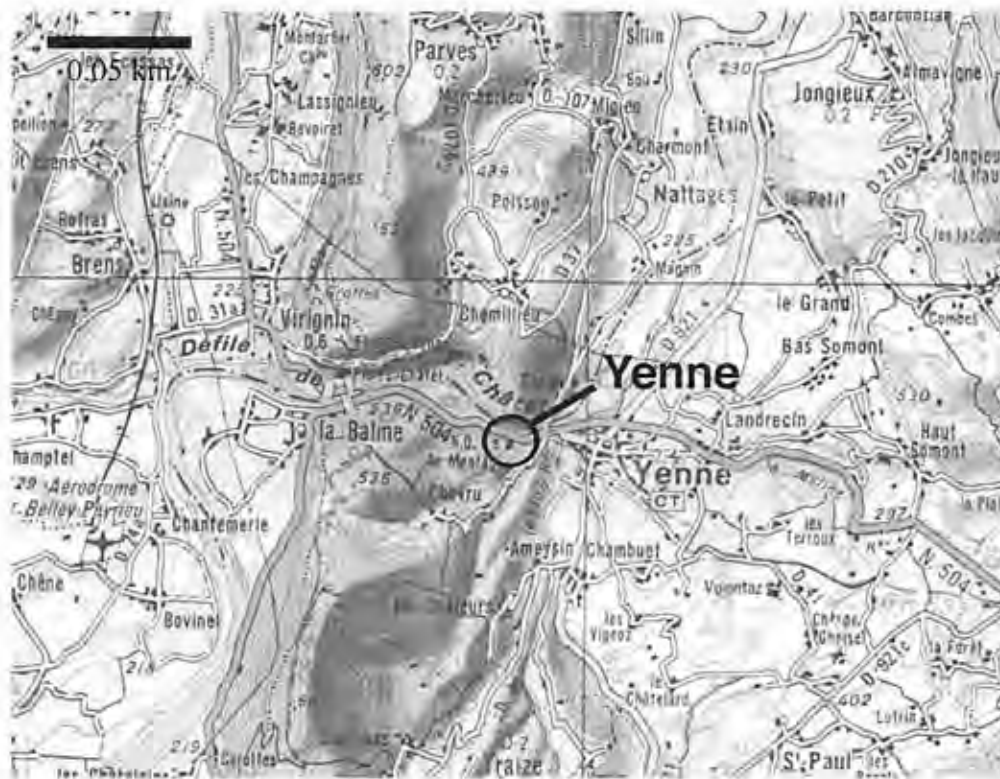


Figure 21. Map of the section at Yenne.

The Dorset Coast

Durlston Bay

Durlston Bay is considered the type section for the Purbeck beds. It can be found at the eastern end of the Isle of Purbeck in Dorset (Figure 29). The outcrop is located on the southern coastal side of the town of Swanage. At Durlston Bay (North) the outcrop spans 0.5 kilometers. The section at Durlston Bay (South) is located 0.25 kilometers south of the north section ($1^{\circ} 56' 08''$ W Longitude/ $50^{\circ} 36' 02''$ N Latitude, coordinates (North) 3.75/78.50, (South) 3.70/77.80, Ordnance Survey map, 1/25000, Purbeck and South Dorset).



Figure 22. Map of the section at Durlston Bay.

Stair Hole

The section at Stair Hole is located on the coast approximately 25 kilometers to the west of the type section at Durlston Bay (Figure 33). This outcrop is located a few kilometers east of Dungy Head. It appears on the coast and is a major attraction for tourists. The strata are near vertical and dip slightly toward the east ($1^{\circ} 15' 00''$ W Longitude/ $50^{\circ} 37' 01''$ N Latitude, coordinates 82.85/79.78, Ordnance Survey map, 1/25000, Purbeck and South Dorset).

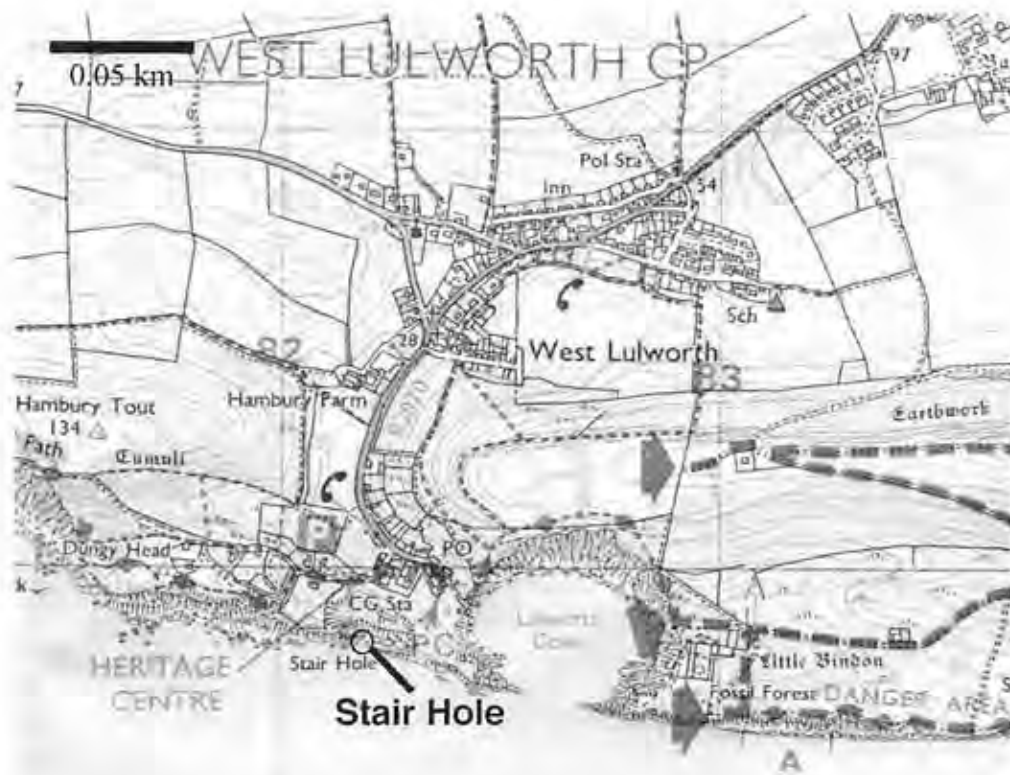


Figure 23. Map of the section at Stair Hole.

CHAPTER 6 LITHOLOGY AND CYCLIC STRUCTURE

This chapter examines in detail the lithology and cyclic structure of the study intervals for paleoenvironmental interpretations, patterns of stratigraphic accumulation, and correlation. It then compares the type sections at Salève in the French Jura and Durlston Bay (North) in England to previously drafted columns of Strasser and Hillgärtner (1998) and Clements (1990). Strasser and Hillgärtner (1998) have done extensive work interpreting sequences, and sequence boundaries throughout the section at Salève (Figure 3). The cyclostratigraphic interpretations of Strasser and Hillgärtner are marked on the columns at Salève and they are discussed in the appropriate section below for the lower and upper study intervals. Columns of the study intervals at each locality (Crozet, Chapeau de Gendarme, Salève, and, Yenne) are correlated and the cyclostratigraphy is discussed. Previous work on the Durlston Bay (North) type section is done by Clements (1993), where he describes in detail and numbers each bed (Figure 4). These numbers are indicated on the columns drafted for this study at the Durlston Bay localities. Cyclostratigraphic interpretations and correlations of the lower and upper intervals in England are done at the Durlston Bay and Stair Hole localities. The cyclostratigraphy of each section in both regions (France and England) is described in terms of lithology with some limestone beds characterized in thin section according to the Folk (1974) classification.

The French Jura

Lower Cretaceous carbonate sediments of the French Jura were deposited in the Paris Sub-basin and formed on a wide and very shallow carbonate shelf at the northern margin of the Tethys Ocean (Strasser, 1988, 1994). Facies occur in shallowing upward, 0.2 – 1.5 meter thick sequences. Most sequences consist of lagoonal, supratidal, intertidal, and restricted marine facies where salinities range from normal marine to hypersaline or fresh (Strasser, 1994). Facies differ within sequences of the carbonate platform depending on the magnitude of sea-level events that produced cycle boundaries. Most sequences in the two study intervals show well defined transgressive surfaces and some contain reworked lag deposits, such as pebbles, at their base. Pasquier and Strasser (1997) observed that most of these shallowing-upward sequences (their elementary cycles) terminated with intertidal features such as birdseyes or keystone vugs. Commonly seen microfossils in limestones include dasycladacean algae, foraminifera, pelecypods, ostracods, and gastropods (Appendix B). Echinoderms and peloids (in thin section, Appendix B) are less abundant and are usually only seen in more marine facies of the Chambotte Formation.

Lower Interval

Cycles in the Goldberg Formation consist of restricted marine to lacustrine facies that often display black pebbles or pedogenic brecciation at the tops. The Goldberg Formation is composed of Purbeckian facies assemblages of shallow-subtidal to supratidal that shallow upward to restricted-marine to lacustrine sediments. Pasquier and Strasser (1997) suggest that some of the Purbeckian sediments, including the Goldberg

Formation, were subaerially exposed or dominated by shallow lakes, as indicated by the abundance of fresh water ostracods, charophytes, and black pebbles. The sediments overlying the Goldberg Formation represent a flooding event that deposited more marine facies of the Pierre-Châtel Formation. This formational boundary marks the top of the lower study interval and is characterized by a soil-like rubble-rich transitional zone within the Goldberg Formation. This major transgressive event can be correlated throughout the French Jura. The separation at the top of this paleosol marks the lower boundary of a 3rd order sequence (Anderson, personal communication 2002). The Pierre-Châtel Formation is composed of more marine facies consisting of coarse grainstones and packstones (Strasser, 1994). Microfacies of Pierre-Châtel limestones at Crozet show fossiliferous micrite with abundances of foraminiferas, pelecypods, and ostracods (Appendix A and Appendix B).

The lower study interval in the French Jura consists of four 4th order sequences (II, III, IV, and V) within the upper part of the Goldberg Formation. These sequences coincide with the stratigraphic interval between Strasser's sequence boundaries Be 2 and Be 4 (Figure 3). Columns at Salève, Crozet, and Yenne are interpreted to contain the 4th order sequences II, III, IV, and, V of the 3rd order sequence in the Goldberg Formation. Sequences II, III, and IV are described in reference to previous drafted columns from Strasser and Hillgärtner (1998), and sequence V will be described in detail according to the lithostratigraphy and the Croll-Milankovitch stacking pattern. The V 4th order sequence is highly condensed and/or incomplete at all localities where paleosols and rubble beds occur at the top of this sequence. This unconformity represents the lower 3rd order sequences boundary, as well as the Goldberg/Pierre-Châtel Formational boundary.

Salève

The lower study interval at Mt. Salève consisting of the upper four 4th order sequences (II, III, IV, and V) in a 3rd order sequence (Figure 24) and is 24 meters thick (Figure 3). Most 400 ka and 100 ka sequence boundaries interpreted in this paper are similar to the ones described by Strasser and Hillgärtner (1998). Both interpretations are similar because 3rd and 4th order boundaries are always placed above the most restricted facies. For example, Be 2, which is also a 4th order boundary, is placed right above mudcracks (Strasser and Hillgärtner boundary 16/17). Other 4th order boundaries are placed above reworked pebble beds (Be 3 and Be 4) or sabkha facies (Strasser boundaries 22/23 and 24/25). Interpreted 5th order boundaries are recognized on restricted facies of a lesser degree such as thin pebble beds, poorly developed soil beds, or reworked shale beds. Nine of sixteen 100 ka boundaries from Strasser coincide with boundaries interpreted in this study. However all boundaries interpreted by Strasser and Hillgärtner match either 5th or 6th order boundaries interpreted in my paper.

The V 4th order sequence is 4.75 meters thick and in this sequence the D 5th order sequence is missing in a soil and/or rubble zone at the Goldberg/Pierre Châtel formational boundary (i.e., a 3rd order sequence boundary). There are three PACs in the A and C sequences and two PACs in the B sequence (Figure 24). The A sequence contains three massive calcarenite beds that become progressively thinner upsection, and the uppermost calcarenite bed contains mudcracks. PAC 1 within the A sequence consists of a massive calcarenite bed (1.5 meters thick) with marl on top. PAC 2 is composed of a single calcarenite bed (0.5 meters thick) with marl on top. PAC 3 contains

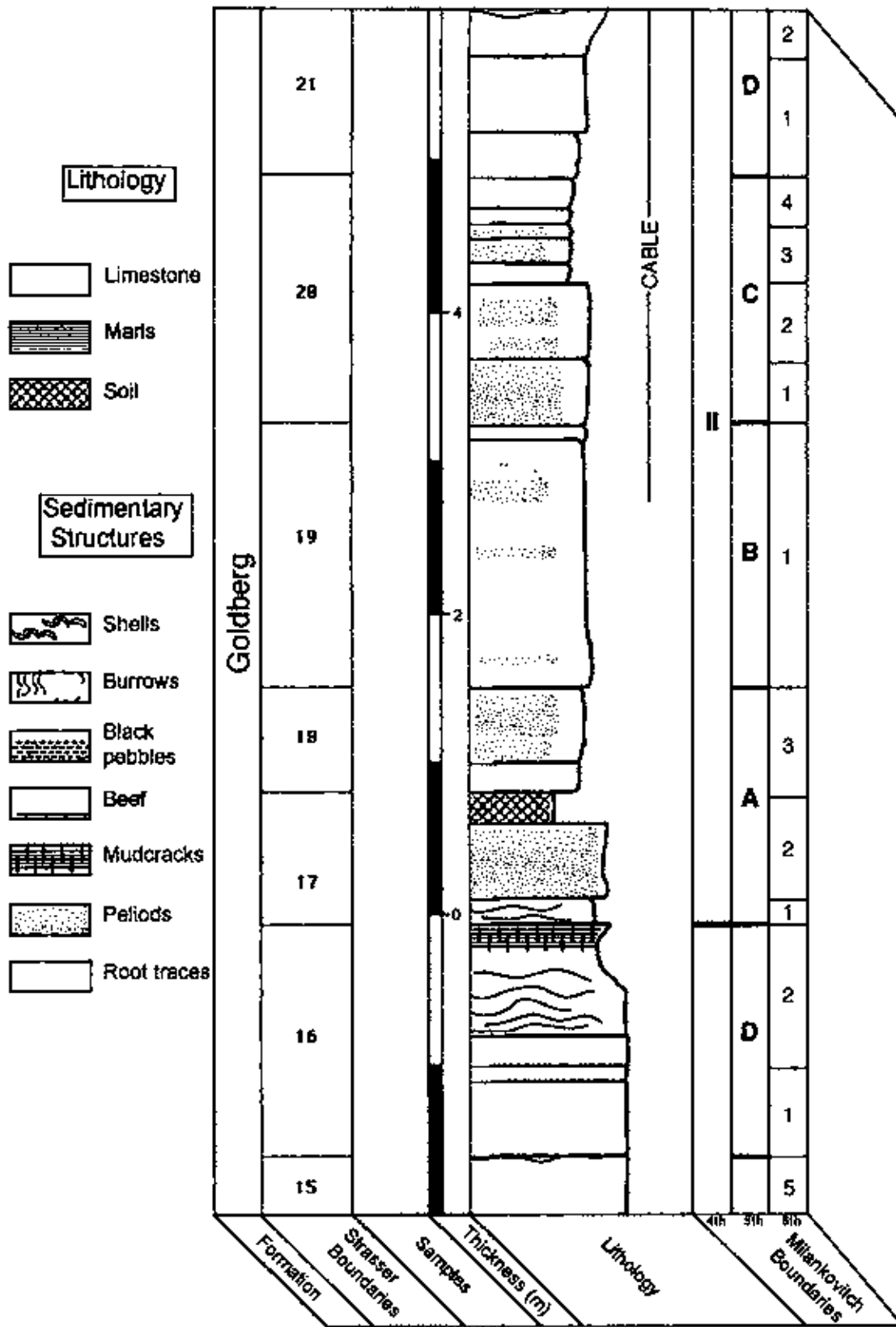


Figure 24. Lower interval at Saleve.

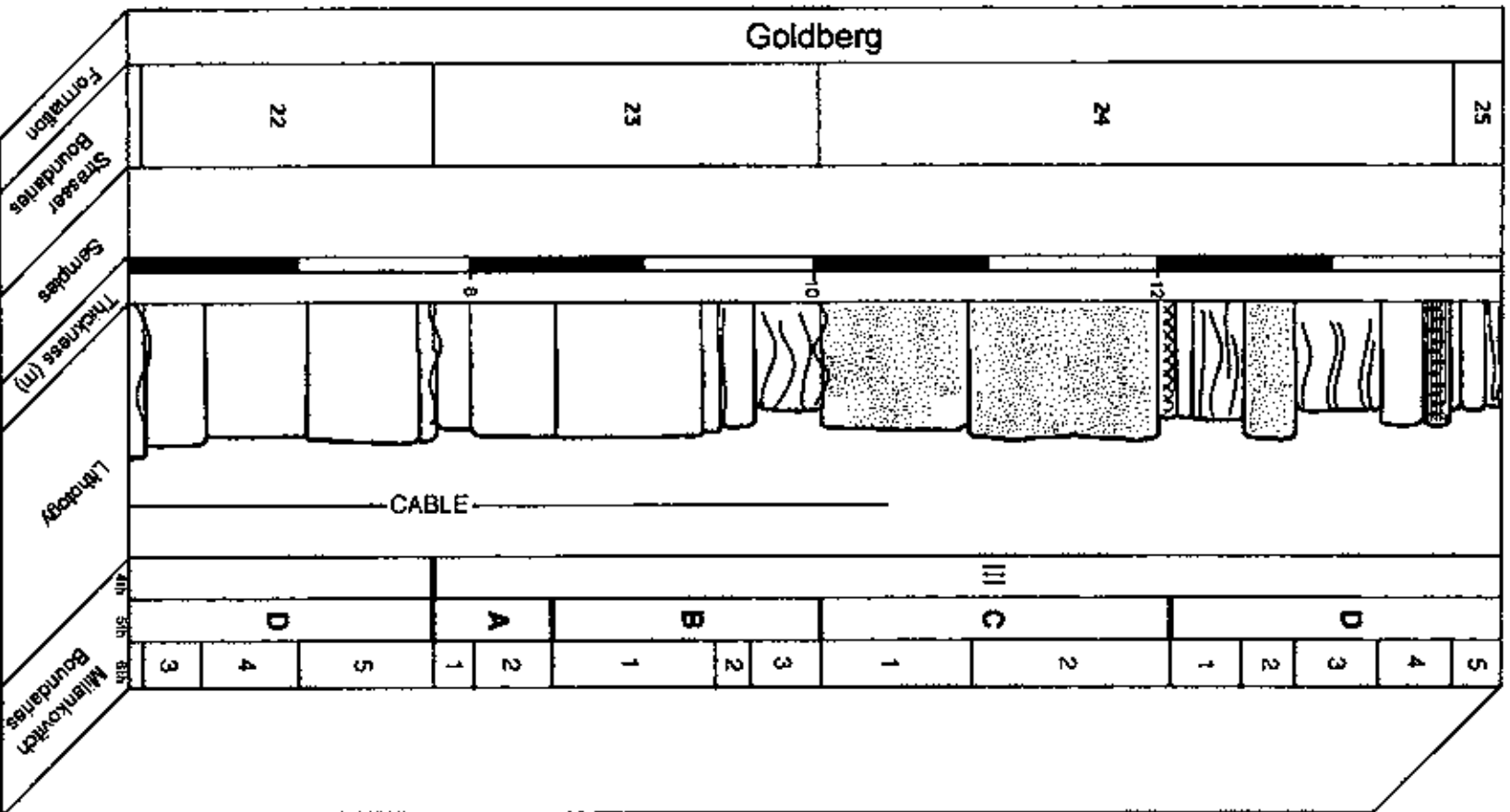


Figure 24. (continued)

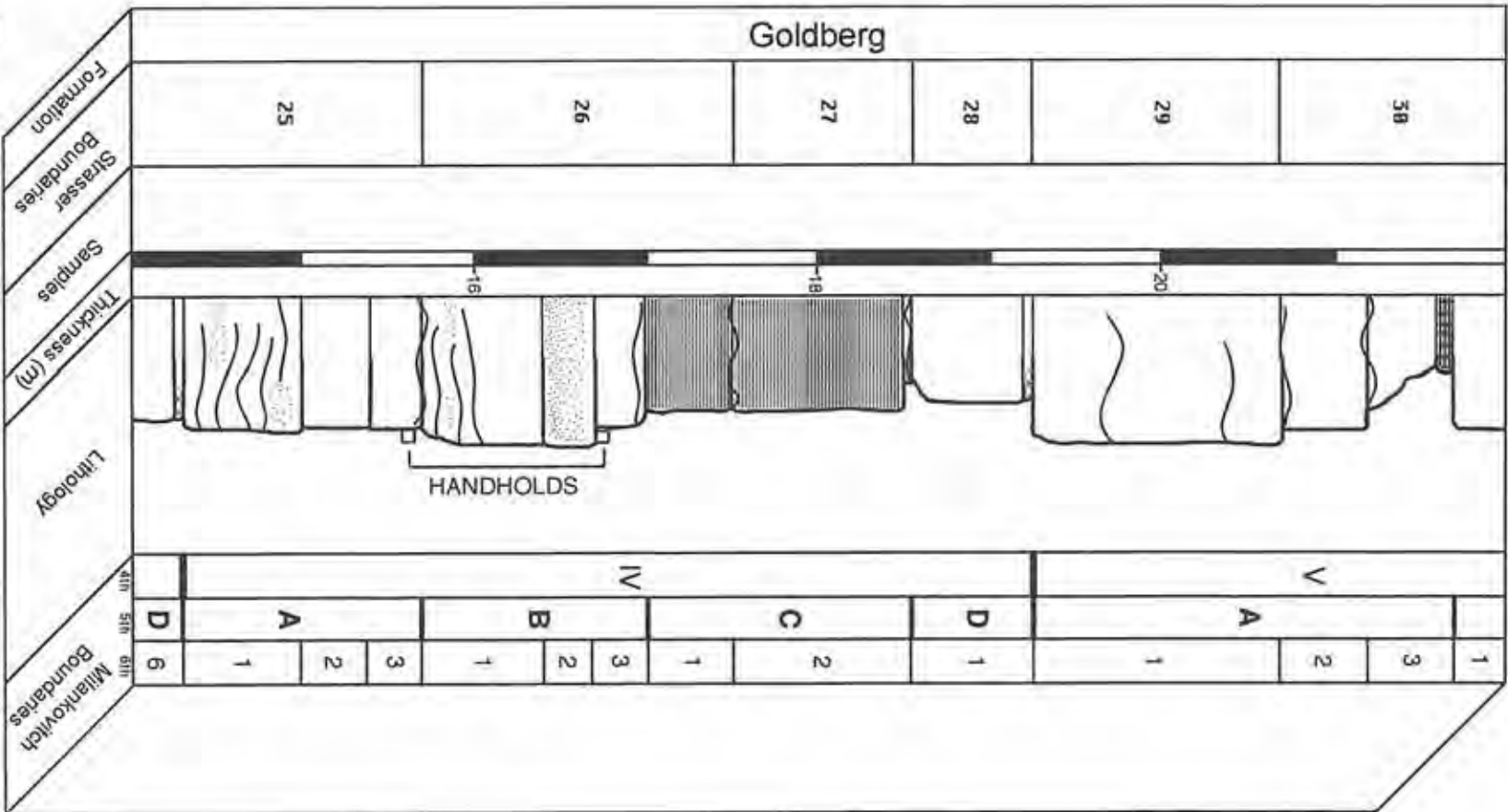


Figure 24. (continued)

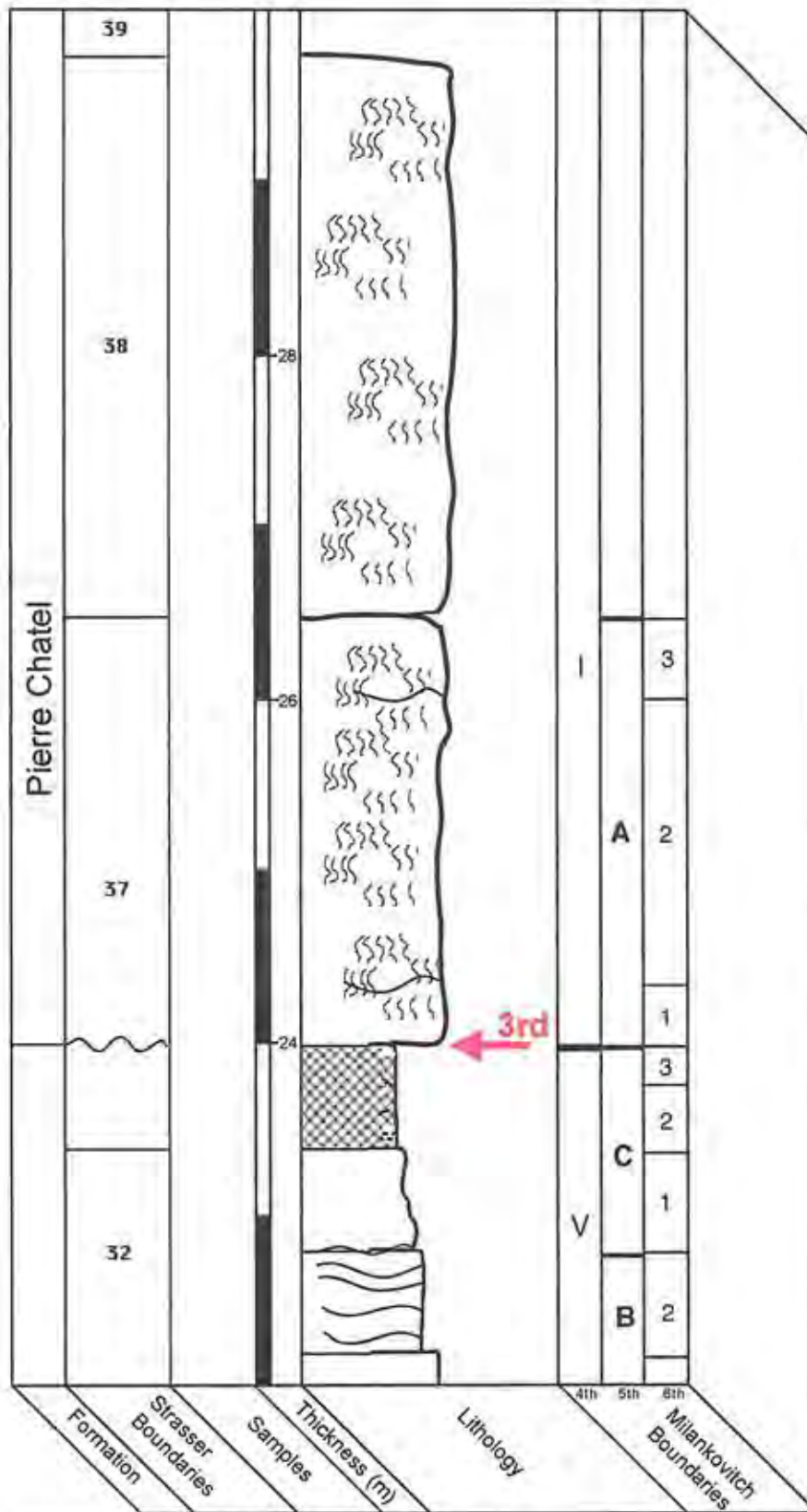


Figure 24. (continued)

a calcarenite bed overlain by marl with mudcracks. The B 5th order sequence contains two PACs. PAC 1 consists of a single calcarenite bed with marl on top. PAC 2 is composed of a marly limestone with a thin shale bed on top. Sequence C starts with a massive calcarenite (PAC 1) bed and ends with PACs 2 and 3 that consist of soily rubble zones with marl and black pebbles.

Crozet

At the locality near Crozet all the 4th order sequences are complete except for the V 4th, which is composed of only the A and B 5th order sequences (Figure 25). Similar to Salève, this section shows an abundance of marl and soil beds near the formational and 3rd order boundary, here these facies are shallower and more restricted than at Salève. Also, the study interval is 16.75 meters thick and therefore is more condensed than at the Salève type section. The II 4th order sequence is significantly condensed and measures two meters less than at the other two localities (Salève and Yenne). The V 4th order sequence is missing the C and D 5th order sequences. The A sequence is composed of four PACs, each consisting of a calcarenite bed topped with a thin 1-3 cm marl. The B sequence contains two PACs. PAC 1 starts with a fossiliferous micrite (sample R-3) with foraminifera, pelecypods, and ostracods, and ends with a poorly developed 1.5 meter paleosol (paleosol R-2, Table 1, Appendix A and B). PAC 2 is truncated at the 3rd order boundary and is composed a marly fossiliferous micrite that contains the same fossils as in PAC 1 (sample R-1, Appendix A and B)

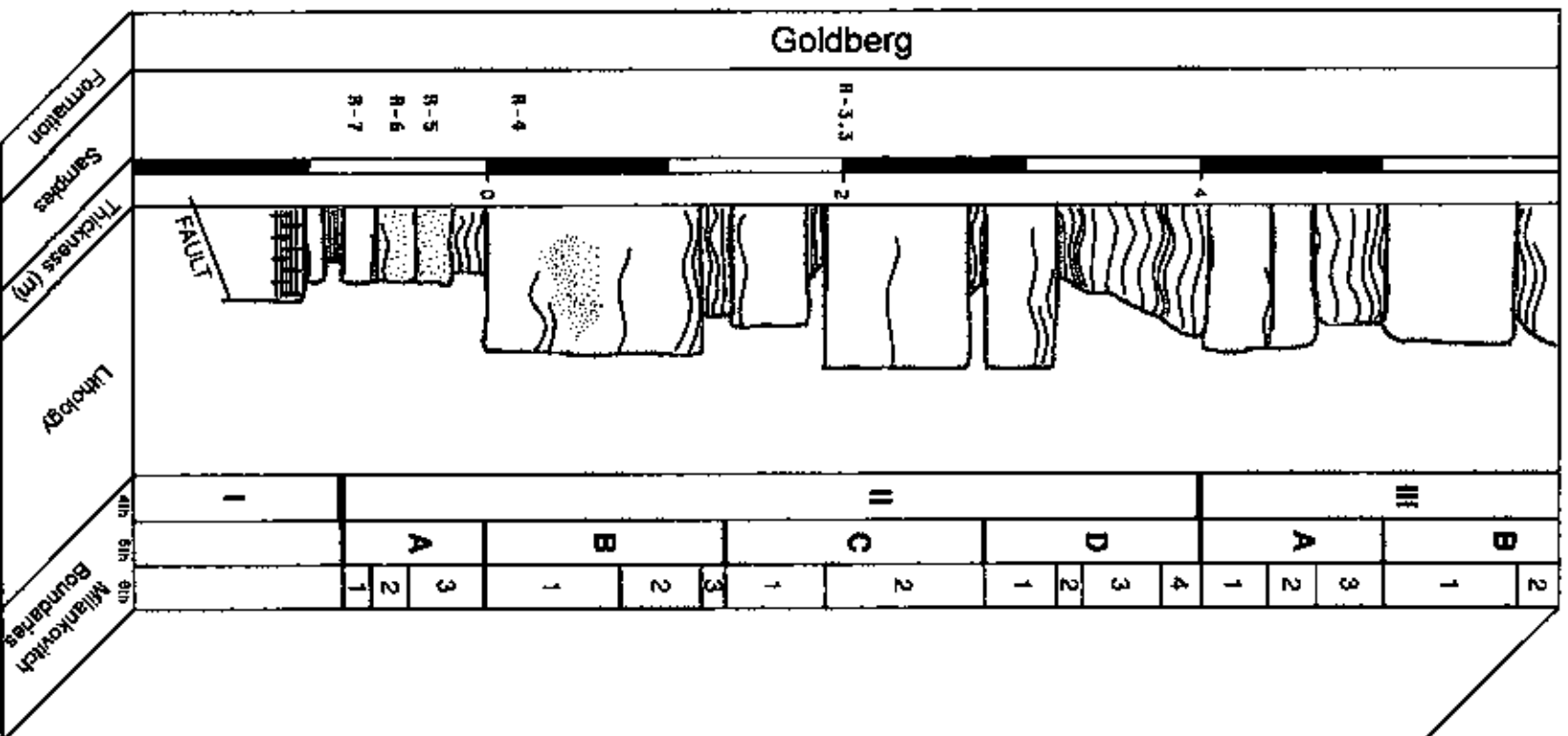


Figure 25. Lower interglacial at Crozet.

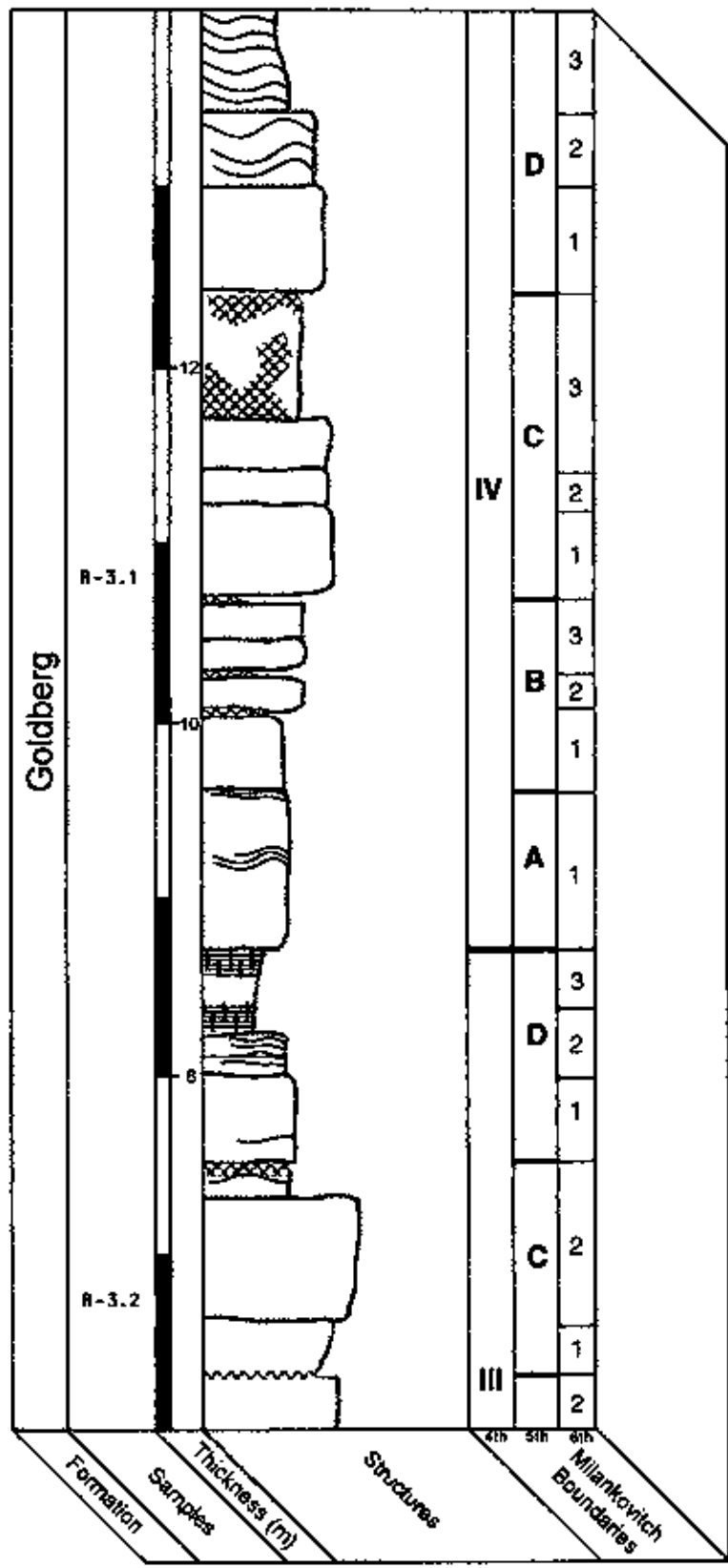


Figure 25. (continued)

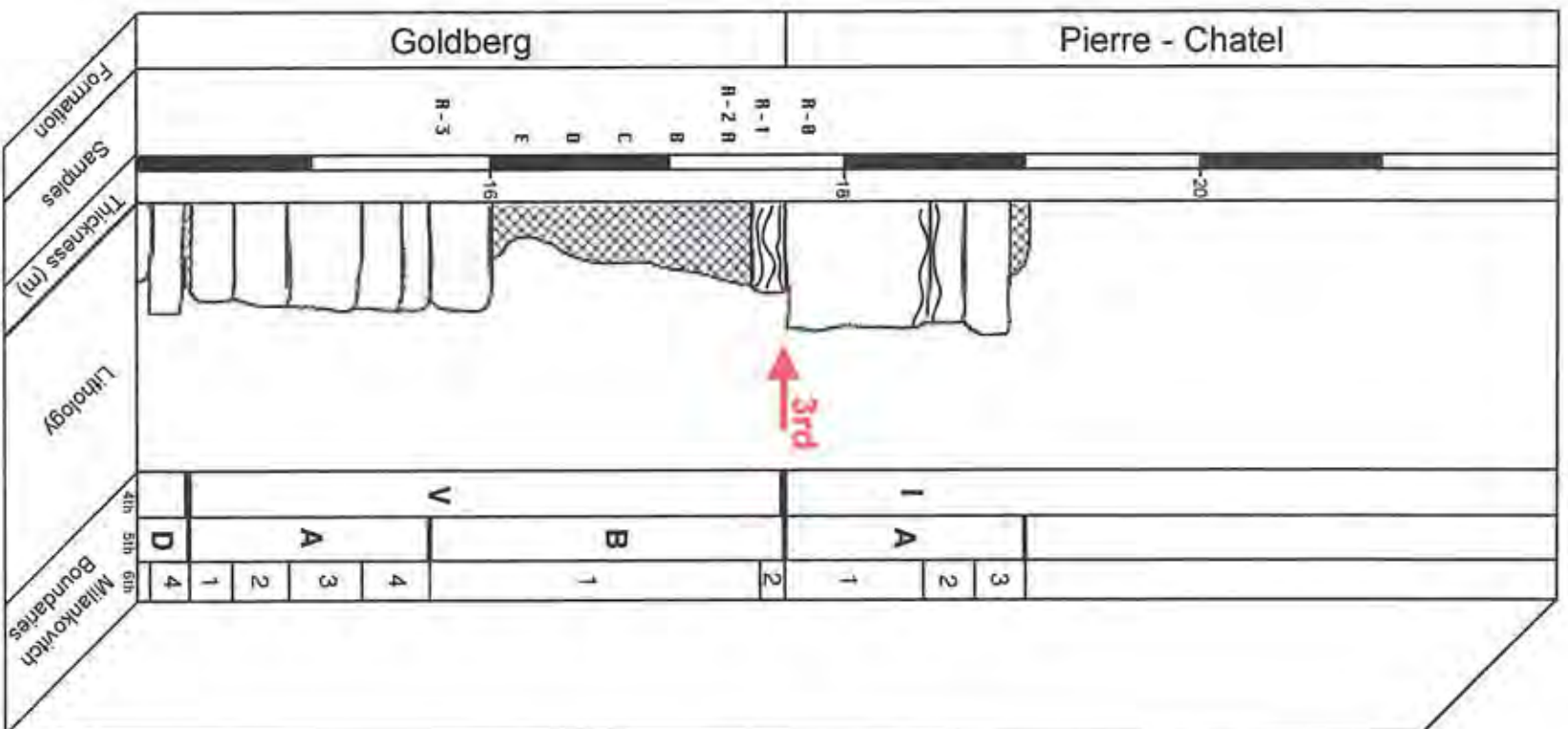


Figure 25. (continued)
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Yenne

The study interval at Yenne measures 18.5 meters and is more condensed than that at Salève, but is thicker than the Crozet locality (Figure 26). The overall facies trend follows the one at Salève except that the shale and rubble beds just below the Goldberg/Pierre-Chatel boundary are much thicker. The III and IV 4th order sequences at this locality are mostly complete and the IV 4th is missing the D 5th order sequence. A soily and rubble bed appears where this sequence is missing. The V 4th order Figure 26a sequence is condensed to only the A component. The A component contains three PACs that are represented by marls below and soils above. This 4th order sequence again shows that 5th order sequences (B, C, and D) are missing where soils and rubble beds are present and at the lower 3rd order and Goldberg/Pierre-Châtel Formational boundary.

Upper Interval

The upper study interval also encompasses a 3rd order boundary and is characterized by restricted marine facies in the Vions Formation and more marine facies in the massive beds of the overlying Chambotte Formation. The Vions Formation consists of more shale and paleosol beds than the Goldberg Formation in the lower interval. The shallowest beds of a sequence often have features such as burrows or reworked sediment with rubble. However, deeper water marine facies appear in the upper 10 meters of the Vions Formation. These deeper water facies lie directly on top of the upper 3rd order boundary (Anderson, personal communication 2002). The Chambotte Formation overlies the Vions and its facies are more marine than the facies of the

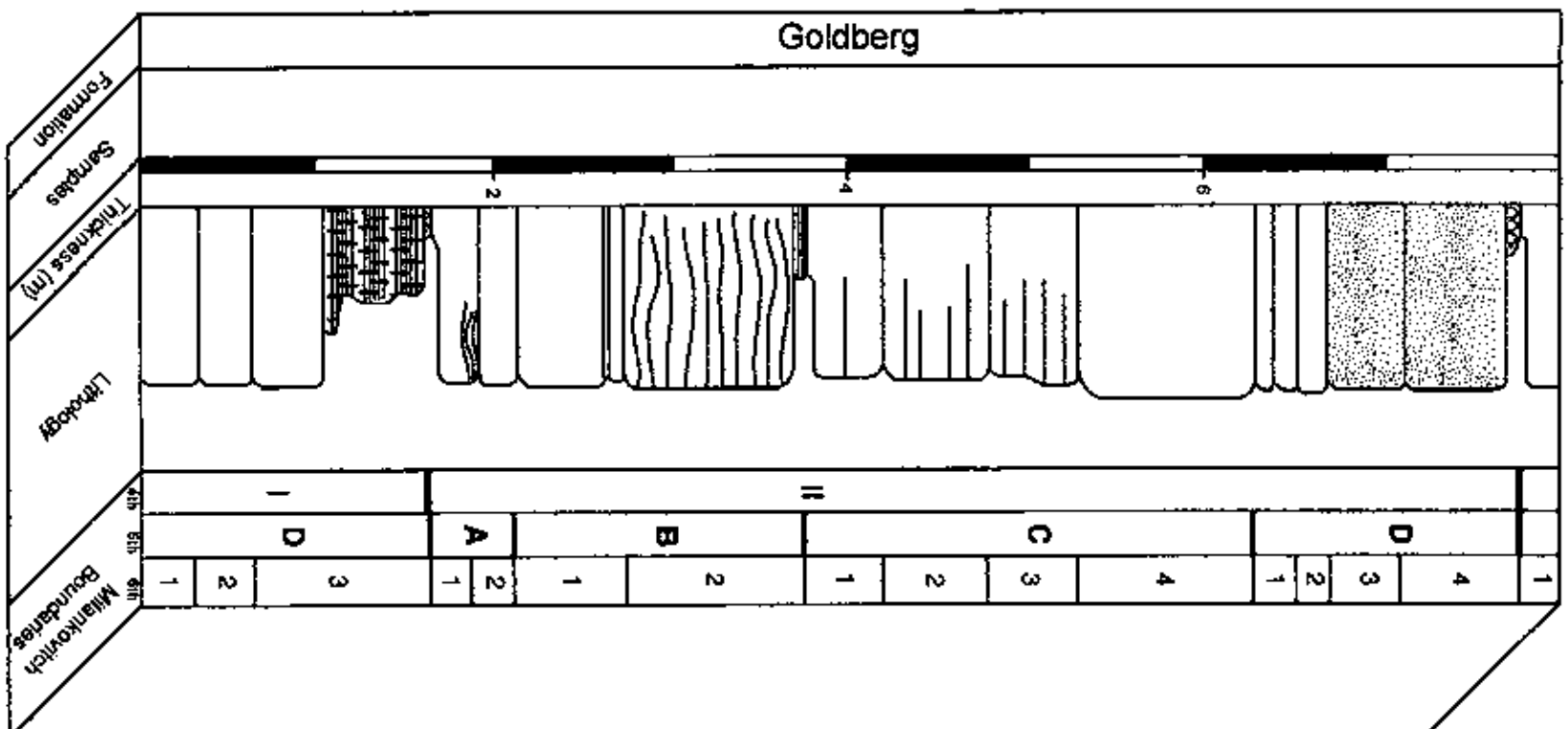


Figure 26. Lower interval at Yenne.

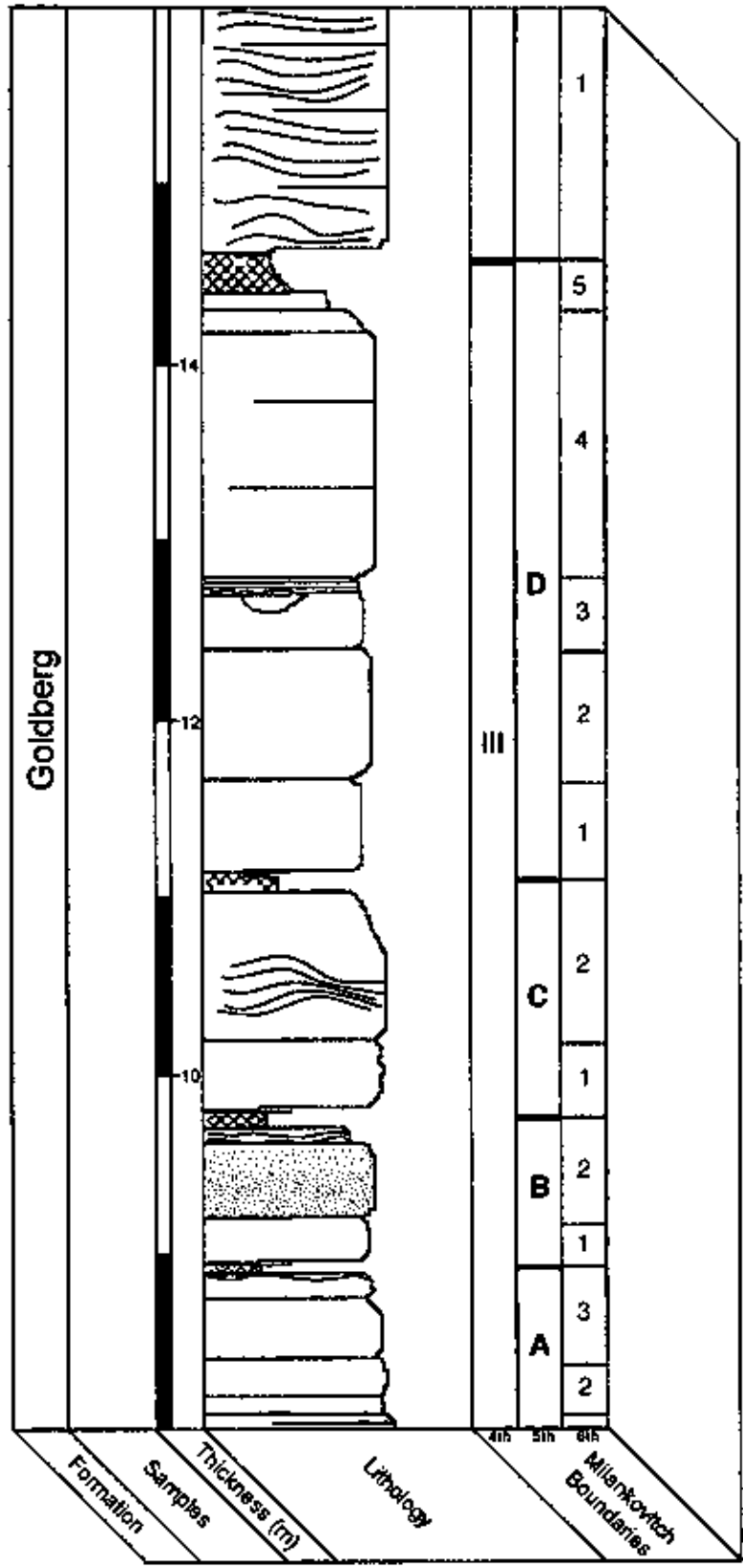


Figure 26. (continued)

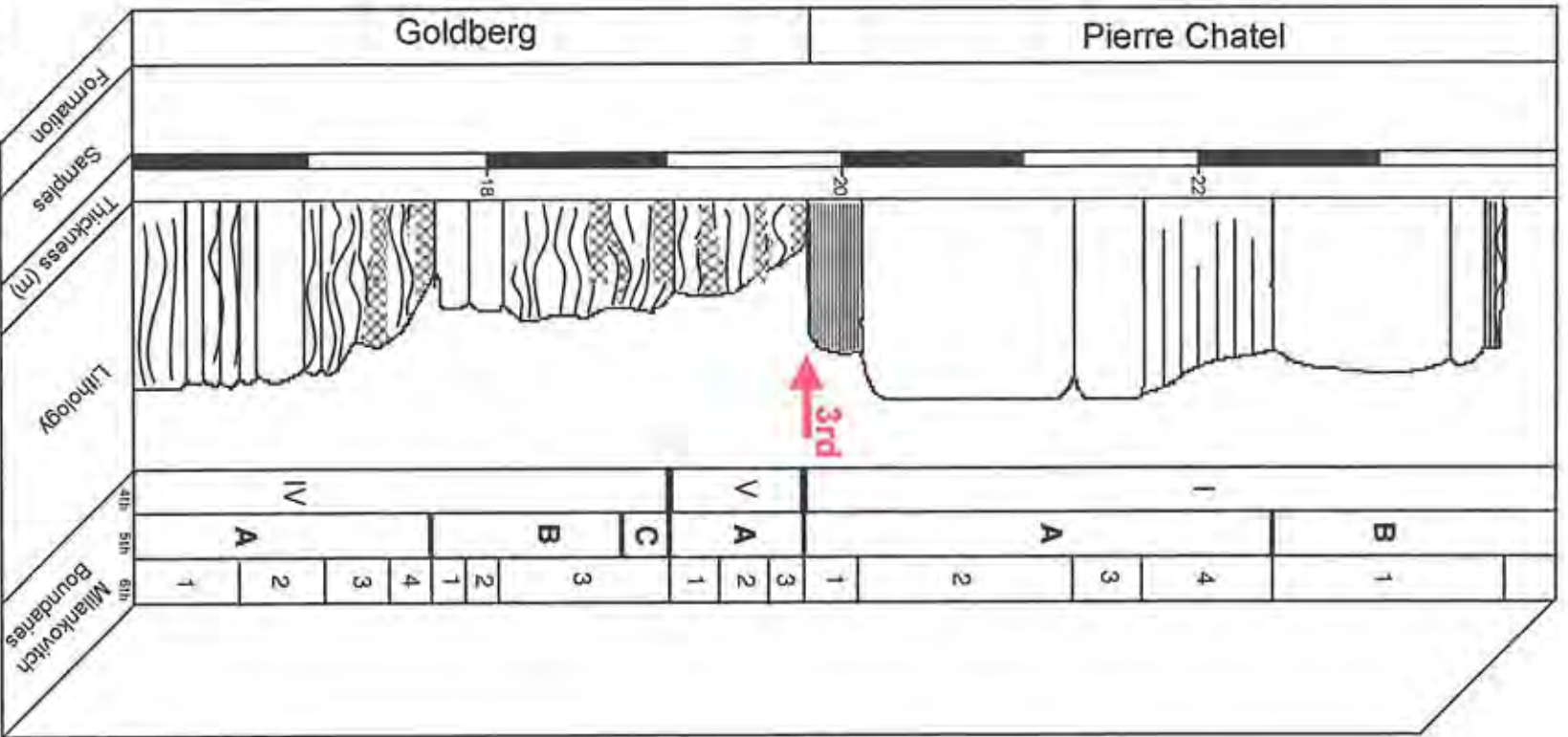


Figure 26. (continued)
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underlying Vions Formation. The beds are more massive in the Chambotte Formation with little soil or shale. Peloids are particularly abundant in macro- and microfacies of limestones in the Chambotte Formation, especially in the Salève section. Microscopic observations reveal an abundance of packed biomicrite beds at Crozet and Salève (Appendix A and B). However, the section at Chapeau de Gendarme is dominated by unsorted biopelsparite and poorly washed biosparite limestones. Fossils in thin sections of limestones in the Chambotte Formation include echinoderm spines, ostracods, foraminifera, and pelecypods.

The upper study interval in The French Jura (i.e., the upper parts of the Vions Formation) coincides with Strasser boundaries 59/60 and Be8 (Figure 3). The study interval consists of one 4th order sequence that starts at a 3rd order boundary and ends at the Vions/Chambotte Formational boundary (Figure 27). Strasser and Hillgärtner (1998) interpret two 4th order sequences (400 ka) within this interval and their 100 ka boundaries coincide with both 5th and 6th order boundaries in this study (Figure 27).

This interval is equivalent to the upper interval in England (Anderson, 2001a). It consists of one 4th order sequence labeled as 'I'. The overall change in facies toward the Vions/Chambotte boundary is from more limestone to more shale and soil rich. At all locations except Yenne this 4th order sequence has all 5th order components preserved (A, B, C, and D).

Salève

The study interval at Salève contains one 4th order sequence that measures 12.2 meters in thickness (Figure 27). The A 5th order sequence consists of three PACs. PAC

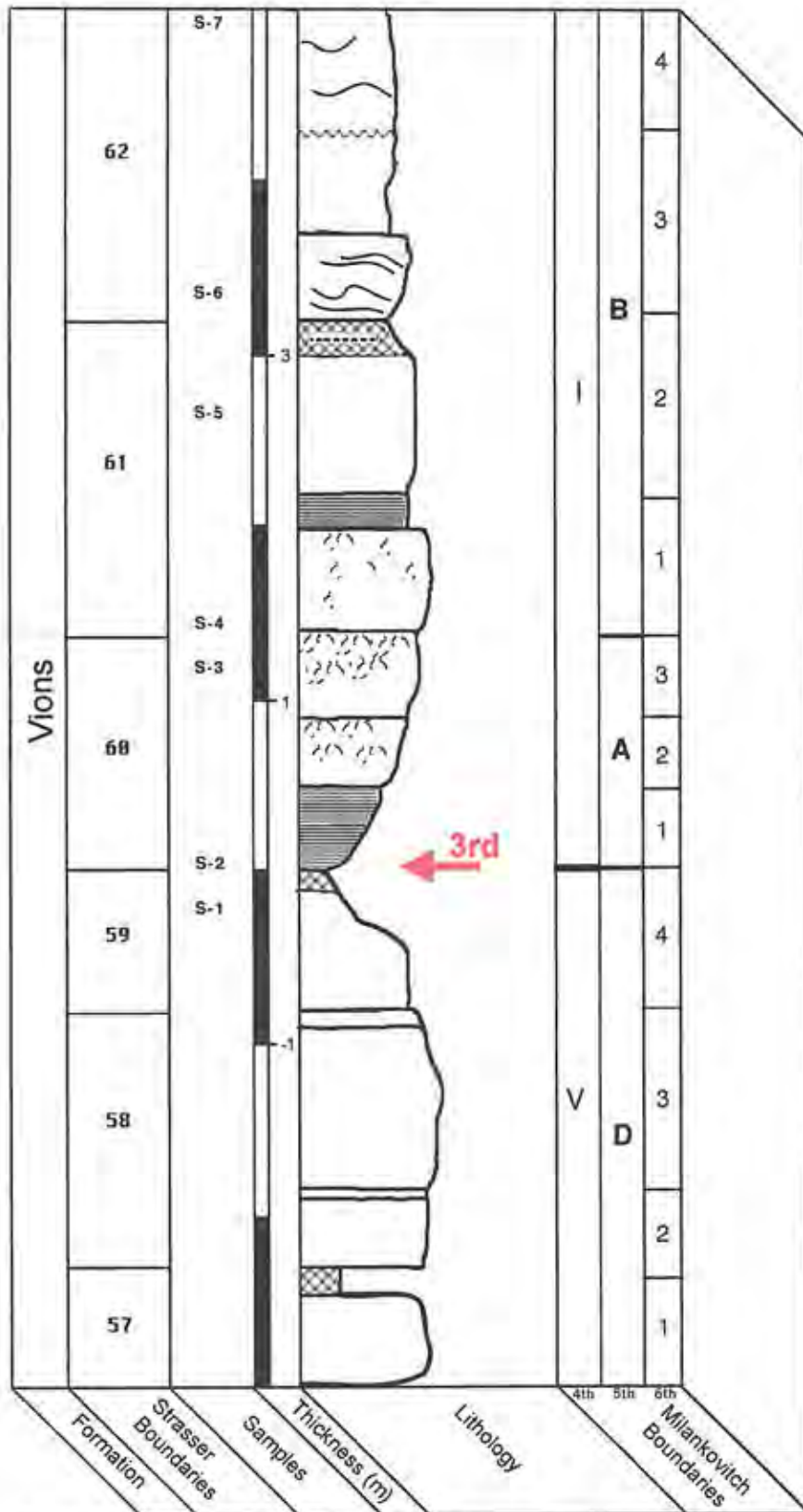


Figure 27. Upper interval at Saleve.

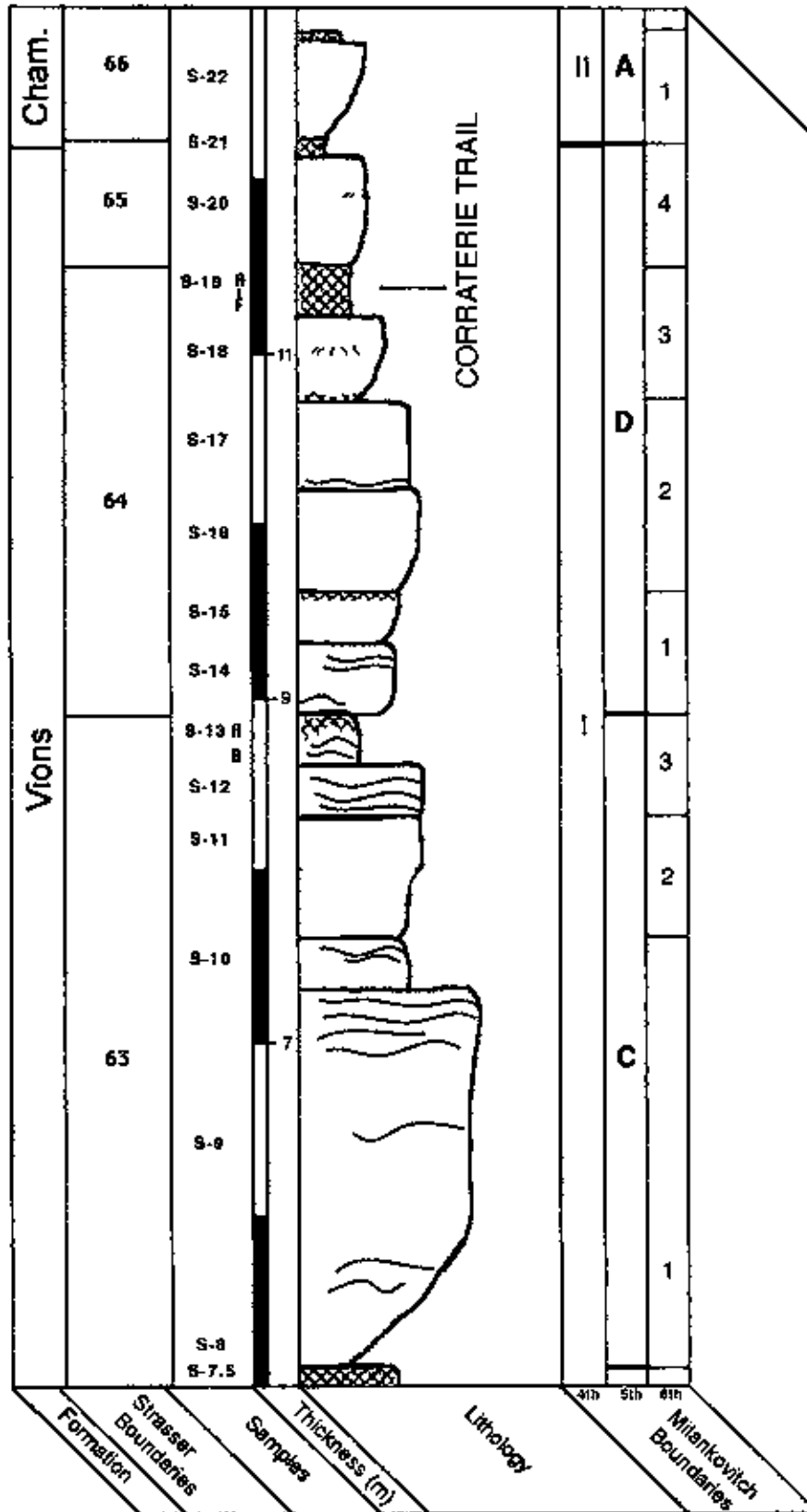


Figure 27. (continued)

1 is composed of marly limestone and PACs 2 and 3 both consists of a carbonate bed with burrows. Microfacies for PAC 3 indicate packed biomicrite with an abundance of foraminifera, calpionellids, pelecypods, ostracods, gastropods, and dasycladacean green algae (sample S-3, Appendix A and B). Microfacies also show peloids, intraclasts, diagenetic hematite and pyrite, and geopetal structures. The B component contains four PACs. PAC 1 consists of a poorly washed sparite bed with fossils (sample S-5) below with shale on top. PAC 2 consists of a massive packed biomicrite bed with fossils (sample S-5) and a rubble rich soil on top. PAC 3 consists of a packed biomicrite bed with fossils (sample S-6) that is overlain by a limestone bed. The boundary of PAC 3 is above a very thin soily layer. PAC 4 consists of a poorly washed intrasparite bed with fossils (sample S-7) and a soil above. The C 5th order sequence contains three PACs. PAC 1 starts with a massive packed biomicrite bed with fossils (sample S-8) at the base and a sparse biomicrite bed with fossils (sample S-9) at the top. PAC 2 is composed of a poorly washed biopelsparite bed with fossils (sample S-11). PAC 3 starts with a poorly washed biopelsparite bed with fossils (sample S-12) and ends with a marly soil rich bed on top. The D component contains four shallowing upward PACs. PAC 1 and 2 is each composed of two packed biomicrite beds (samples S-14, 15, 16, and 17) and a thin soil bed below the upper boundary. PAC 3 starts with a packed biomicrite bed with fossils and burrows (sample S-18) that ends with a poorly developed paleosol (paleosol S-19, Figure 42, and Table 4). PAC 4 is composed of a pelmicrite bed with fossils (sample S-20) overlain by a soil.

Crozet

This 4th order sequence is complete and measures 8.4 meters (Figure 28). The A 5th order sequence is composed of three PACs. PACs 1 and 2 each consists of a peloid-rich calcarenite bed. PAC 3 consists of a massive packed biomicrite bed with fossils (sample C-9) and a marl on top. The B component consists of five PACs, all of which start with a calcarenite bed, with either bedding planes or peloids, and ends with either shale, marl, or a soil. PAC 1 starts with a packed biopelmicrite bed with fossils (sample C-8) and ends with shale. PAC 2 contains a packed biomicrite bed with fossils (sample C-7) and shale on top. The C component contains three PACs. PAC 1 consists of a peloid-rich calcarenite bed. PAC 2 is a poorly washed intrapelsparite bed with few fossils (sample C-5). PAC 3 starts with a poorly washed intrapelsparite bed with few fossils (sample C-4) and ends with a marl. PAC 4 consists of a peloid-rich calcarenite bed overlain by a marl bed. The D sequence contains three PACs. PAC 1 is a marly limestone bed. PAC 2 contains a poorly washed biosparite bed with few fossils (sample C-3) overlain by a limestone bed. PAC 3 consists of a marly bed overlain by a soil.

Chapeau de Gendarme

This interval is complete and measures 9.75 meters (Figure 29). This interval becomes more soil and shale rich towards the formational boundary, but in general the section contains much more rubble, bioturbation, and soil than at the other localities. The A component measures 1 meter thicker than at Crozet and consists of three PACs. PACs 1 and 2 both start with a peloid-rich calcarenite bed with either shale or marl, and ends

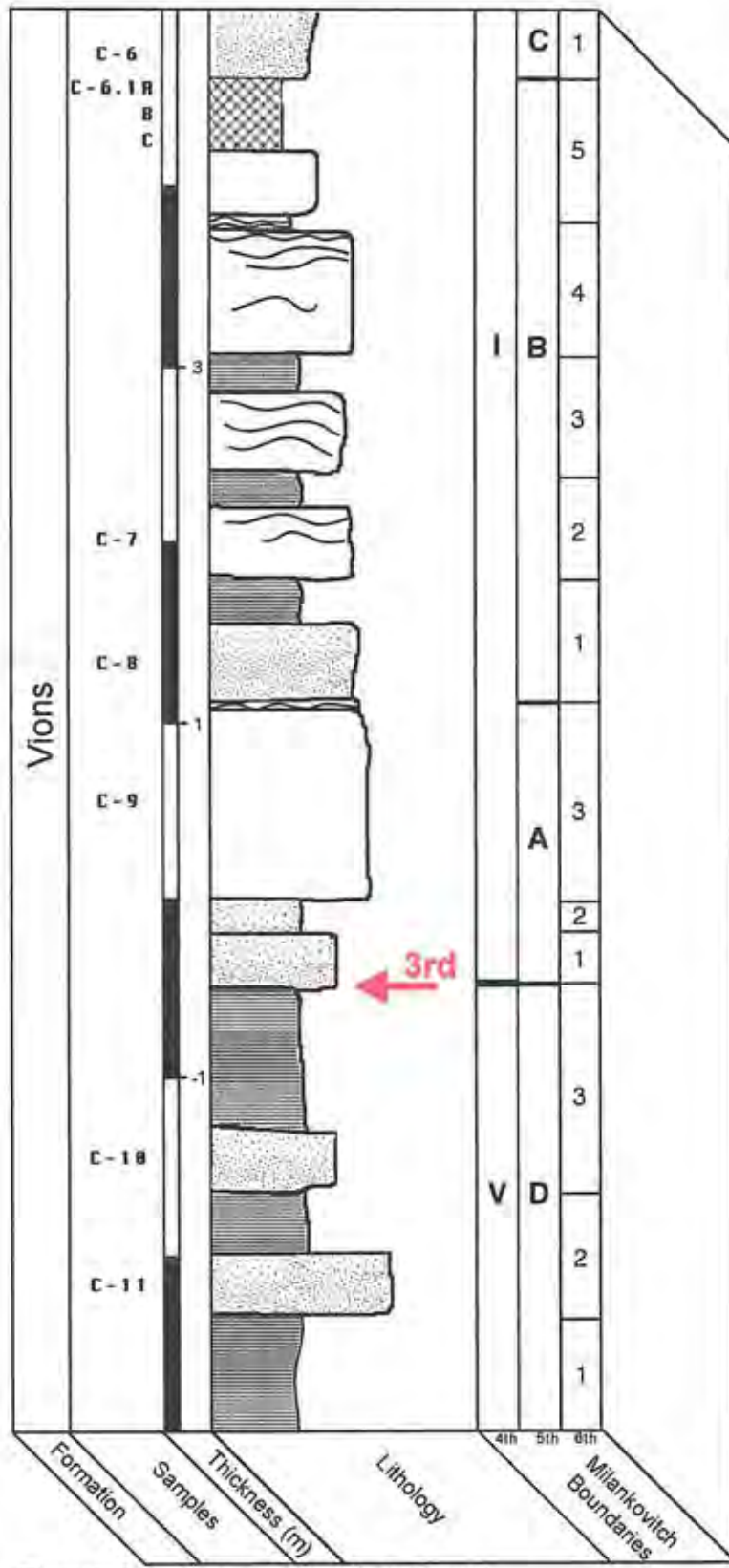


Figure 28. Upper interval at Crozet.

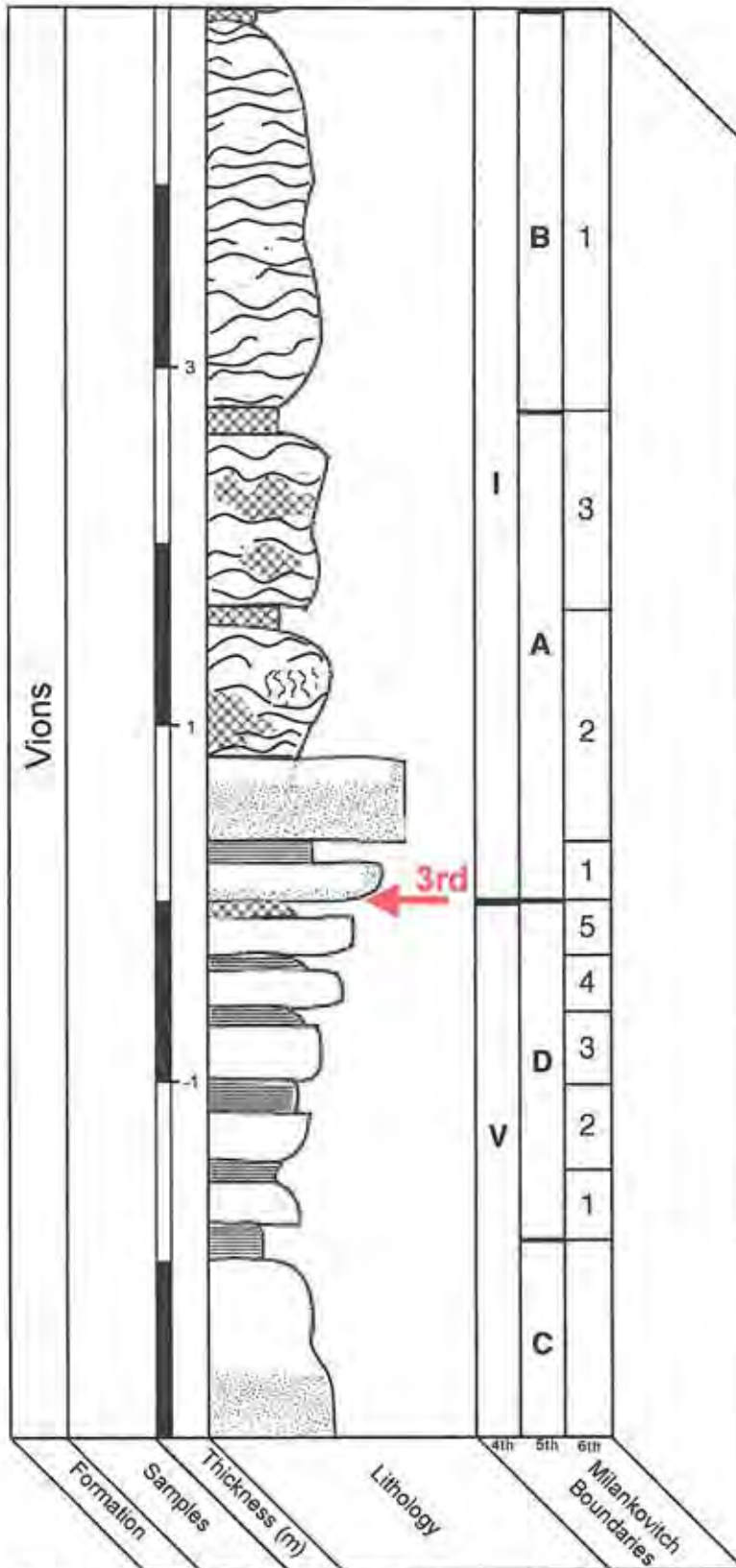


Figure 29. Upper interval at Chapeau de Gendarme.

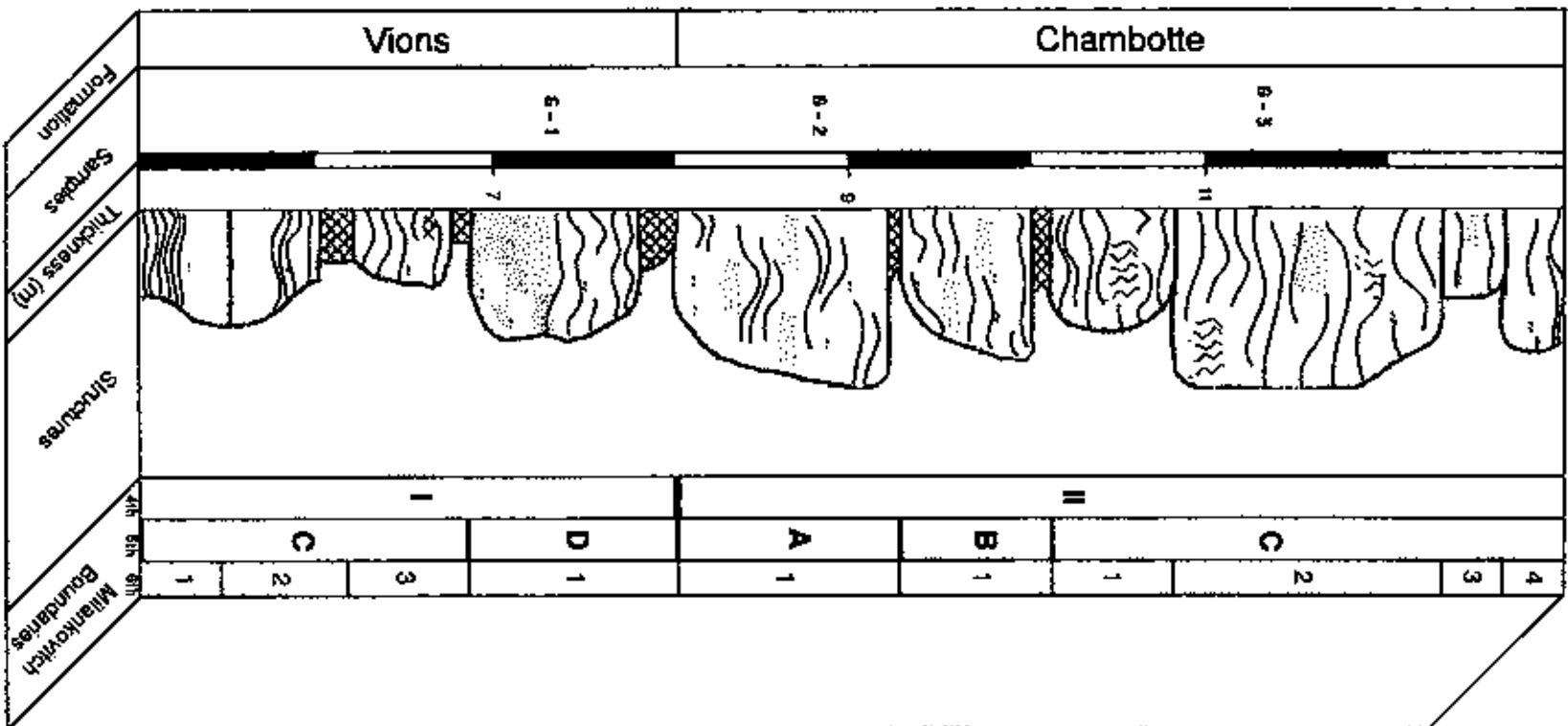


Figure 29. (continued)

with a soil. PAC 3 consists of a bioturbated marl that terminates with a soil. The B sequence consists of one PAC that is composed of a bioturbated marl that terminates with a soil. The C component consists of three PACs that are each composed of bioturbated marl, with soil at the top of PACs 2 and 3. The D sequence contains one PAC that consists of a peloid rich calcarenite bed followed by bioturbated marl and capped with a soil.

The Dorset coast

In Dorset, England, Purbeck sediments in the Wessex Basin consist of mainly brackish marine to freshwater facies (Morter, 1984). These rocks are divided into the Durlston and Lulworth Formations. The type section of the Purbeck is at Durlston Bay. Forbes (1851) divided the Purbeck Beds of the Dorset coast into the Lower, Middle, and Upper Purbeck based on differences in lithofacies and biofacies. The Lower Purbeck is mainly composed of brackish water fossils including *Hydrobia*, *Procardia*, and *Serpula* (Morter 1984). The study intervals are in the Middle and Upper Purbeck described below. Wimbledon (1987) states that these sections are the finest in Northwest Europe.

Lower interval

The lower study interval is within the Middle Purbeck and in the upper part of the Lulworth Formation. It is divided by Clements (1993) into two members recognized by differing bio- and lithofacies: the Marly Freshwater and the Cherty Freshwater Members. These beds mostly contain fossils that are representative of brackish and freshwater environments, except for some beds in the upper parts of each member that contain more

marine facies. The study interval contains two distinct soils that are extremely useful in correlation; they include the 'mammal bed' (Clements, 1993; bed 83) and the 'fern bed' (top of bed 93). The mammal bed is a thick dark soil composed of rich black dirt and leaves, and is associated with the lower 3rd order boundary (Anderson, 2001a). The fern bed may be equally developed, but is thinner at all localities and occurs at a 5th order boundary. A meter thick chert-bearing freshwater limestone bed with abundant charophytes is also prominent in the lower interval. These beds are present at every locality and are marker beds that can be traced throughout the Dorset coast.

The lower interval consists of the Marly Freshwater and the Cherty Freshwater Members and is composed of almost 50% soils and shale. The bottom of this 4th order sequence marks the lower boundary of a 3rd order sequence. This first 4th order sequence in the Middle Purbeck 3rd order sequence is designated the Mammal 4th after a previously named mammal bone-bearing soil (Clements, 1993; bed 83) that is just above the lower boundary of the sequence. The top part of the B 5th order sequence contains a well-developed root-bearing soil referred to by Clements (1993) as the 'fern bed' (top of bed 93). The mammal and fern beds are two examples of distinct organic rich soils within this interval. The C sequence contains a massive chert-bearing freshwater limestone bed composed of micrite. Unique soil beds along with a massive cherty bed in the C sequence allow for lithological tie points for correlation between the three localities. Facies fine upward within each 5th order sequence and PAC. The thickness of this lower interval is slightly condensed 0.5 kilometers to the south at Durlston Bay (South) and much thinner 25 kilometers to the west at Stair Hole in comparison to the type section at Durlston Bay (North).

Durlston Bay (North)

The lower study interval measures 5.5 meters in thickness and contains all four components of the Mammal 4th (Figure 30). This 4th order sequence shows the A, B, and C sequences reasonably complete with a highly truncated D sequence. The A component contains two PACs. PAC1 consists of a limestone bed with a shaley soil over top of it. PAC 2 starts with a pelecypod-rich marl and ends with a soil. The B sequence contains four PACs. PAC 1 consists of a coarse biosparite bed overlain by a shaley soil. PAC 2 is a marl bed. PAC 3 starts with a limestone bed and ends with a soil. PAC 4 starts with a thin limestone bed and is overlain by a shale bed. PAC 5 consists of a limestone bed overlain by a soily pelecypod rich bed with the fern bed soil on top. The C 5th order sequence has three PACs in it. PAC 1 starts with a limestone bed and ends in a shale bed. PAC 2 starts with two limestone beds at the base and ends with a cherty-rich marl. PAC 3 consists of a massive cherty limestone bed that is capped with a soil. The D sequence contains one PAC that is condensed to 20 cm, and consists of a carbonate bed with shale on top.

Durlston Bay (South)

The lower interval within the Purbeck beds consists of one 4th order sequence and measures 5.8 meters (Figure 31). This interval is moderately complete with all four 5th order sequences. The A 5th order component consists of one PAC that is composed of shale. The B sequence contains five PACs that show fining upward facies. PAC 1 contains a calcarenite bed with shale on top. PAC 2 consists of a thin chert-bearing

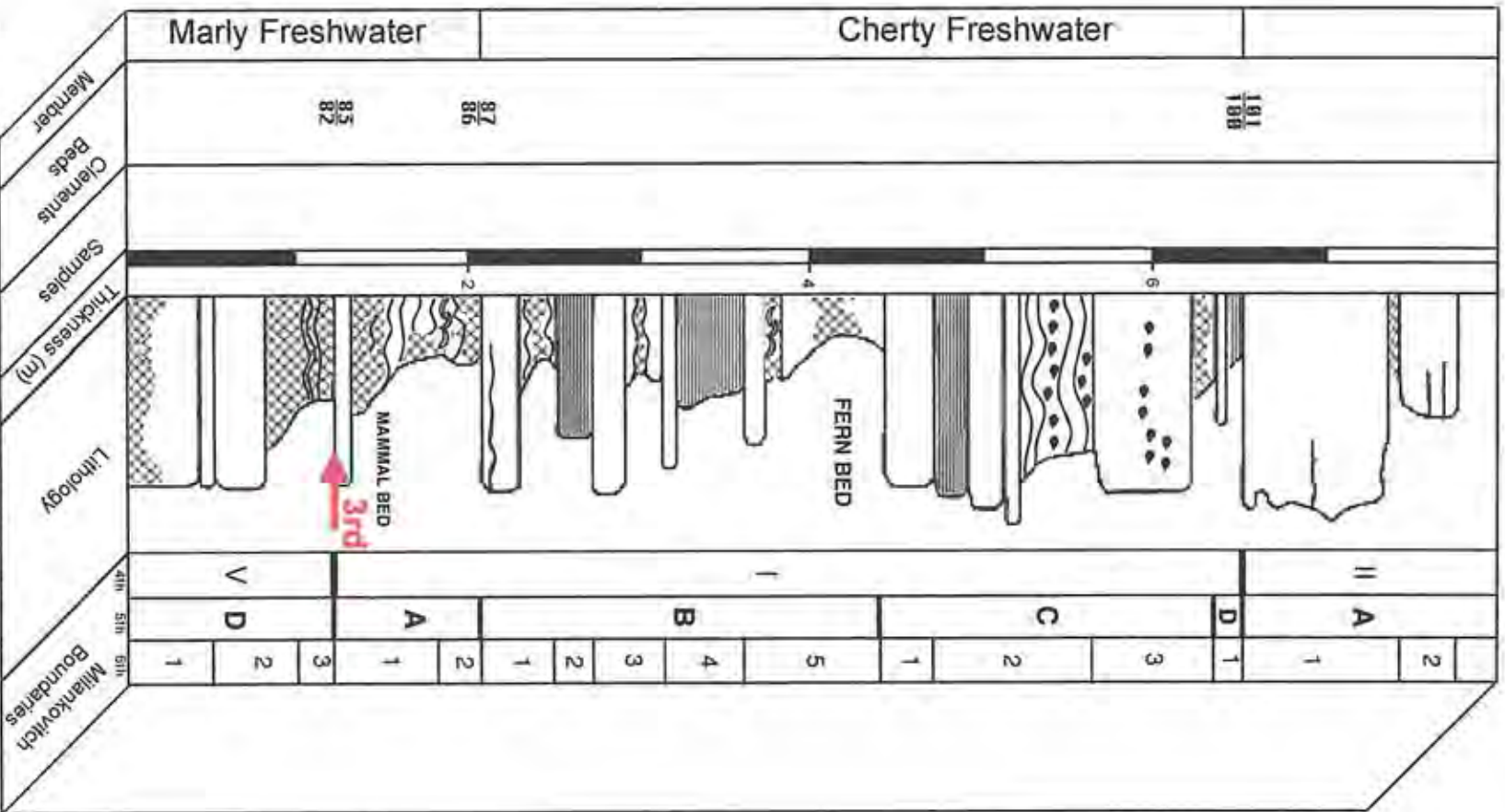


Figure 30. Lower interval at Durlston Bay (North).

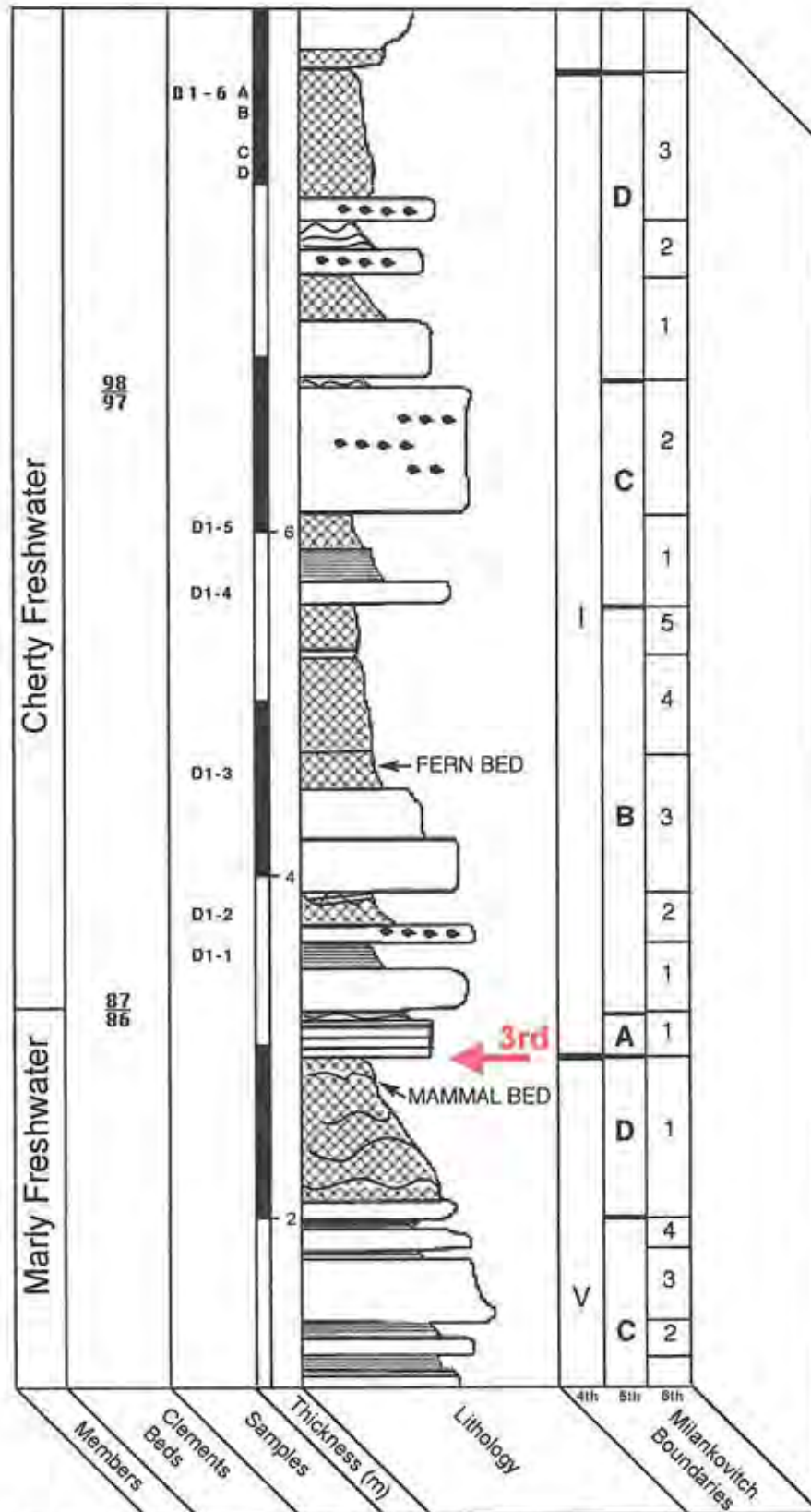


Figure 31. Lower interval at Durlston Bay (South).

limestone bed with a soil on top. PAC 3 consists of two calcarenite beds with the fern bed paleosol on top. PAC 4 is composed entirely of soil. PAC 5 has a thin limestone bed overlain by a soil. The C component contains two PACs. PAC 1 has an unsorted biosparite bed with pelecypods (sample D1-4, Appendix A) at the base and then a shale-rich bed overlain by a soil. PAC 2 is composed of a prominent cherty bed measuring 0.75 meters that is overlain by a marl bed. The D 5th order sequence contains three PACs. PAC 1 contains a limestone bed overlain by a soil. PAC 2 contains a cherty limestone bed overlain by marl. PAC 3 starts with a cherty limestone bed and ends with a well-developed soil with peds (paleosol D1-6).

Stair Hole

This locality contains the most condensed interval with a total thickness of only 2.85 meters, as opposed to the equivalent of 5.5 meters at Durlston Bay North (Figure 32). The A and D 5th order sequences are missing at this locality. The B 5th component starts on top of the 'mammal bed' soil and ends at the 'fern bed', which looks less developed than at the other localities. The B sequence contains five PACs. PAC 1 consists of a soily shale bed and PAC 2 is all shale. PAC 3 consists of a micrite bed with no fossils (sample H-5, Appendix A and B). PAC 4 consists of three micrite beds with no fossils (sample H-4) overlain by a shale bed. PAC 5 starts with a micrite bed with no fossils (sample H-5) and ends with the fern which that contains marl and chert. The C component contains one PAC that starts with the massive cherty packed biomicrite bed with pelecypods (sample H-1) and ends with a shale bed.

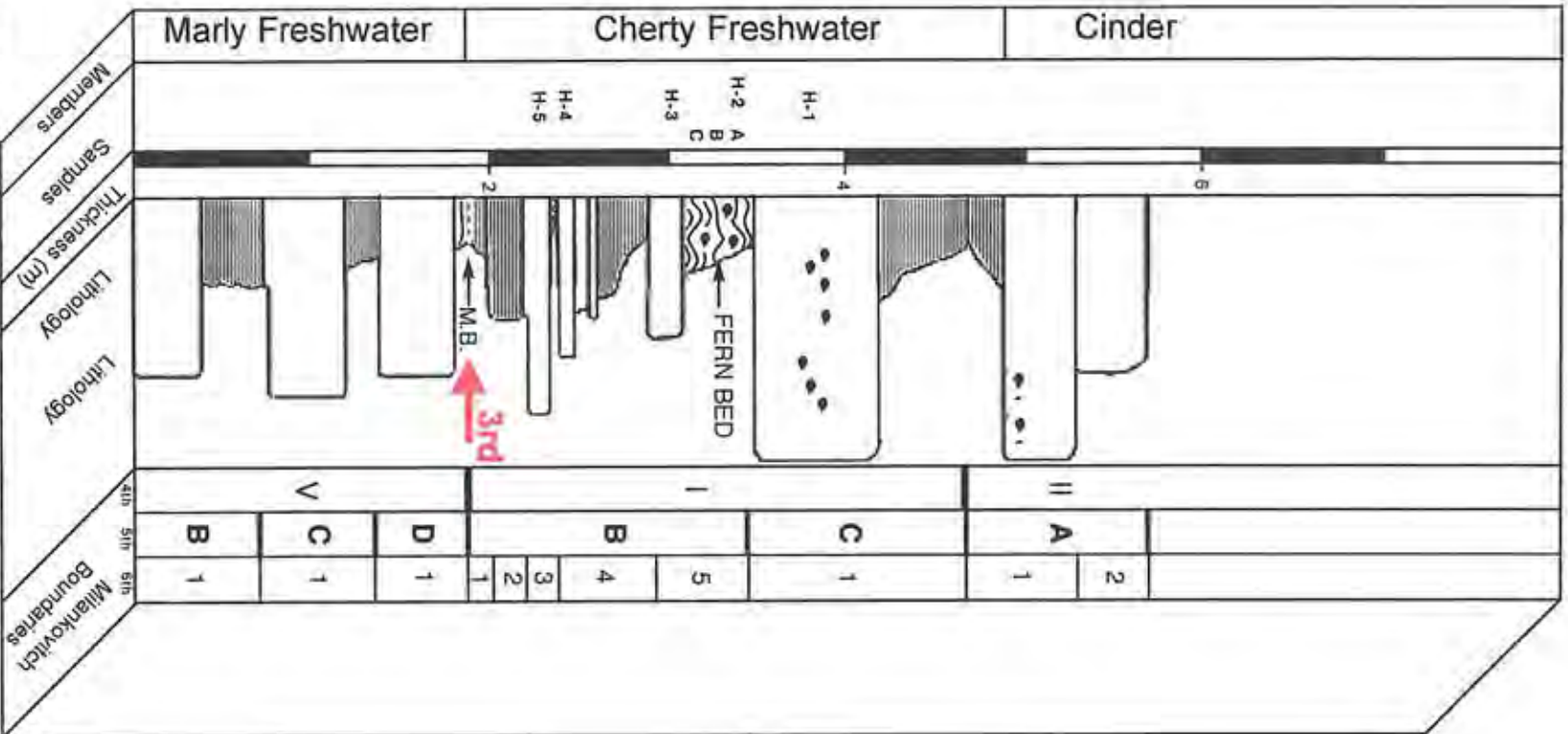


Figure 32. Lower interval at Stair Hole.

Upper interval

The upper study interval is located in the upper parts of the Durlston Formation within the Chief Beef and Broken Shell Limestone Members and is composed of an abundance of lowstand paleosols and shale interbedded with calcarenite beds of deeper water facies. Approximately five meters below the top of the Chief Beef Member, the upper 3rd order boundary is marked by a transition to more deeper water facies above (Anderson, 2001a). The study interval just above this boundary is composed of limestone beds interlayered with soil and diagenetic calcite referred to by Clements (1993) as 'beef'. The microfacies of limestones in the Durlston Bay (North) section directly above the upper interval (Broken Shell Limestone Member) contain unsorted- or poorly washed biosparite (sample D3-8 and S-1). The Broken Shell Limestone Member contain beds that are more massive and facies that change to more marine with little shale. An abundance of pelecypods are observed in all thin sections.

The upper interval in the Purbeck of Dorset consists of one 4th order sequence. It appears in the Chief Beef Member within the Middle Purbeck. The bottom of this 4th order sequence marks the top boundary of a 3rd order sequence, therefore the study interval is the first 4th order sequence in the top Purbeck 3rd order sequence. Within this 4th order sequence the D component is missing at all localities. The interval mainly consists of calcarenite beds and thicker shales with developed paleosols.

Durlston Bay (North)

This 4th order sequence (in the upper study interval) is 3.8 meters thick and consists of the A, B, and C 5th order components (Figure 33). The A sequence consists of

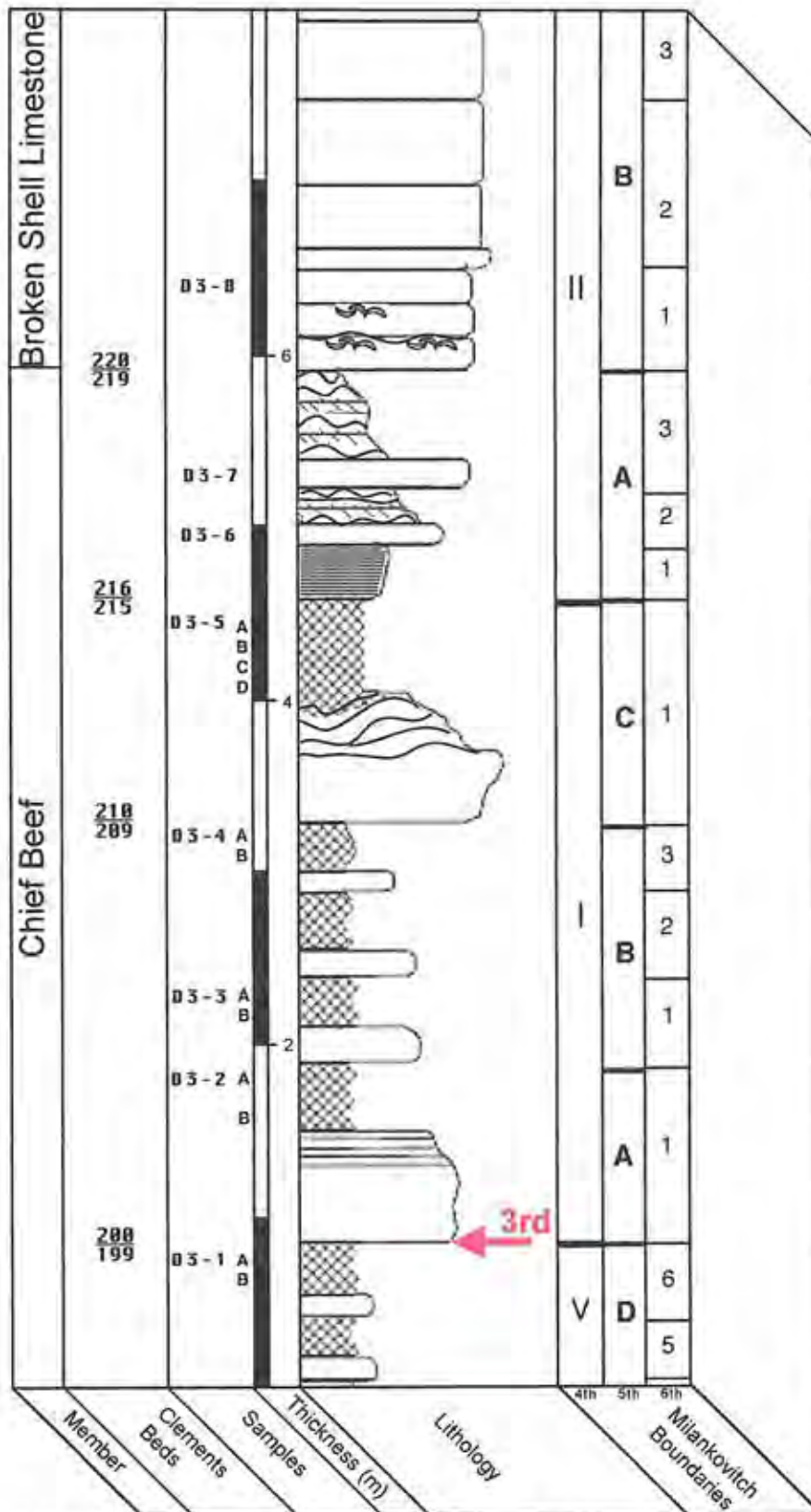


Figure 33. Upper interval at Durlston Bay (North).