Macrofossil magnetobiostratigraphy for the upper Santonian – lower Campanian interval in the Western Interior of North America: comparisons with European stage boundaries and planktonic foraminiferal zonal boundaries

G.D. Leahy and J.F. Lerbekmo

Abstract: Magnetostratigraphic samples were collected from the Milk River and Pakowki formations of southeastern Alberta to determine the polarity chron 34–33r boundary. This boundary was located in the upper half of the Deadhorse Coulee Member, and is below the first local occurrence of the Western Interior ammonite *Baculites obtusus*. Comparison with the laterally equivalent Eagle Sandstone of Montana and Niobrara Formation of Colorado indicates that the 34–33r contact is within either the *Baculites* sp. (smooth) or *Baculites* sp. (weak flank ribs) ammonite zone in the Western Interior of North America. Direct correlation of the *Desmoscaphites erdmanni* through *Baculites asperiformis* Western Interior ammonite zones with magnetobiostratigraphic sections of the upper Santonian – lower Campanian stages in Europe suggests that (*i*) the Santonian–Campanian boundary as defined in Europe is within the lower *Baculites obtusus* Zone and (*ii*) the Western Interior appearance of some ammonites and crinoids (*Scaphites hippocrepis*, *Trachyscaphites spiniger*, *Marsupites*, *Uintacrinus*) is profoundly time transgressive relative to the appearance of these same species in Europe. The date of 84 Ma for the Santonian–Campanian boundary is too old, and a date of around 80 Ma may be more accurate. The Santonian–Campanian boundary defined by ammonites, crinoids, and belemnites in Europe is within the lower part of chron 33r, and is younger than the Santonian–Campanian boundary as determined by planktonic foraminifera at Gubbio, Italy.

Résumé : Des échantillons magnétostratigraphiques ont été prélevés dans les formations de Milk River et de Pakowki, dans le sud-est de l'Alberta, pour déterminer la polarité de la limite séparant les chrons 34 et 33r. Cette limite a été localisée dans la moitié supérieure du Membre de Deadhorse Coulee, et elle est sous-jacente au niveau marquant le début de l'apparition de l'ammonite *Baculites obtusus* dans la plate-forme de l'Intérieur. Une comparaison avec les unités, latéralement équivalentes, du Grès d'Eagle du Montana et de la Formation de Niobrara du Colorado suggère que le contact 34–33r se trouve à l'intérieur de la zone à ammonites *Baculites* sp. (unie) ou *Baculites* sp. (flancs à côtes fines), dans la plate-forme de l'Intérieur de l'Amérique du nord. La mise en corrélation directe des zones à ammonites *Desmoscaphites erdmanni* jusqu'à *Baculites asperiformis* avec les coupes magnétostratigraphiques des étages Santonien supérieur – Campanien inférieur en Europe suggère (*i*) que la limite Santonien–Campanien, telle que définie en Europe, est localisée dans la partie inférieure de la Zone à *Baculites obtusus* et (*ii*) que l'apparition de certaines espèces d'ammonites et de crinoïdes (*Scaphites hippocrepis*, *Trachyscaphites spiniger*, *Marsupites*, *Uintacrinus*) reflète une phase transgressive largement diachronique, relativement à l'apparition de ces mêmes espèces en Europe. La date de 84 Ma assignée à la limite Santonien–Campanien est trop ancienne, une date de 80 Ma serait plus exacte. La limite Santonien–Campanien définie par les ammonites, crinoïdes et bélemnites en Europe est localisée dans la partie inférieure du chron 33r, et elle est plus jeune que la limite Santonien–Campanien telle que déterminée par les foraminifères planctoniques à Gubbio, en Italie.
[Traduit par la rédaction]

Received March 28, 1994. Accepted November 9, 1994.

G.D. Leahy. 2405 Bailey Hill Road, Eugene, OR 97405, U.S.A.
J.F. Lerbekmo. Department of Geology, University of Alberta, Edmonton, AB T6G 2E3, Canada.

Introduction

The Santonian–Campanian stage boundary is usually placed just below the base of magnetic polarity chron 33r (Alvarez et al. 1977). This determination is based on correlation of planktonic foraminifera with magnetostratigraphy, whereas the type sections for the Santonian and Campania stages have been zoned using ammonites (Kennedy 1986, 1987). This has led to disagreement between foraminifera and ammonite specialists as to where the boundary should be designated (Birkelund et al. 1984).

The Western Interior of North America contains a diverse ammonite assemblage (Gill and Cobban 1973), and some species have been directly correlated to the magnetic polarity time scale (Shive and Frerichs 1974). The purpose of this paper is to present new data from the Milk River and Pakowki formations of southern Alberta, linking Western Interior ammonite zones to magnetic polarity intervals, thus determining the relationship of chron 33r to Western Interior ammonite ranges. Magnetobiostratigraphic comparison of the Western Interior upper Santonian – lower Campanian sequence with the Santonian and Campanian stages in Europe will be discussed, and this sequence will be related to the position of chron 33r relative to planktonic foraminiferal zones.

Alberta sections

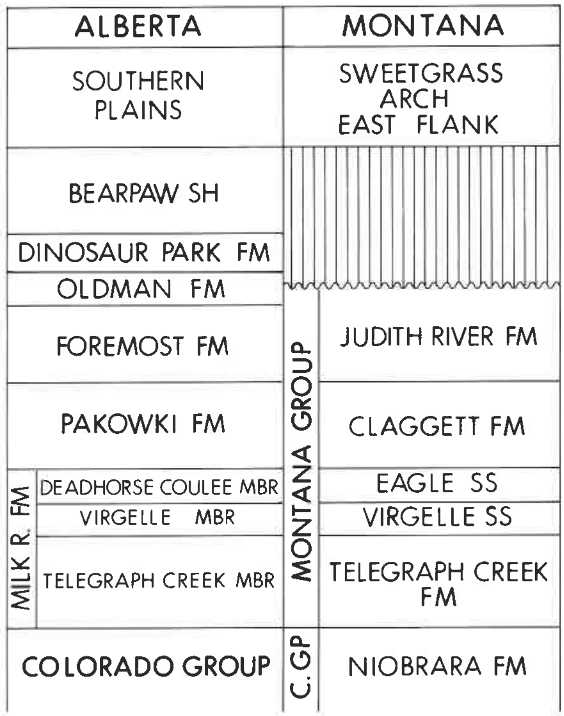
The stratigraphic sequence containing the Santonian–Campanian boundary in southern Alberta and northern Montana is shown in Fig. 1. The marine Colorado shales occur only in the subsurface in southern Alberta except for a small exposure bisecting the International Boundary at Deer Creek in Section 5, Range 12 (Russell and Landes 1940; Wall 1967). The upper beds of the Telegraph Creek Member of the Milk River Formation outcrop at the bottom of the Milk River valley and along Police Coulee in Range 13 (Fig. 2). The overlying Virgelle Sandstone and Deadhorse Coulee members are well exposed from Writing-on-Stone Provincial Park downstream to beyond the bridge over the Milk River (Fig. 2). The stratigraphically higher Pakowki shales crop out only rarely along coulees draining the Sweetgrass Hills into the Milk River. Some of the best outcrops are along Miner's Coulee where Lerbekmo (1989) established the position of the 33–33r polarity boundary in the basal beds of the Foremost Formation (Fig. 2). The base of the Pakowki Formation is also exposed at the south end of Verdigris Lake (Fig. 2).

Magnetostratigraphy

Sampling

Magnetostratigraphic sampling to determine the position of the 33r–34 boundary was continued downward in the Pakowki Formation below the outcrop on Miner's Coulee (M.C.1) that was used to establish the position of the 33–33r boundary (Lerbekmo 1989). The middle Pakowki Formation crops out very poorly and only one useful exposure was found (M.C.2) (Fig. 2). The basal Pakowki was sampled at Verdigris Lake; however, the basal Pakowki is also exposed on Miner's Coulee and this outcrop was used to establish the thickness of the Pakowki in the Milk River field area. The entire Deadhorse Coulee Member of the Milk River Formation is exposed in the vicinity of the bridge over the Milk River in Range 12 (Fig. 2). The entire Virgelle Sandstone Member is exposed in Writing-on-Stone Park, as are the upper few metres of the Telegraph Creek Member (Fig. 2). The Virgelle, however, is a cliff-forming sequence of sandstones, and was not sampled except for one site in the Writing-on-Stone section where the uppermost sandstone unit is locally shaly.

Fig. 1. Stratigraphy of the Sweetgrass Arch area of southern Alberta and northern Montana (after Meijer Drees and Myhr 1981; Eberth and Hamblin 1993). C. GP, Colorado Group; FM, formation; MBR, member; SH, shale; SS, sandstone.

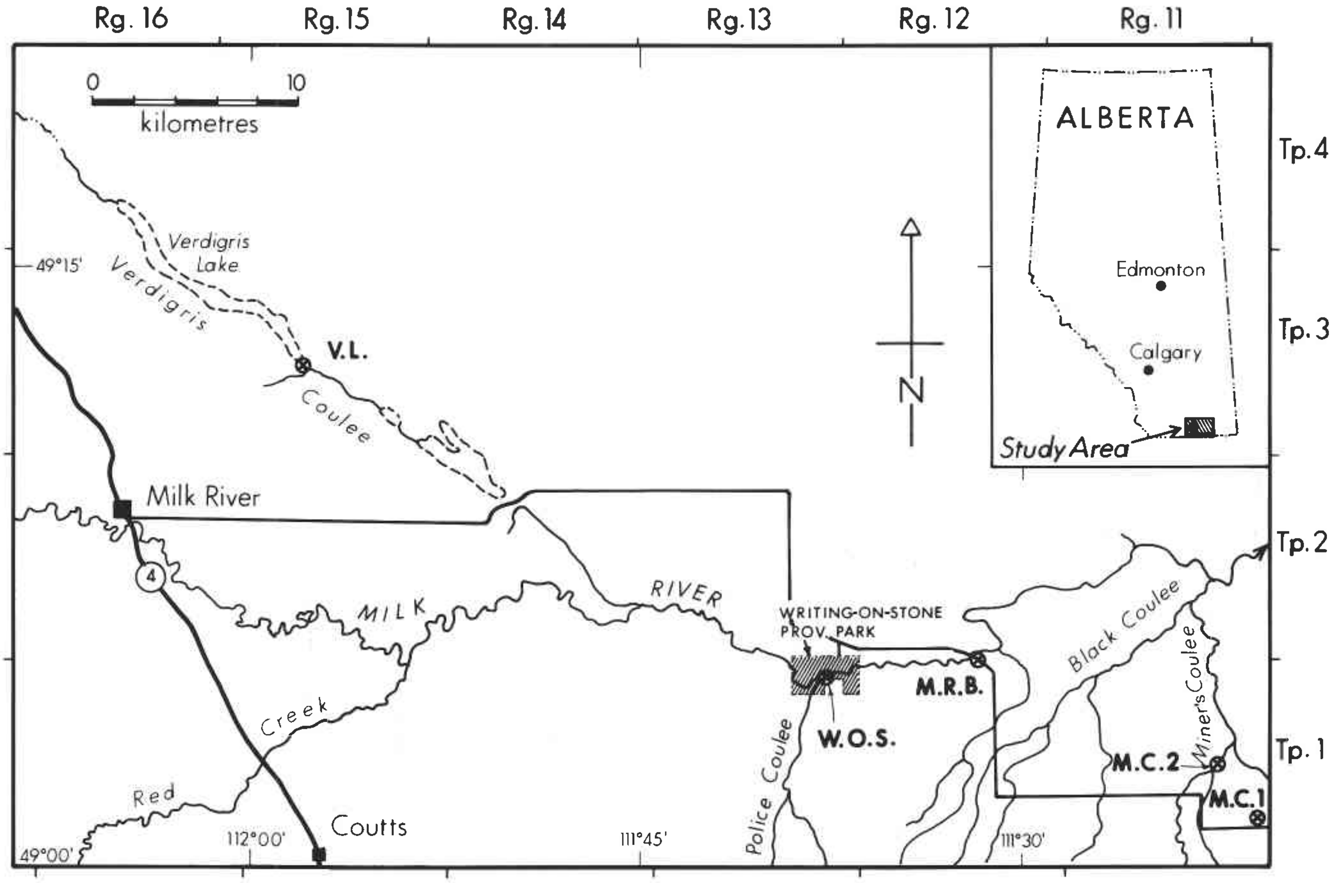


Sampling was done by cutting a horizontal bench down to undisturbed rock and then driving a 2.5 cm diameter oriented core barrel 5 cm into the fresh rock surface (Lerbekmo 1990). After reconnaissance sampling at about 3 m spacing (where possible), critical intervals were later resampled more closely. Three or four independently oriented samples were taken at each site (horizon).

Magnetic measuring

Magnetic measurements were made on a MOLSPIN spinner magnetometer in the Paleomagnetism Laboratory of the Department of Physics at the University of Alberta. The samples are relatively weak magnetically. As a general procedure, standard alternating field (AF) demagnetization was carried out in steps of 2.5 or 5.0 mT until an endpoint was reached or magnetization became too weak to obtain further meaningful measurements. Termination of demagnetization usually took place at 10–20 mT. If two samples at a site showed little tendency to change magnetic direction during AF demagnetization, and were suspected of having a magnetic overprint, the third and sometimes fourth samples were treated thermally in steps of 50°C until an endpoint was

Fig. 2. Location of magnetostratigraphic sections in the Pakowki and Milk River formations in southeastern Alberta. M.C.1 and M.C.2, Miner's Coulee sections 1 and 2; M.R.B., Milk River Bridge section; V.L., Verdigris Lake sections; W.O.S., Writing-on-Stone section.



reached or samples became too weak to measure.

These rocks have been variably overprinted. Most have a weak, presumably recent, viscous normal overprint, which largely disappears with AF treatment at 20 mT or less. However, some levels have a stronger normal overprint, likely due to chemical remanent magnetism (CRM) acquired during diagenesis. This overprinting is relaxed only by thermal treatment, and, in some cases, only partially. Even though an endpoint may not be reached, a systematic change in direction with demagnetization is usually sufficient to indicate whether the characteristic magnetization is normal or reversed (see, e.g., Fig. 7).

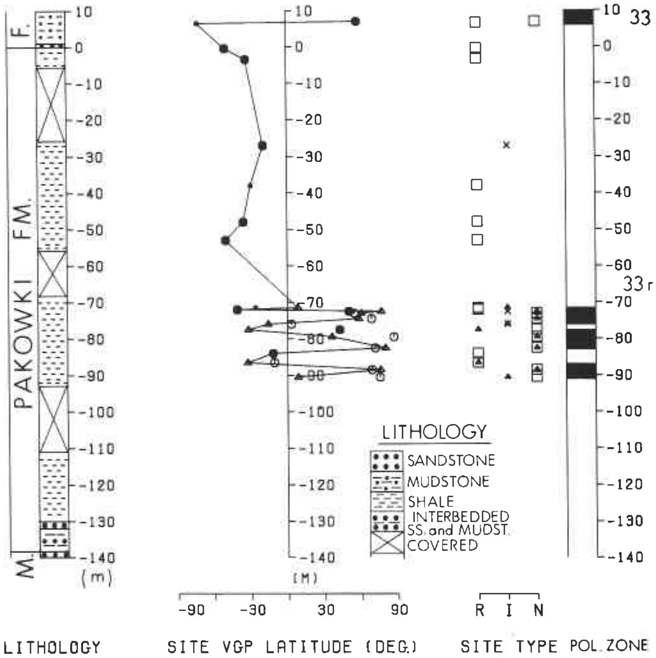
Results

Figures 3–6 display the results obtained from the Miner's Coulee, Verdigris Lake, Milk River Bridge, and Writing-on-Stone sections. Site type (normal, reversed, or indeterminate) is selected by computer program on the following basis: The paleopole utilized is Irving's (1979) 80 Ma location at 69°N, 193°E; a site is taken to be reversed if one or more samples at a site provides a paleopole position within 70° of the reversed paleopole location. If *all* samples at a site yield a paleopole position within 70° of the normal paleopole, the site is classified as normal. If neither of these criteria is met the site is classified as indeterminate. The bias favoring reversed designations is to compensate for recent overprinting in a normal field (Hillhouse et al. 1977). The virtual geomagnetic pole (VGP) latitude is the mean VGP latitude provided by all samples at a site (for further discussion see Lerbekmo and Coulter 1985). Where thermal data are available, VGP latitudes based on thermal data have been used for the joining lines.

Figure 3 shows an interval in the middle Pakowki from which a wide range of magnetic directions was obtained. Several sites were classified as normal even after thermal demagnetization. It was originally assumed that part of this interval was overprinted, although this was surprising, since this outcrop is a very fresh steep cutbank of a creek and shows no evidence of unusual diagenesis. However, recent magnetostratigraphic studies by Montgomery (1994) on the upper chalk on the Isle of Wight show four normal intervals at a similar level in chron 33r. This mixed zone has also been documented at Deep Sea Drilling Project (DSDP) site 516 (Berggren et al. 1983), DSDP site 530A (Stradner and Steinmetz 1984), and in California (Fig. 14 in Verosub et al. 1989). Therefore, we now believe that there is a mixed-polarity interval near the middle of chron 33r. A bentonite at the top of this mixed zone has been collected and is presently being dated.

The site VGP latitudes plotted in Fig. 3 are the means of several samples taken at each site. Thus, they may not show directions that are fully normal or reversed, but individual

Fig. 3. Magnetostratigraphy of the middle and upper Pakowki in Miner's Coulee. M., Milk River Formation; F., Foremost Formation; R, I, N, reversed, indeterminate, normal polarities. □ and × indicates AF cleaning; ▲ indicates thermal cleaning.



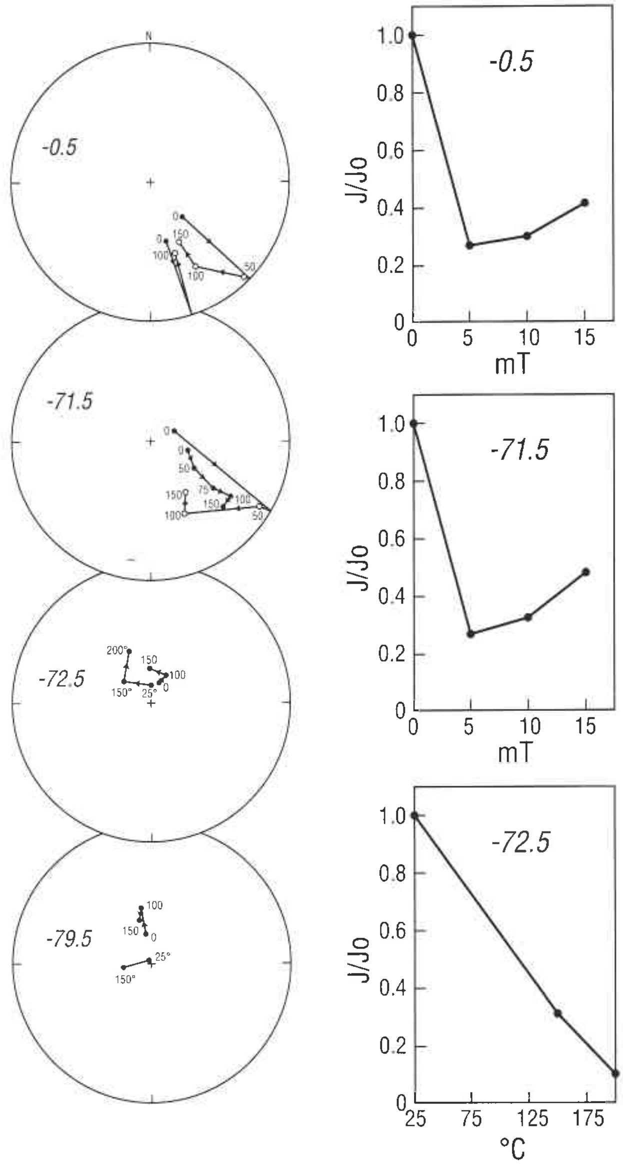
samples commonly do so. As examples, Fig. 4 shows three reversed samples and two normal samples from sites in the Pakowki Formation. Less definitive directions are given by samples that have a higher degree of overprinting, such as one of the samples at −71.5 m. The intensity plots of the reversed samples show that a normal overprint of low coercivity is nearly always present, but is largely removed at 5 mT. The examples shown of relationship of intensity changes with stepwise demagnetization are compatible with those to be expected from samples of differing strengths of the normal and reversed components, and differing coercivity spectra.

The covered interval just below this section has slumped badly and bedrock is nowhere exposed. It is probable that this part of the section corresponds to the Ardmore Bentonite interval of the Claggett Formation in Montana (Gill and Cobban 1973).

The lowest 17 m of the Pakowki Formation is best exposed in a roadcut at the south end of Verdigris Lake (Fig. 2). The underlying Milk River Formation is poorly exposed in a natural outcrop. The polarity in the basal part of this section appears to be normal or mixed (Fig. 5). This was suspected to be due, in part at least, to overprinting, but Montgomery (1994) shows two short normal intervals separated by an equally short reversed interval at a similar position in chron 33r on the Isle of Wight, so we now believe we are seeing the same polarity subzone here.

Figure 6 shows the results from the Deadhorse Coulee Member of the Milk River Formation in roadcuts east of the bridge over the Milk River (Fig. 2). This section is believed to contain essentially all of the Deadhorse Coulee Member. The base of the member is exposed in the river cutbank at

Fig. 4. Examples of directional behavior and intensity change of samples producing good reversed and normal directions after stepwise demagnetization, from Pakowki Formation, Miner's Coulee. Polar projection, equal-area stereographic plots; ●, lower hemisphere; ○, upper hemisphere. Numbers followed by degree symbol are for values in degrees centigrade; unlabelled numbers are for values in milliteslas.



the bridge. The base of the Pakowki Formation is not present in the roadcut, but occurs about 3 km to the southeast at the same stratigraphic elevation as the top of the roadcut (Russell and Landes 1940). The measured thickness (corrected for tilting) in the roadcut is, in fact, a little greater than the maximum thickness given for this member by Russell and Landes (1940).

The base of chron 33r is placed in the middle of the Deadhorse Coulee Member at an elevation of about 38 m above the base and above the top of the Virgelle Sandstone. Extracted characteristic magnetic directions in the Deadhorse Coulee Member are not very consistent. This is probably in part due to some overprinting. Although this part of

Fig. 5. Magnetostratigraphy of the basal Pakowki and uppermost Milk River formations at Verdigris Lake. M.R., Milk River Formation. See Fig. 3 for additional explanation.

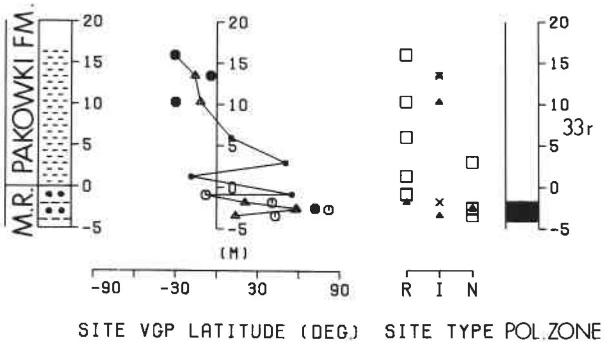
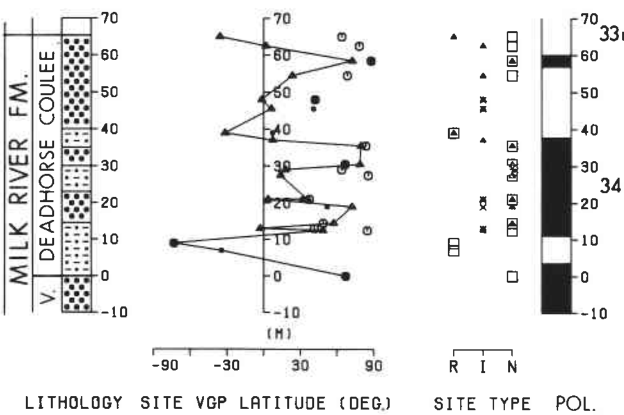
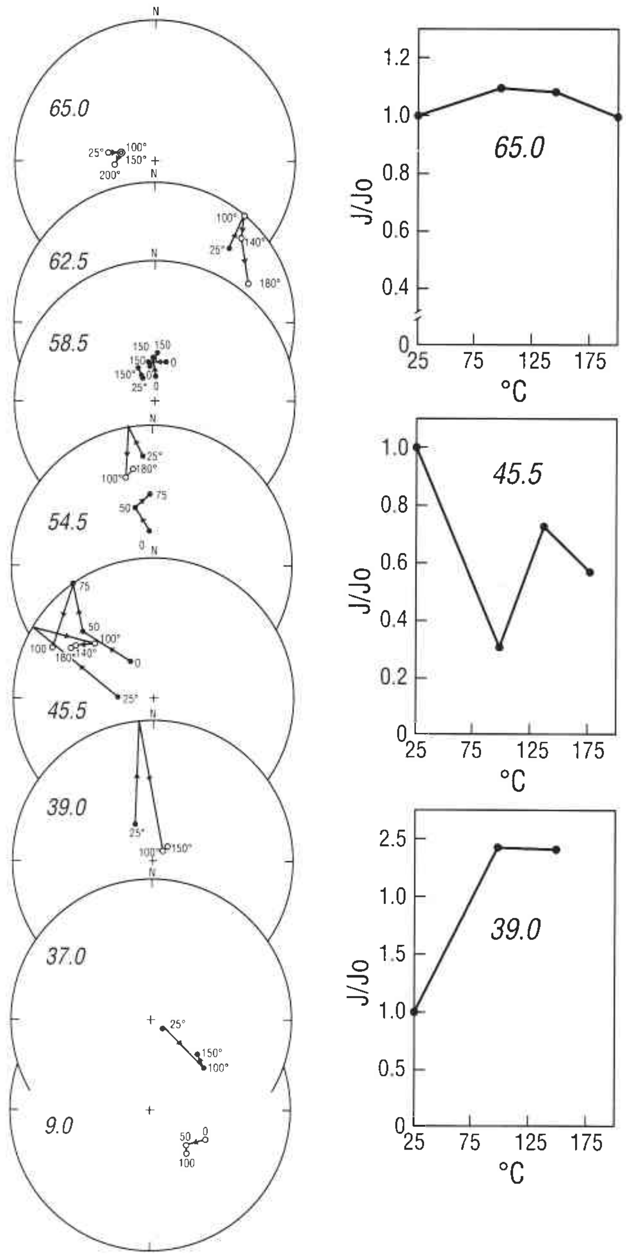


Fig. 6. Magnetostratigraphy of the Deadhorse Coulee Member of the Milk River Formation near the Milk River bridge (Fig. 2). V., Virgelle Member. See Fig. 3 for further explanation.



the member is dominated by sandstone, as indicated in the lithology column of Fig. 6, the sampled sites are in thinner mudstone units. Though clearly reversed sites are only present at the top of the member and at the base of the reversed zone, demagnetization trends, as exemplified in Fig. 7, show a strong tendency for directions to move toward the reversed paleopole. The only exception is the site at 58.5 m, which appears to be a legitimate normal site and corresponds in position to the thin normal interval at Verdigris Lake and the one shown by Montgomery (1994). The site at 37 m is classified as indeterminate, but is likely to be transitional, as the samples are magnetically very weak. Only the thermally demagnetized sample gave acceptable results, which is a down direction but in the southeast quadrant (Fig. 7). The sites between 10 and 38 m are indicated to be normal after both AF and thermal cleaning except at 12.5 and 13.0 m, where again the sites may be in a transition zone with a direction intermediate between normal and reversed. The two sites at 9.0 and 7.0 m are believed to represent a real reversed interval. This short reversed horizon has also been recorded in southern England (Montgomery 1994), California (Verosub et al. 1989), DSDP site 516 (Berggren et al. 1983), and Ocean Drilling Program (ODP) site 700B (Hailwood and Clement 1991). As the Cretaceous Long Normal (chron 34) was coming to an end, the magnetic field may

Fig. 7. Examples of directional behavior and intensity change during demagnetization of samples from the upper part of the Deadhorse Coulee Member of the Milk River Formation (Fig. 6). For examples at 58.5 m, intermediate demagnetization steps have been deleted from figure. See Fig. 4 for further explanation.



have been rather unstable for some time, contributing to the mixed data obtained from this section.

The Writing-on-Stone section (Fig. 8) at the lookout in Writing-on-Stone Provincial Park (Fig. 2) consists mostly of the cliff-forming Virgelle Sandstone Member of the Milk River Formation, but includes the lower 15 m of the Deadhorse Coulee Member. This part of the Deadhorse Coulee Member is very soft and only three sites could be sampled. The middle of these, at 10 m, is classed as indeterminate, but is probably reversed, as the pole direction is in the southern

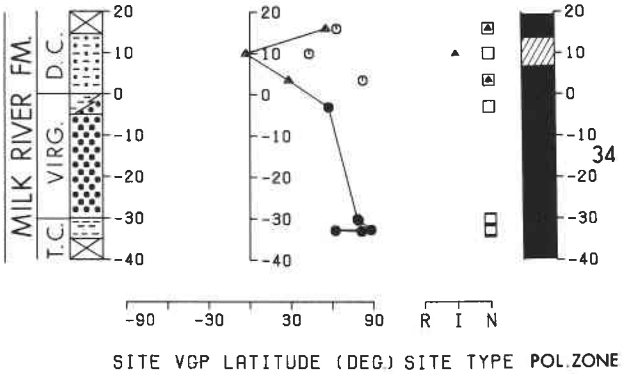


Fig. 8. Magnetostratigraphy of the Writing-on-Stone section of the Milk River Formation in Writing-on-Stone Provincial Park. T.C., Telegraph Creek Member; VIRG., Virgelle Member; D.C., Deadhorse Coulee Member. See Fig. 3 for further explanation.

hemisphere but slightly down. This site would have been considered a poor normal had it not been at the same stratigraphic position as the better documented reversed interval at Milk River Bridge (Fig. 6), 7 km downstream.

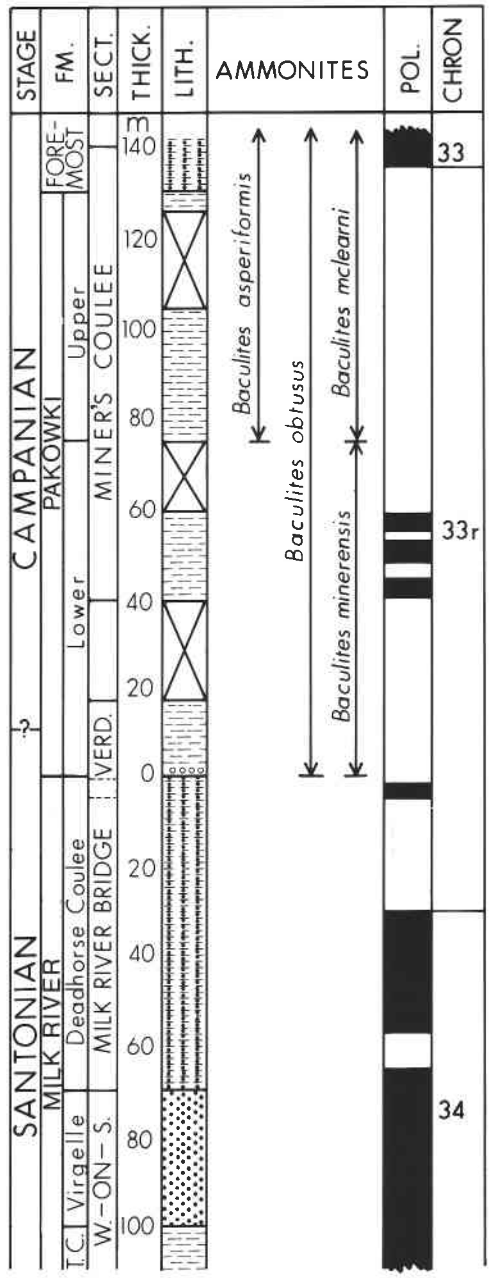
The Virgelle Member could not be sampled except for the uppermost few metres where a local facies change to shale occurs. The Telegraph Creek Member is not exposed at the lookout itself, but the uppermost few metres are exposed across the river in Police Coulee and also in the campground area of the park, 1 km downstream. The Virgelle and Telegraph Creek sites are strongly normal.

Figure 9 is a composite section combining the Miner's Coulee, Verdigris Lake, Milk River Bridge, and Writing-on-Stone sections into a single stratigraphic section showing the upper and lower limits of polarity chron 33r. The ammonite zone fossil distribution shown is from Russell and Landes (1940). The lower Pakowki is in the *Baculites obtusus* Zone of the Western Interior basin, and the upper Pakowki in the *Baculites mclearni* and *Baculites asperiformis* zones (Obradovich and Cobban 1975).

Interestingly, the ranges of *Baculites obtusus*, *B. mclearni*, and *B. asperiformis* overlap in the Pakowki Formation (Russell and Landes 1940). A similar overlap occurs in the Lea Park Formation of Saskatchewan (Price and Ball 1973), but is not duplicated in the United States (Gill and Cobban 1973).

The *Baculites obtusus* Zone extends to the base of the Pakowki Formation (Russell and Landes 1940). The Milk River–Pakowki contact contains a distinctive layer of grey chert pebbles (Russell 1970), which is found just beneath the base of the *B. obtusus* Zone throughout the Western Interior, even in continuous marine sequences (Gill and Cobban 1973; Gill et al. 1972). This suggests most or all of the *B. obtusus* Zone is represented in the Pakowki Formation. The Deadhorse Coulee Member is laterally equivalent to the middle and upper members of the Eagle Sandstone in central Montana (Meijer Drees and Mhyr 1981; "unnamed member" of Gill et al. 1972) and the middle and upper Eagle Sandstone is equivalent to the ammonite zones of *Scaphites hippocrepis* III through *Baculites* sp. (weak flank ribs) (Gill et al. 1972); thus the base of chron 33r is probably contained within one of these zones.

Fig. 9. Composite stratigraphic column based on data from sections in the Milk River area of Alberta. Ammonite ranges from Russell and Landes (1940). Upper Pakowki magnetostratigraphy previously published as part of Lerbekmo (1989, Fig. 2). T.C., Telegraph Creek Member; W.-ON-S., Writing-on-Stone; VERD., Verdigris Lake.



The chron 33r–34 contact can be constrained further. In the Niobrara Formation at Pueblo, Colorado, both ammonites and magnetostratigraphy are known (Scott and Cobban 1964; Shive and Frerichs 1974; our Fig. 10). According to Shive and Frerichs (1974), the entire Niobrara Formation at Pueblo is of normal polarity. About 24 m below the top, the Niobrara yields *Haresiceras placentiforme*, an ammonite restricted to the uppermost part of the *Scaphites hippocrepis* I and all of the *S. hippocrepis* II zones within the Western Interior (Cobban 1969). Fossils representing the *S. hippo-*

crepis III Zone have not been found at Pueblo, but farther north near Boulder, Colorado, *Haresiceras natronense*? has been collected from the Niobrara Formation approximately 15 m below the top (Scott and Cobban 1964). *Haresiceras natronense* is restricted to the *S. hippocrepis* III Zone (Cobban 1964). The uppermost Niobrara contains ammonites of the *Baculites* sp. (smooth) Zone, one zone above *S. hippocrepis* III (Scott 1969, p. 68, Pl. 1; Gill and Cobban 1966, Pl. 4). The *Baculites* sp. (smooth) Zone continues well into the overlying Pierre Shale (Scott 1969, pp. 67–69, Pl. 1). The base of chron 33r appears to be within the *Baculites* sp. (smooth) – *Baculites* sp. (weak flank ribs) interval. We place the chrons 33r–34 contact within the lower *Baculites* sp. (smooth) Zone, since this represents its probable maximum age, though it could be somewhat higher. Chron 33r ends within the *B. asperiformis* Zone (Lerbekmo 1989).

Biostratigraphy of the upper Santonian – lower Campanian

Europe

The type sections for the Santonian and Campanian stages are in northern Aquitaine, France (Kennedy 1986, 1987). Ammonites from the type Santonian consist of *Placenticeras polyopsis*, *Placenticeras paraplanum*, *Texanites gallicus*, *Eulophoceras austriacum*, and *Boehmoceras arculus* (Kennedy and Cobban 1991). According to Kennedy (1987), the Santonian cannot be subdivided on the basis of ammonites, and the entire stage corresponds to the *P. polyopsis* Zone. Hancock (1991) proposed two subzones for the *P. polyopsis* Zone: a lower one of *T. gallicus* and an upper one of *P. paraplanum*.

Placenticeras paraplanum has not been found at the same level as *Texanites gallicus*, but does occur with *P. polyopsis*, *Boehmoceras arculus*, and *Eulophoceras austriacum* in the uppermost Santonian in the Gosau Basin of Austria (Summesberger 1979, 1980). This collection includes the inoceramid bivalve *Inoceramus* (*Cordiceramus*) *muelleri*, a species restricted to the upper Santonian (Dhondt 1987; Lopez et al. 1992).

The pelagic crinoid *Marsupites* is also restricted to the upper Santonian, and has been found with *Placenticeras polyopsis*, *P. paraplanum*, and *Boehmoceras arculus* in Germany. The extinction of *Marsupites* has been proposed as a Santonian–Campanian boundary marker (Birkelund et al. 1984).

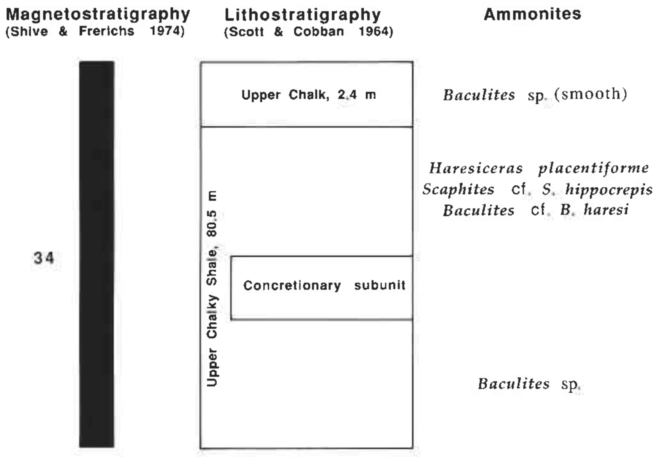
Kennedy (1986) has designated the following ammonite zones for the type Campanian in Aquitaine (from youngest to oldest):

Upper Campanian
- *Nostoceras* (*Bostrychoceras*) *polyplocum*
- *Hoplitoplacenticeras marroti*

Lower Campanian
- *Menabites* (*Delawarella*) *delawarensis*
- *Placenticeras bidorsatum*

As Kennedy (1986) has noted, all of the index species are rare and the zonation is correspondingly coarse. The first appearance of *Placenticeras bidorsatum* (a descendant of the Santonian *P. paraplanum*) marks the base of the Campanian in France, Austria, and Germany (Kennedy 1986; Kennedy and Cobban 1991). *Placenticeras bidorsatum* is unknown elsewhere, and the first occurrence of the belemnite *Gonioteuthis granulataquadrata* is frequently used instead.

Fig. 10. Magnetobiostratigraphy of the upper Niobrara Formation at Pueblo, Colorado. Data from Shive and Frerichs (1974), Scott (1969), and Scott and Cobban (1964).



Gonioteuthis granulataquadrata is restricted to Boreal localities, though, and the first occurrences of the widespread ammonites *Submortoniceras* and *Scaphites hippocrepis* have been suggested as boundary indices (Birkelund et al. 1984). *Submortoniceras* is extremely rare in Europe (Kennedy 1986), and *S. hippocrepis* first occurs very low in, but not at the base of, the Campanian there (Kennedy 1986; Jagt 1989).

Magnetostratigraphy of Santonian–Campanian boundary sequences in Europe indicates that this boundary lies within the lower part of chron 33r (Perchersky et al. 1983; Montgomery 1994). In western Turkmenia, the range of *Marsupites* is restricted to the lower part of this chron (Pechersky et al. 1983). In southern England, the entire range of *Marsupites* is also within the lower portion of chron 33r, as is the first appearance of *Gonioteuthis granulataquadrata* (Montgomery 1994; Christensen 1991). On the Russian Platform, the "Pteria beds" (containing the Boreal pelecypod *Oxytoma tenuicostata*) are restricted to chron 33r (Pechersky et al. 1983). *Gonioteuthis granulataquadrata* is associated with the "Pteria beds" on the Russian Platform (Christensen 1991), consistent with the magnetostratigraphy from western Turkmenia and southern England. As noted above, the first appearance of *Submortoniceras* has been suggested as a Santonian–Campanian boundary indicator, but this genus is first observed within chron 34 in California (Verosub et al. 1989, Fig. 8; Saul 1983, pp. 59–60), and would be Santonian in age.

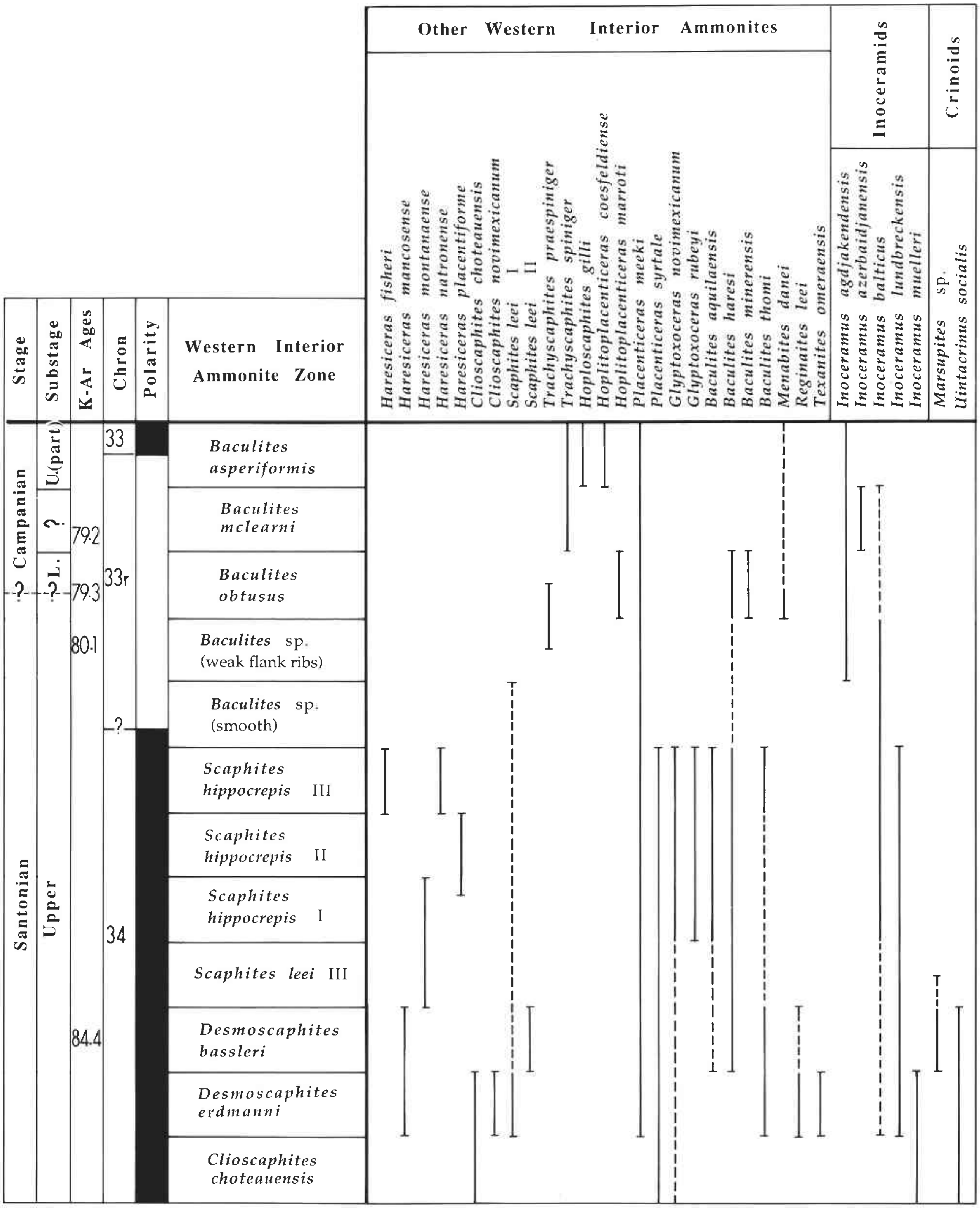
Western Interior, North America

Obradovich and Cobban (1975) and Cobban (1964, 1993) have proposed the following ammonite zonation for the upper Santonian – lower middle Campanian of the Western Interior of North America (from youngest to oldest):

Middle Campanian (part)
- *Baculites asperiformis*
- *Baculites mclearni*
- *Baculites obtusus*

Lower Campanian
- *Baculites* sp. (weak flank ribs)

Fig. 11. Magnetobiostratigraphy for the *Clioscaphites choteauensis* through *Baculites asperiformis* zones in the Western Interior of North America. Biostratigraphic data from various sources cited in the text, plus Reeside (1927), Klinger and Kennedy (1989), Cobban et al. (1974), and W.A. Cobban (written communication, 1993). Not all species listed are discussed in the text, however. Range of some species approximate. Sold lines indicate known occurrences, broken lines indicate probable range extensions either inside or outside the Western Interior. K–Ar ages in Ma.



Baculites sp. (smooth)
Scaphites hippocrepis form III
Scaphites hippocrepis form II
Scaphites hippocrepis form I
Scaphites leei form III

Upper Santonian
Desmoscaphites bassleri
Desmoscaphites erdmanni
Clioscaphites choteauensis

The *Desmoscaphites erdmanni* Zone contains the highest Western Interior occurrence of *Inoceramus* (*C.*) *muelleri*. This zone also contains *Uintacrinus socialis*, a crinoid restricted to the upper Santonian in Europe (Scott et al. 1986; Cobban 1964; our Fig. 11). No *D. erdmanni* Zone ammonites are found in Europe, but in the United States Gulf Coast both *Scaphites leei* I and *Reginaites leei* (found only in the *D. erdmanni* Zone in the Western Interior) are associated with *Boehmoceras arculus*, implying equivalence to the upper Santonian as defined in Europe (Kennedy and Cobban 1991).

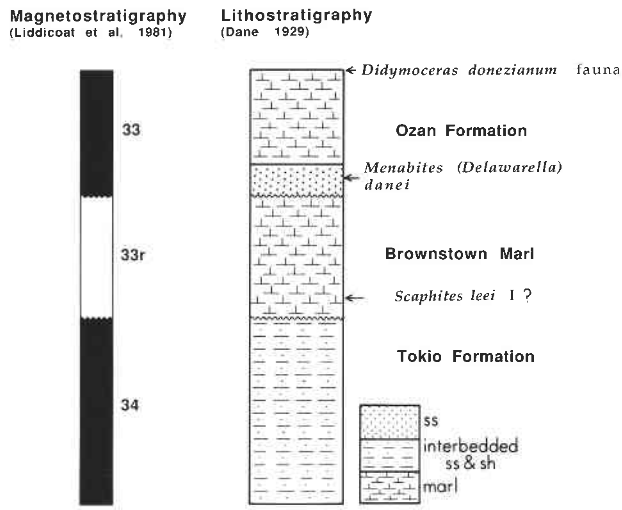
The *Desmoscaphites bassleri* Zone has been regarded as upper Santonian (Cobban 1964, 1993) on the basis of the presence of *Uintacrinus socialis* and *Marsupites*. As noted above, the last appearance of *Marsupites* in Europe is in chron 33r. The latest occurrences of *D. bassleri* in the Sweetgrass Arch region are in the Telegraph Creek Formation of northern Montana (Cobban 1964), which, in southern Alberta, falls within chron 34 (Fig. 8). Magnetobiostratigraphic comparisons with southern England (Montgomery 1994; Mortimore 1986) suggest the *D. bassleri* Zone is upper Coniacian in age, equal to the lower *Micraster coranguinum* Zone there (Mortimore 1986).

Hattin (1982) reports that *Uintacrinus socialis* is restricted to the *Clioscaphites choteauensis* Zone in western Kansas, but is found only in the *Desmoscaphites erdmanni* – *D. bassleri* zones elsewhere in the Western Interior (Cobban 1993). The last occurrence of *U. socialis* in southern England is within the lowermost part of chron 33r (Montgomery 1994), which probably corresponds to the basal Pakowki Formation in Alberta. As with *Marsupites*, the last Western Interior appearance of *Uintacrinus* appears to be older than that in Europe.

A radiometric date of 84.4 ± 1.6 Ma has been obtained for the *Desmoscaphites bassleri* Zone (Kennedy and Cobban 1991). This is essentially the same as a date of 84.2 ± 0.9 Ma for a bentonite just below the *Boehmoceras* fauna in Mississippi (Kennedy and Cobban 1991). This provides additional evidence that some Western Interior ammonites may exhibit different ranges elsewhere, since the *Boehmoceras* fauna contains ammonites restricted to the older *D. erdmanni* Zone (*Scaphites leei* I, *Reginaites leei*). In addition, Kennedy and Cobban (1991) have referred an ammonite from the lower Brownstown Marl of Arkansas (Dane 1929, p. 52, Pl. 9, Fig. 3) to *S. leei* I. Magnetostratigraphy of the Brownstown Marl (Liddicoat et al. 1981; our Fig. 12) shows it was deposited during chron 33r. If correctly identified, this example further documents a diachronous range for an ammonite, as *S. leei* I is restricted to chron 34 in the Western Interior.

The zones of *Scaphites leei* III and *S. hippocrepis* I contain no species that can be used to precisely correlate these zones to European zones, though their presence in chron 34 in the Western Interior establishes a Santonian age. Specimens of *S. hippocrepis* described by Van der Tuuk (1987, Figs. 14, 15) from the Vaals Formation in the southeastern Netherlands appear to represent *S. hippocrepis* II (W.A. Cobban, written communication, 1992), documenting the first occurrence of this form in the Campanian of Europe. Specimens of *S. hippocrepis* intermediate between forms II and III are known from northern Aquitaine (Kennedy 1986), and Belgium (Jagt 1989), and *S. hippocrepis* III is well represented in Europe (Cobban 1969).

Fig. 12. Magnetobiostratigraphy of the Tokio Formation, Brownstown Marl, and Ozan Formation of southwestern Arkansas. Biostratigraphy from Dane (1929) and Kennedy and Cobban (1993). The *Didymoceras donezianum* fauna of Kennedy and Cobban (1993) correlates best with the upper Campanian *Nostoceras* (*Bostrychoceras*) *polyplocum* Zone in Europe (Kennedy and Summesberger 1984; Kennedy 1986). Undulating lines at the Tokio–Brownstown and Brownstown–Ozan boundaries indicate disconformable contacts.



The presence of *Haresiceras placentiforme* and *H. natronense*? in the Niobrara Formation of Colorado (Scott and Cobban 1964), and *Scaphites hippocrepis* I–II from the Niobrara Formation of northeastern New Mexico (Scott et al. 1986), plus the Niobrara magnetostratigraphy of Shive and Frerichs (1974), support restriction of *S. hippocrepis* to chron 34 in the Western Interior. The Gober Chalk of northeastern Texas also contains *S. hippocrepis* III (Cobban and Kennedy 1992*b*), and probably corresponds to chron 34 (contra Liddicoat et al. 1981). By contrast, *S. hippocrepis* is known from chron 33r in southern England (Montgomery 1994; Bailey et al. 1983). The earliest members of the *S. leei* – *S. hippocrepis* lineage are unknown from Europe (Cobban 1969; Kennedy 1986). The time-transgressive range of *S. hippocrepis* might be explained by initial evolution of this lineage in the Western Interior, coupled with later dispersal of the more derived forms (*S. hippocrepis* II–III) to Europe.

The zones of *Baculites* sp. (smooth) and *Baculites* sp.

(weak flank ribs) cannot be compared to European zones, though the probable magnetostratigraphic position of these zones indicates an uppermost Santonian age.

Magnetobiostratigraphic data strongly suggest the Santonian–Campanian boundary as defined in Europe falls within the lower *Baculites obtusus* Zone. In southern England, two closely spaced, short, normal magnetic intervals occur just below the last appearance of *Uintacrinus socialis* (Montgomery 1994). As previously noted, a short normal interval also occurs in a very similar stratigraphic position in Alberta (Figs. 5, 6, 9). If this short normal interval represents the same ones documented in southern England by Montgomery (1994), which we believe is likely, then the *B. obtusus* Zone spans the Santonian–Campanian boundary.

Based on the *Desmoscaphites bassleri* Zone K–Ar age of 84.4 Ma, the Santonian–Campanian boundary has been dated at about 84 Ma (Kennedy and Cobban 1991). Since this boundary is within chron 33r in Europe, and the *D. bassleri* Zone is in chron 34, this date is too old. Obradovich (1988, Fig. 4) dates the uppermost *Baculites obtusus* – lowermost *B. mclearni* Zone interval as $79.2 \pm 0.7 - 79.3 \pm 0.8$ Ma, and the slightly older *Baculites* sp. (weak flank ribs) Zone at 80.1 ± 0.8 Ma. As the Santonian – Campanian boundary as defined in Europe probably lies within the lower *B. obtusus* Zone, the base of the Campanian should be approximately 80 Ma.

The *Baculites obtusus* Zone also contains the mixed polarity interval found in the upper part of the lower Pakowki Formation (Fig. 9). In southern England, the same mixed-polarity interval ends below the last appearance of the belemnite *Gonioteuthis quadrata*, which marks the top of the lower Campanian (Montgomery 1994; Mortimore 1986; Christensen 1991). The *B. obtusus* Zone is probably equivalent to most, if not all, of the lower Campanian Stage as defined in Europe. The *B. obtusus* Zone contains *Hoplitoplacenticeras marroti* in Wyoming (Cobban and Kennedy 1992*a*; our Fig. 11), and *H. marroti* is generally thought to be restricted to the upper Campanian in Europe (Hancock 1991), but it is found at the same level as lower Campanian *Scaphites hippocrepis* in Aquitaine (Kennedy 1986, Table 2), and both species are known from the Vaals Formation in the southeastern Netherlands (Van der Tuuk 1987; Jagt 1989).

In the middle Ozan Formation of Texas, *Baculites obtusus* occurs with *Trachyscaphites spiniger* (Cobban and Kennedy 1992*b*; Echols 1984), a species restricted to the upper Campanian in Europe (Cobban and Kennedy 1992*a*). However, *B. obtusus* also occurs with *Menabites (Delawarella) delawarensis* in Texas, a species known from the lower Campanian in Aquitaine (Cobban and Kennedy 1992*b*).

Two fragments resembling *Scaphites hippocrepis* have been found with *Baculites obtusus* in Texas (Cobban and Kennedy 1992*a*; Echols 1984). The presence of *B. obtusus*, *Menabites delawarensis*, *Trachyscaphites spiniger*, and possible *S. hippocrepis* together suggests the middle Ozan Formation (and the top of the *B. obtusus* Zone in the Western Interior) approximates the lower–upper Campanian boundary in Europe.

The age of the *Baculites mclearni* Zone is unclear. A lower Campanian age is supported by the collection of *Inoceramus azerbaidjanensis* from this zone (Cobban and Scott 1964). *Inoceramus azerbaidjanensis* is also associated with *B. mclearni* in Texas (Cobban and Kennedy 1993), and is located within chron 33r in Turkmenia (Perchersky et al. 1983), as is *B. mclearni* in Alberta (Fig. 9).

By contrast, *Trachyscaphites spiniger* is found with *Baculites mclearni* in both the Western Interior and Texas (Cobban and Scott 1964; Cobban and Kennedy 1993). *Trachyscaphites spiniger* is exclusively upper Campanian in Europe. However, as with *Scaphites hippocrepis*, the oldest examples of *Trachyscaphites* (*Trachyscaphites praespiniger*; Fig. 11) are not found in Europe, and may represent a stock initially endemic to the Western Interior, with only the end members of the lineage dispersing to other regions.

Magnetostratigraphy of the range of *Baculites mclearni* in Alberta (Fig. 9), shows it to begin shortly above the mixed-polarity interval, which ends very close to the top of the lower Campanian as defined in southern England (Montgomery 1994). This would suggest that part of the *B. mclearni* Zone is upper Campanian.

Magnetostratigraphy of rocks containing the *Baculites asperiformis* Zone indicates it is upper Campanian (Montgomery 1994). *Trachyscaphites spiniger* and *Hoplitoplacenticeras coesfeldiense* occur within this zone (Scott and Cobban 1964; Cobban 1963; Klinger and Kennedy 1989; our Fig. 11). Both species are restricted to the Upper Campanian in Europe (Cobban and Kennedy 1992*a*; Kennedy 1986).

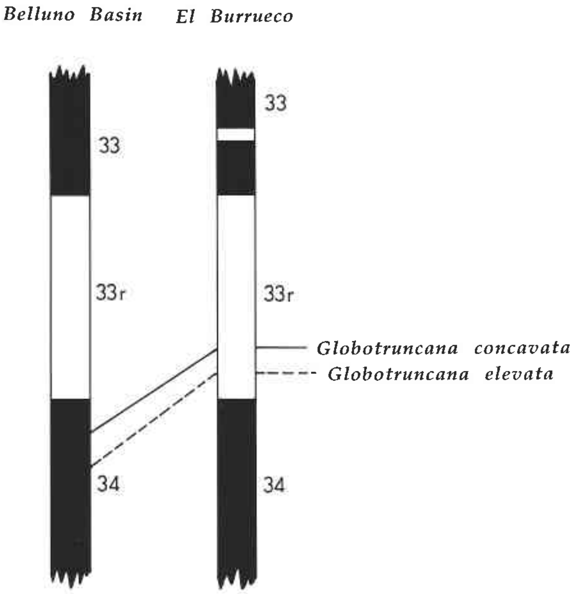
Comparisons with planktonic foraminifera

The planktonic Santonian–Campanian boundary has been placed just below the base of chron 33r (Alvarez et al. 1977) and is marked by either the first appearance of *Globotruncana elevata* (Dowsett 1984) or the last appearance of *Globotruncana concavata* (P. Marks 1984). For purposes of discussion we follow Lillegraven (1991) in considering *G. concavata* the senior synonym of *Dicarinella asymetrica* and *Dicarinella concavata*. As the base of the Campanian in Europe as defined by ammonites, belemnites, and crinoids is within the lower part of chron 33r, the two boundaries do not coincide.

There are few studied sections where macrofossil and foraminiferal biostratigraphy can be directly compared. In the Merchantville Formation of New Jersey, *Globotruncana concavata* (as *Marginotruncana concavata*) is associated with the lower Campanian ammonites *Scaphites hippocrepis* III and *Menabites delawarensis* (Petters 1977; Owens and Sohl 1973). *Globotruncana concavata* and *S. hippocrepis* III are also found in the Blufftown Formation of Georgia (Cobban and Kennedy 1992*a*; Rosen 1985). On the Isle of Wight, southern England, *G. concavata* disappears more than 80 m below the first appearance of the upper Santonian crinoid *Uintacrinus socialis* (Barr 1961; Mortimore 1986).

In the Gosau Basin of Austria, the first appearance of *Globotruncana elevata* and the basal Campanian ammonite *Placenticeras bidorsatum* (as *Diplacmoceras*) is coincident (Summesburger 1979, p. 162). However, *G. elevata* is found with upper Santonian ammonites in France (Kuhry 1970) and Israel (Reiss et al. 1985). In Mississippi, *G. elevata* and *G. concavata* first appear at the same level, above examples of the *Boehmoceras* fauna (Kennedy and Cobban 1991), but below *Marsupites* (Dowsett 1989; Stephenson and Monroe 1940; E. Marks 1952).

Fig. 13. Magnetobiostratigraphy of the El Burrueco section, Spain, and the Belluno basin, Italy, documenting the time-transgressive ranges of *Globotruncana concavata* and *G. elevata*. The solid line indicates the youngest occurrence of *G. concavata*, the broken line the oldest occurrence of *G. elevata*. Modiifed from Vandenberg (1980) and Channell and Medizza (1981).



In addition, magnetostratigraphy from the El Burrueco area, Spain (Vandenberg 1980), demonstrates that *Globotrumcana concavata* persists into chron 33r, a younger last appearance than at Gubbio (Alvarez et al. 1977) and the Belluno basin, Italy (Channell and Medizza 1981; our Fig. 13). The range of *G. concavata* may extend into chron 33r in other areas of Italy (Vandenberg and Wonders 1980). At Gubbio, and the Belluno basin, *G. elevata* first appears in the uppermost part of chron 34 (Alvarez et al. 1977; Channell and Medizza 1981). In Ocean Drilling Program (ODP) Hole 762C from the Exmouth Plateau, Australia (Wonders 1992; Bralower and Siesser 1992), *G. elevata* first occurs well down in chron 34, below the first occurrence of *G. concavata*. At El Burrueco, however, the first appearance of *G. elevata* is within chron 33r (Vandenberg 1980). Since both the first occurrence of *G. elevata*, and the last occurrence of *G. concavata* appear to be time transgressive, using either species to designate the Santonian–Campanian boundary could lead to inaccurate correlations.

Summary and conclusions

Magnetostratigraphy of the Milk River – Pakowki formations in Alberta has shown that the top of polarity chron 33r lies within the Western Interior *Baculites asperiformis* ammonite zone (Lerbekmo 1989; present study). The base of chron 33r extends below the *B. obtusus* Zone. Supplementary magnetostratigraphy from Colorado suggests the base of chron 33r is somewhere within the Western Interior *Baculites* sp. (smooth) – *Baculites* sp. (weak flank ribs) interval.

Biostratigraphic correlation of Western Interior ammonite zones to magnetostratigraphy from Europe indicates the Santonian–Campanian boundary falls within the lower portion of chron 33r, which would be equal to the lower part of the *Baculites obtusus* Zone. A radiometric date of 84 Ma for the Santonian–Campanian boundary, which is from the *Desmoscaphites bassleri* Zone, is too old, and magnetobiostratigraphic comparisons suggest the Santonian–Campanian boundary should be approximately 80 Ma. Ammonites (*Scaphites hippocrepis*, *Trachyscaphites*) and crinoids (*Marsupites*, *Uintacrinus*) frequently used for intercontinental correlations appear to have much older ranges in the Western Interior than elsewhere. Magnetostratigraphy suggests the planktonic foraminifera *Globotruncana elevata* and *G. concavata* are diachronous, so using these species to globally fix the Santonian–Campanian boundary would be unreliable.

Acknowledgments

G.D. Leahy wishes to thank W.A. Cobban, W.J. Kennedy, K. Young, J.G. Eaton, G.J. Retallack, Z. Lewy, and J.W.M. Jagt for providing much information (both published and unpublished) and to G.J. Retallack for interlibrary loan assistance. We particularly appreciate the help of W.A. Cobban, who kindly permitted us to include previously unpublished comments in this paper. Fieldwork by J.F. Lerbekmo was supported by a grant from the Natural Sciences and Engineering Research Council of Canada, and he wishes to thank Alberta Recreation and Parks for permission to work within Writing-on-Stone Provincial Park. He especially thanks M.E. Evans for his permission and cooperation in the use of the Paleomagnetism Laboratory in the Department of Physics. He also wishes to thank P. Montgomery for discussions concerning Isle of Wight magnetostratigraphy. He expresses his appreciation to G.A. Williams for assistance in the field. We would also like to thank J.G. Eaton and G.J. Retallack for review of the original manuscript.

References

Alvarez, W., Arthur, M.A., Fischer, A.G., Lowrie, W., Napoleone, G., Primoli Silva, I., and Roggenthen, W.M. 1977. Upper Cretaceous – Paleocene magnetic stratigraphy at Gubbio, Italy. V. Type section for the Late Cretaceous – Paleocene geomagnetic reversal time scale. Geological Society of America Bulletin, **88**: 383–389.

Bailey, H.W., Gale, A.S., Mortimore, R.N., Swiecicki, A., and Wood, C.J. 1983. The Coniacian–Maastrichtian stages of the United Kingdom, with particular reference to southern England. Newsletters on Stratigraphy, **12**: 29–42.

Barr, F.T. 1961. Upper Cretaceous planktonic foraminifera from the Isle of Wight, England. Palaeontology, **4**: 552–580.

Berggren, W.A., Hamilton, N., Johnson, D.A., Pujol, C., Weiss, W., Cepek, P., and Gombos, A.M., Jr. 1983. Magnetobiostratigraphy of Deep Sea Drilling Project Leg 72, sites 515–518, Rio Grande Rise (South Atlantic). *In* Initial Reports of the Deep Sea Drilling Project, **72**: 939–947.

Birkelund, T., Hancock, J.M., Hart, M.B., Rawson, P.F., Remane, J., Robaszynski, F., Schmid, F., and Surlyk, F.

1984. Cretaceous stage boundaries—proposals. Bulletin of the Geological Society of Denmark, **33**: 3–20.

Bralower, T.J., and Siesser, W.G. 1992. Cretaceous calcareous nannofossil biostratigraphy of sites 761, 762, and 763, Exmouth Plateau and Wombat Plateaus, northwest Australia. Proceedings of the Ocean Drilling Program: Scientific Results, **122**: 529–548.

Channell, J.E.T., and Medizza, F. 1981. Upper Cretaceous and Palaeogene magnetic stratigraphy and biostratigraphy from the Venetian (Southern) Alps. Earth and Planetary Science Letters, **55**: 419–432.

Christensen, W.K. 1991. Belemnites from the Coniacian to lower Campanian chalks of Norfolk and southern England. Palaeontology, **34**: 695–749.

Cobban, W.A. 1963. Occurrence of the late Cretaceous ammonite *Hoplitoplacenticeras* in Wyoming. United States Geological Survey, Professional Paper 475-C, pp. 60–62.

Cobban, W.A. 1964. The late Cretaceous cephalopod *Haresiceras* Reeside and its possible origin. United States Geological Survey, Professional Paper 454-I.

Cobban, W.A. 1969. The late Cretaceous ammonites *Scaphites leei* Reeside and *Scaphites hippocrepis* (DeKay) in the Western Interior of the United States. United States Geological Survey, Professional Paper 619.

Cobban, W.A. 1993. Diversity and distribution of late Cretaceous ammonites, Western Interior, United States. *In* Evolution of the Western Interior Foreland Basin. *Edited by* W.G.E. Caldwell and E.G. Kauffman. Geological Association of Canada, Special Publication 39, pp. 435–451.

Cobban, W.A., and Kennedy, W.J. 1992*a*. Campanian *Trachyscaphites spiniger* ammonite fauna in north-east Texas. Palaeontology, **35**: 63–93.

Cobban, W.A., and Kennedy, W.J. 1992*b*. Campanian ammonites from the Upper Cretaceous Gober Chalk of Lamar County, Texas. Journal of Paleontology, **66**: 440–454.

Cobban, W.A., and Kennedy, W.J. 1993. Middle Campanian ammonites and inoceramids from the Wolfe City Sand in northeastern Texas. Journal of Paleontology, **67**: 71–82.

Cobban, W.A., and Scott, G.R. 1964. Multinodose scaphitid cephalopods from the lower part of the Pierre Shale and equivalent rocks in the conterminous United States. United States Geological Survey, Professional Paper 483-E.

Cobban, W.A., Landis, E.R., and Dane, C.H. 1974. Age relations of upper part of Lewis Shale on east side of San Juan Basin, New Mexico. New Mexico Geological Society, 25th Field Conference Guidebook, pp. 279–282.

Dane, C.H. 1929. Upper Cretaceous formations of southwestern Arkansas. Arkansas Geological Survey, Bulletin 1.

Dhondt, A.V. 1987. Bivalves from the Hochmoos Formation (Gosau Group, Oberösterreich, Austria). Annalen des Naturhistorischen Museums in Wien, **88A**: 41–101.

Dowsett, H.J. 1984. Documentation of the foraminiferal Santonian–Campanian boundary in the northeastern Gulf of Mexico. Journal of Foraminiferal Research, **4**: 129–133.

Dowsett, H.J. 1989. Documentation of the Santonian–Campanian and Austinian–Tayloran Stage boundaries in Mississippi and Alabama using calcareous microfossils. United States Geological Survey, Bulletin 1884.

Eberth, D.A., and Hamblin, A.P. 1993. Tectonic, stratigraphic, and sedimentologic significance of a regional discontinuity in the upper Judith River Group (Belly River wedge) of southern Alberta, Saskatchewan, and northern Montana. Canadian Journal of Earth Sciences, **30**: 174–200.

Echols, J. 1984. Ammonite zonation in condensed zone, Middle Ozan Formation (Taylor Group, Upper Cretaceous) in northeast Texas. American Association of Petroleum Geologists Bulletin, **68**: 473.

Gill, J.R., and Cobban, W.A. 1966. The Red Bird Section of the Upper Cretaceous Pierre Shale in Wyoming. United States Geological Survey, Professional Paper 393A.

Gill, J.R., and Cobban, W.A. 1973. Stratigraphy and geologic history of the Montana Group and equivalent rocks, Montana, Wyoming and North and South Dakota. United States Geological Survey, Professional Paper 776.

Gill, J.R., Cobban, W.A., and Schultz, L.G. 1972. Correlation, ammonite zonation, and a reference section for the Montana Group, central Montana. Montana Geological Society, 21st Annual Field Conference, pp. 91–93.

Hailwood, E.A., and Clement, B.M. 1991. Magnetostratigraphy of sites 699 and 700, East Georgia Basin. *In* Proceedings of the Ocean Drilling Program: Scientific Results, **114**: 337–353.

Hancock, J.M. 1991. Ammonite scales for the Cretaceous System. Cretaceous Research, **12**: 259–291.

Hattin, D.E. 1982. Stratigraphy and depositional environments of Smoky Hill Chalk Member, Niobrara Chalk (Upper Cretaceous) of the type area, Western Kansas. State Geological Survey of Kansas, Bulletin 225.

Hillhouse, J.W., Ndombi, J.W.M., Cox, A., and Brock, A. 1977. Additional results on paleomagnetic stratigraphy of the Koobi Fora Formation, east of Lake Turkana (Lake Rudolf), Kenya. Nature (London), **265**: 411–415.

Irving, E. 1979. Paleopoles and paleolatitudes of North America and speculations about displaced terrains. Canadian Journal of Earth Sciences, **16**: 669–694.

Jagt, J.W.M. 1989. Ammonites from the early Campanian Vaals Formation at the CPL Quarry (Haccourt, Liege, Belgium) and their stratigraphic implications. Mededelingen Rijks Geologische Dienst, No. 43-1.

Kennedy, W.J. 1986. Campanian and Maastrichtian ammonites from northern Aquitaine, France. Special Papers in Palaeontology, No. 36.

Kennedy, W.J. 1987. Ammonites from the type Santonian and adjacent parts of northern Aquitaine, western France. Palaeontology, **30**: 765–782.

Kennedy, W.J., and Cobban, W.A. 1991. Upper Cretaceous (upper Santonian) *Boehmoceras* fauna from the Gulf Coast region of the United States. Geological Magazine, **128**: 167–189.

Kennedy, W.J., and Cobban, W.A. 1993. Campanian ammonites from the Annona Chalk near Yancy, Arkansas. Journal of Paleontology, **67**: 83–97.

Kennedy, W.J., and Summesberger, H. 1984. Upper Campanian ammonites from the Geschliefgraben (Ultrahelvetic, Upper Austria). Bieträge zur Palaeontologie von Oesterreich, **11**: 149–206.

Klinger, H.C., and Kennedy, W.J. 1989. Cretaceous faunas from Zululand and Natal, South Africa. The ammonite family Placenticeratidae Hyatt, 1900; with comments on the systematic position of the genus *Hypengonoceras* Spath, 1924. Annals of the South African Museum, **98**: 241–408.

Kuhry, B. 1970. Some observations on the type material of *Globotruncana elevata* (Brotzen) and *Globotruncana concavata* (Brotzen). Revista Espanola de Micropaleontologia, **2**: 291–304.

Lerbekmo, J.F. 1989. The statigraphic position of the 33–33r (Campanian) polarity chron boundary in southeastern Alberta. Bulletin of Canadian Petroleum Geology, **37**: 43–47.

Lerbekmo, J.F. 1990. A tool for obtaining oriented samples of weakly to moderately indurated sedimentary rocks for paleomagnetic measurements. Sedimentary Geology, **66**: 295–299.

Lerbekmo, J.F., and Coulter, K.C. 1985. Late Cretaceous to early Tertiary magnetostratigraphy of a continental sequence: Red Deer Valley, Alberta, Canada. Canadian Journal of Earth Sciences, **22**: 567–583.

Liddicoat, J.C., Hazel, J.E., Brouwers, E.M., Bryant, W.A., and Bottjer, D.J. 1981. Magnetostratigraphy of Upper Cretaceous deposits in the northeastern Mississippi embayment. United States Geological Survey, South-Central Section, Abstracts with Programs, **13**: 240–241.

Lillegraven, J.A. 1991. Stratigraphic placement of the Santonian–Campanian boundary (Upper Cretaceous) in the North American Gulf Coastal Plain and Western Interior, with implications to global geochronology. Cretaceous Research, **12**: 115–136.

Lopez, G., Martinez, R., and Lamolda, M.A. 1992. Biogeographic relationships of the Coniacian and Santonian inoceramid bivalves of northern Spain. Palaeogeography, Palaeoclimatology, Palaeoecology, **92**: 249–261.

Marks, E. 1952. Occurrence of Santonian Crinoid in western Gulf region. American Journal of Science, **250**: 226–227.

Marks, P. 1984. Proposal for the recognition of boundaries between Cretaceous stages by means of planktonic foraminifera biostratigraphy. Bulletin of the Geological Society of Denmark, **33**: 163–169.

Meijer Drees, N.C., and Mhyr, D.W. 1981. The Upper Cretaceous Milk River and Lea Park formations in southeastern Alberta. Bulletin of Canadian Petroleum Geology, **29**: 42–74.

Montgomery, P. 1994. Late Cretaceous magnetostratigraphy and timing of sea level changes. Abstract, Postgraduate Research in Progress in Marine Geology and Geophysics, The Geological Society – Marine Studies Group, University of Cambridge, England, Feb. 1994.

Mortimore, R.N. 1986. Stratigraphy of the Upper Cretaceous White Chalk of Sussex. Proceedings of the Geologists' Association, **97**: 97–139.

Obradovich, J.D. 1988. A different perspective on glauconite as a chronometer for geologic time scale studies. Paleoceanography, **3**: 757–770.

Obradovich, J.D., and Cobban, W.A. 1975. A time scale for the Late Cretaceous of the Western Interior of North America. *In* The Cretaceous System in the Western Interior of North America. *Edited by* W.G.E. Caldwell. Geological Association of Canada, Special Paper 13, pp. 31–54.

Owens, J.P., and Sohl, N.F. 1973. Glauconites from New Jersey – Maryland Coastal Plain: their K–Ar ages and application in stratigraphic studies. Geological Society of America Bulletin, **84**: 2811–2838.

Perchersky, D.M., Naidin, D.P., and Molostovsky, E.A. 1983. The Santonian–Campanian Reversed Polarity Magnetozone and the Late Cretaceous Magnetostratigraphical Time-Scale. Cretaceous Research, **4**: 251–257.

Petters, S.W. 1977. Upper Cretaceous planktonic foraminifera from the subsurface of the Atlantic Coastal Plain of New Jersey. Journal of Foraminiferal Research, **7**: 165–187.

Price, L.L., and Ball, N.L. 1973. Stratigraphy of Cominco Potash Shaft No. 1 Vanscoy, Saskatchewan. Geological Survey of Canada, Paper 72-11.

Reeside, J.B., Jr. 1927. The Cephalopods of the Eagle Sandstone and related formations in the western interior of the United States. United States Geological Survey, Professional Paper 151.

Reiss, Z., Almogi-Labin, A., Hinigstein, A., Lewy, Z., Lipson-Benitah, S., Moshkovitz, S., and Zaks, Y. 1985. Late Cretaceous multiple stratigraphic framework of Israel. Israel Journal of Earth-Sciences, **34**: 147–166.

Rosen, R.N. 1985. Foraminiferal stratigraphy and paleoecology of the Blufftown Formation (Santonian–Campanian) of Georgia and eastern Alabama. Transactions—Gulf Coast Association of Geological Societies, **35**: 485–492.

Russell, L.S. 1970. Correlation of the Upper Cretaceous Montana Group between southern Alberta and Montana. Canadian Journal of Earth Sciences, **7**: 1099–1108.

Russell, L.S., and Landes, R.W. 1940. Geology of the southern Alberta Plains. Geological Survey of Canada, Memoir 221.

Saul, L.R. 1983. Turritella zonation across the Cretaceous–Tertiary boundary, California. University of California, Publications in Geological Sciences, No. 125.

Scott, G.R. 1969. General and engineering geology of the northern part of Pueblo, Colorado. United States Geological Survey, Bulletin 1262.

Scott, G.R., and Cobban, W.A. 1964. Stratigraphy of the Niobrara Formation at Pueblo, Colorado. United States

Geological Survey, Professional Paper 454-L.
Scott, G.R., Cobban, W.A., and Merewether, E.A. 1986. Stratigraphy of the Upper Cretaceous Niobrara Formation in the Raton Basin, New Mexico. New Mexico Bureau of Mines and Mineral Resources, Bulletin 115.
Shive, P.N., and Frerichs, W.E. 1974. Paleomagnetism of the Niobrara Formation in Wyoming, Colorado, and Kansas. Journal of Geophysical Research, **79**: 3001–3007.
Stephenson, L.W., and Monroe, W.H. 1940. The Upper Cretaceous deposits. Mississippi State Geological Survey, Bulletin 40.
Stradner, H., and Steinmetz, J. 1984. Cretaceous calcareous nannofossils from the Angola Basin, DSDP Site 530. Initial Reports of the Deep Sea Drilling Project, **61**: 565–650.
Summesberger, H. 1979. Eine obersantone Ammonitenfauna aus dem Becken von Gosau (Oberösterreich). Annalen des Naturhistorischen Museums in Wien, **82**: 109–176.
Summesberger, H. 1980. Neue Ammoniten aus der Sandkalkbank der Hochmoossichichten (Obersanton; Gosau, Österreich). Annalen des Naturhistorischen Museums in Wien, **83**: 275–283.
Vandenberg, J. 1980. New Paleomagnetic data from the Iberian Peninsula. Geologie en Mijnbouw, **59**: 49–60.
Vandenberg, J., and Wonders, A.A.H. 1980. Paleomagnetism of late Mesozoic pelagic limestones from the southern Alps. Journal of Geophysical Research, B, **85**: 3623–3627.
Van der Tuuk, L.A. 1987. Scaphitidae (Ammonoidea) from the Upper Cretaceous of Limburg, The Netherlands. Palaeontologische Zeitschrift, **61**: 57–79.
Verosub, K.L., Haggart, J.W., and Ward, P.D. 1989. Magnetostratigraphy of Upper Cretaceous strata of the Sacramento Valley, California. Geological Society of America Bulletin, **101**: 521–533.
Wall, J.H. 1967. Microfauna of the Cretaceous Alberta Shale on Deer Creek, International Boundary, Great Plains region. Proceedings of the Geological Association of Canada, **18**: 93–108.
Wonders, A.A.H. 1992. Cretaceous planktonic foraminiferal biostratigraphy, Leg 122, Exmouth Plateau, Australia. Proceedings of the Ocean Drilling Program: Scientific Results, **122**: 587–593.