

**A LATE CRETACEOUS (CENOMANIAN) MARINE
VERTEBRATE-RICH BIOCLASTIC HORIZON FROM
THE NORTHEASTERN MARGIN OF THE WESTERN
INTERIOR SEAWAY, CANADA**

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A thesis submitted to the Faculty of Graduate Studies in partial fulfillment of the
requirements for the degree of
Master of Science

Department of Earth Sciences
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ABSTRACT

Throughout the Cretaceous Western Canadian Sedimentary Basin, concentrations of the remains of fossilized marine vertebrates & invertebrates (macrofossils) occur as dense bioclastic and bonebed horizons. In Manitoba and Saskatchewan, Canada, these horizons are particularly abundant within the Belle Fourche Member of the Ashville Formation, deposited along the eastern margin of the Cenomanian Western Interior Seaway (WIS). Concentrations of abundant bones, teeth, and scales of marine and, very rarely, terrestrial, vertebrates are found along with bivalve-rich horizons such as the regionally wide-spread *Ostrea beloiti* layer along the length of the Manitoba Escarpment.

A newly discovered locality near the southern end of the escarpment has yielded calcarenites, composed primarily of inoceramid-derived calcitic prisms and abundant, disarticulated marine vertebrate elements and microcoprolites, as well as oyster valves. Stratigraphically, these deposits are believed to be of early Middle Cenomanian age, originating lower in the Belle Fourche Member than previously described marine vertebrate bonebeds from the region.

The preserved vertebrate fossils reveal a diverse paleocommunity comprised of 12 chondrichthyan taxa, 13 osteichthyan taxa, and 2 reptilian taxa. Several of these, including *Protosphyraena* sp., *Squalicorax falcatus*, a salmoniform, *Xiphactinus audax*, *Enchodus* cf. *E. gladiolus*, *Enchodus* cf. *E. petrosus*, and *Enchodus* cf. *E. shumardi* represent earliest occurrences of these taxa in Canada and/or North America, as well as what may be the earliest evidence of eels (Order Anguilliformes) on this continent.

Taphonomic data indicates that the bioclasts were concentrated by physical processes such as winnowing, as well as by the siliciclastically-starved setting of the

eastern margin of the WIS. Evidence of minor transportation, winnowing, and reworking are taken to indicate these bioclastic sediments were initially deposited relatively further offshore than other bonebeds known from the Manitoba Escarpment, at or just beneath storm wave base. Petrographic study of the bonebeds reveals that variability in the amount of inoceramid-derived prismatic calcite buried along with the concentrated vertebrate bioclasts may have affected the timing of cementation, and therefore the susceptibility of these deposits to further reworking.

Comparison with skeletal limestones known from the Greenhorn Limestone in the United States suggests that the calcarenites studied here were deposited in a similar manner: as the result of storms (i.e. as tempestites) impinging on the extremely shallowly sloping sea floor of the eastern margin of the Western Interior Seaway, during one of the frequent oscillations of sea-level during the Cenomanian. Cretaceous marine bioclastic and bonebed horizons are widespread in the WIS and may eventually serve as stratigraphic and sequence stratigraphic markers integrated into a basinwide framework.

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Sincere thanks go to my supervisors Dr. Stephen L. Cumbaa and Dr. Claudia Schröder-Adams for an excellent and challenging M.Sc. project, as well as for their unwavering guidance, instruction, patience and support throughout this project. Steve's energy and enthusiasm for fossil fishes, and Claudia's untiring pursuit of "the big picture" in the WIS, were inspirational. Research funding for this project was supplied by NSERC Discovery Grants to Dr S. L. Cumbaa and Dr. C. Schröder-Adams. I would also like to thank Mr. and Mrs. Henry Van der Voort of Riding Mountain, MB, and Dwayne and Debbie Unger of Kelwood, MB, for access to the site that was so pivotal to my research. Thanks also go to the Manitoba Museum and the Royal Saskatchewan Museum for access to my study material. Special thanks go out to the 2006 Field Party; especially Richard Day, for his wisdom both technical and practical. Further thanks are due to Glenn Poirier at the CMN, who gave freely of his time and expertise on the SEM and the microprobe, and to James Haggart of the GSC for his efforts to identify our mysterious molluscs. The students, faculty and staff of the Earth Sciences Dept. at Carleton University also deserve thanks, many having contributed in some way, with special thanks to David Mans in particular. Dave's work ethic was inspirational (however much it *actually* rubbed off on me), and one couldn't have asked for a better "comrade-in-arms". Eternal gratitude goes out to my parents and my sisters, whose unconditional love, encouragement, and support has always been felt no matter where in the country I may be. Last but by no means least, from the very bottom of my heart I extend thanks to Julie Gundry for her love, patience, support, encouragement, sacrifice, humour and inspiration, which have helped this project come to fruition in ways too numerous to count.

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INTRODUCTION

Recent geological and paleontological research in Canada on Late Cretaceous strata deposited within the Western Canada Sedimentary Basin (WCSB) has resulted in the identification of numerous vertebrate fossil-rich horizons of Cenomanian age (e.g. Leckie et al., 1992; Cumbaa and Tokaryk, 1999; Cook, 2007). These horizons contain extraordinary concentrations of vertebrate skeletal material and occur discontinuously in outcrop and in subsurface cores across the WCSB stretching from eastern British Columbia to central Manitoba (e.g. Mossop and Shetson, 1994; Bloch et al., 1993; Schröder-Adams et al., 1999).

Bioclastic horizons are of interest to sedimentologists, stratigraphers, and paleontologists alike. Their occurrence might be related to changes in relative sea-level, representing times of reduced clastic input and seafloor winnowing (Sageman, 1996). If these lags become regionally extensive and can be detected in wireline logs these beds become important markers for stratigraphic correlation. Their composition provides insight on the vertebrate fauna and its paleoecology, and their taphonomic signature points towards depositional mechanisms and diagenetic histories.

Although horizons with concentrated vertebrate debris have been observed across the Cretaceous WCSB, the best developed bonebeds occur along the eastern margin of the basin due to minimal clastic dilution. One region in which these horizons are abundantly observed in outcrop is along the Manitoba Escarpment, a southeast-northwest trending series of uplands spanning southwestern Manitoba and east-central Saskatchewan. Previous work on Cenomanian-aged bonebeds along the eastern margin concentrated on those found near the Pasquia Hills of Saskatchewan, along the

Bainbridge and Carrot Rivers where bonebeds delivered extraordinarily rich vertebrate assemblages, including the earliest diverse avifauna described from North America. (Cumbaa and Tokaryk, 1999; Schröder-Adams et al., 1999; Cumbaa and Bryant, 2001; Schröder-Adams et al., 2001; Cumbaa et al., 2006). This study focuses on a locality near the town of Riding Mountain, Manitoba, where in July of 2006 vertebrate fossil-rich calcarenites were collected. These calcarenites vary from previously described Cenomanian vertebrate horizons within the Western Interior Sea in terms of the composition of the marine vertebrate fauna and inferred diagenetic history, as well as in terms of stratigraphic position. Comparison with the faunas known from other Cenomanian-aged localities in the North American Western Interior Basin add to our understanding of the depositional and diagenetic history of these deposits. Finally, the combined information gleaned from the above surveys and analyses allows us to gain insight into the paleoecological and paleoenvironmental conditions that predominated within this ancient seaway during Cenomanian time. A better understanding of the cause and frequency of these erosional remnants may contribute to sea-level studies and regional stratigraphic correlations.

GEOLOGICAL SETTING

The Western Canadian Sedimentary Basin

Tectonic Setting and Basin Architecture

Between the Middle Jurassic and Eocene epochs, the Western Interior of the North American continent was the locus for the development of a complex foreland basin, developed in tandem with the simultaneously rising Cordillera (Leckie and Smith, 1992; Kauffman and Caldwell, 1993). Northwestward and westward movement of the North American Plate through these times resulted in the accretion of a significant number of allochthonous terranes carried on “Pacific” plates which were being obducted on the continent’s western margin; the compressional imbrication and thickening of these accreted plates, along with pre-existing deposits along the western continental margin and the products of upper-plate, subduction-related magmatism, resulted in the uplift of the Cordillera (Monger, 1993). Tectonic loading occurring on the western margin resulted in a coeval downwarping of the stable North American craton to the east of the developing Cordillera, and thus an extensive foreland basin was created (Kauffman and Caldwell, 1993). The Western Canadian Sedimentary Basin was a north-south trending trough, oriented parallel to the eastern margin of the Cordillera, being deepest in the western foredeep adjacent to the mountains and shallowing towards the backbulge (Kauffman and Caldwell, 1993) (Fig. 1). This eastward shallowing from the foredeep was, however, not uniform due to the presence of the forebulge; which is defined as “a region of potential flexural uplift along the cratonic side of the foredeep” (Decelles and Giles, 1996).

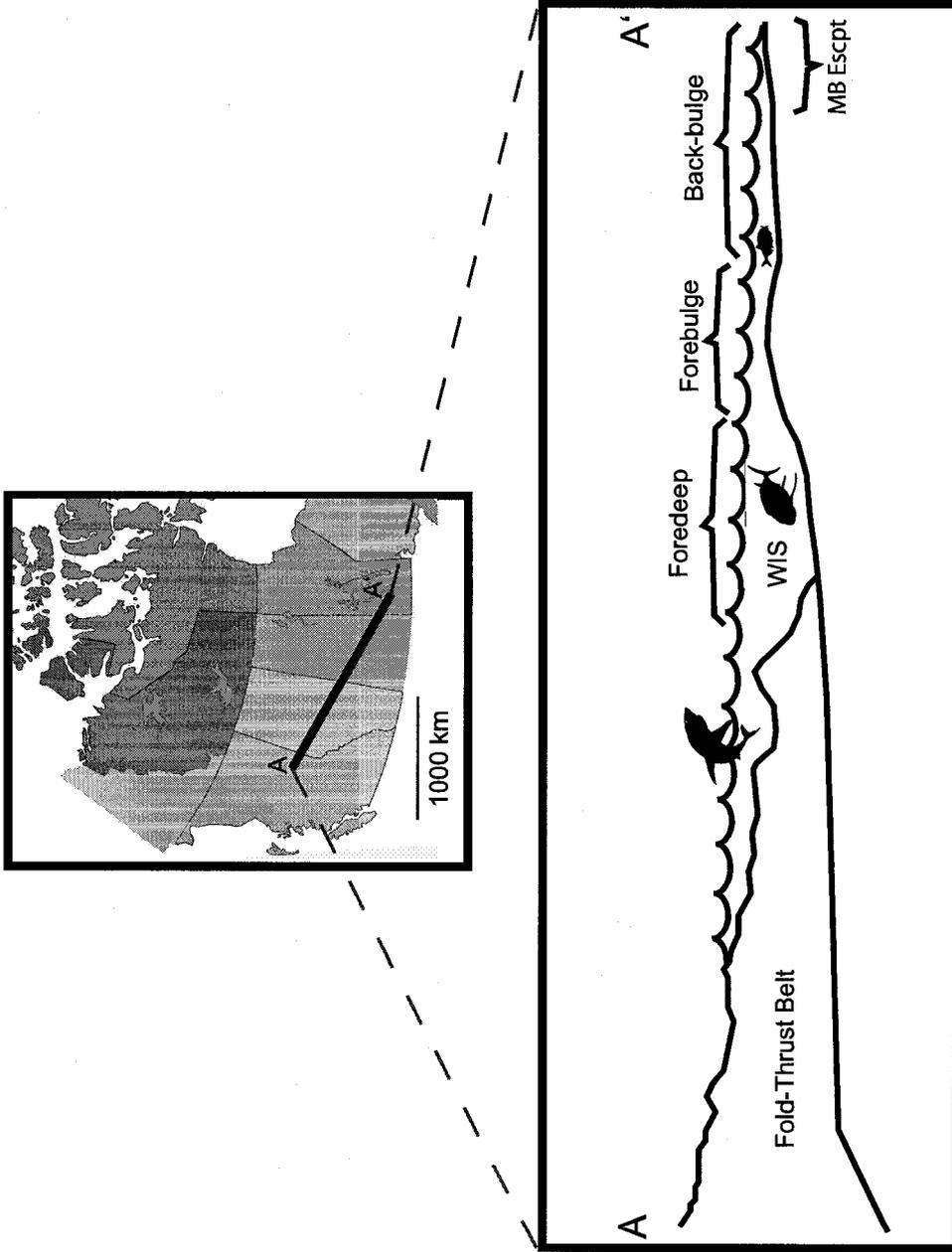


Figure 1: Schematic diagram of a representative cross-section through the Western Interior Seaway (WIS) (modified after Decelles and Giles, 1996). Sediments deposited within the Manitoba Escarpment are located approximately within the area designated by "MB Escpt".

Patterns of Sedimentation

As the Cordillera continued to rise, the Western Canadian Sedimentary Basin became the prime repository for sediments eroding off the newly formed mountains, resulting in a large, roughly wedge-shaped package of terrestrial and marine sediments of Mesozoic and Cenozoic age overlying Paleozoic deposits laid down on the formerly passive western margin of North America (Dixon, 1993). The uplift of a discontinuous forebulge distal to the active tectonic front came to restrict the deposition of synorogenic sediments in the rapidly subsiding foredeep adjacent to the Cordillera, and variably contributed to the expanded sections seen there today (Donaldson et al., 1998; Plint, 2003; Tyagi et al, 2005; Plint and Wadsworth, 2006; Plint and Kreitner, 2007). In contrast, along the eastern margin of the basin, sediment input from the stable craton was relatively low, subsidence was slow and episodic, and the resulting deposits are thin, commonly unconformity-bound condensed sequences with a paucity of coarse-grained terrestrially-derived sediments (McNeil and Caldwell, 1981).

The Late Cretaceous Western Interior Seaway

Sea-level History

The combination of basin subsidence, tectonic uplift and periods of eustatic changes in sea level resulted in the variable flooding of the Western Interior Basin, and thus the coverage of large parts of the Interior of North America by an epicontinental sea known as the Late Cretaceous Western Interior Seaway (Fig. 2). During the Early Cretaceous, inundation of the Interior was only in the northern part of North America, connected to the Boreal Sea. By the early Late Albian sea-level rise resulted in the Joli Fou Seaway

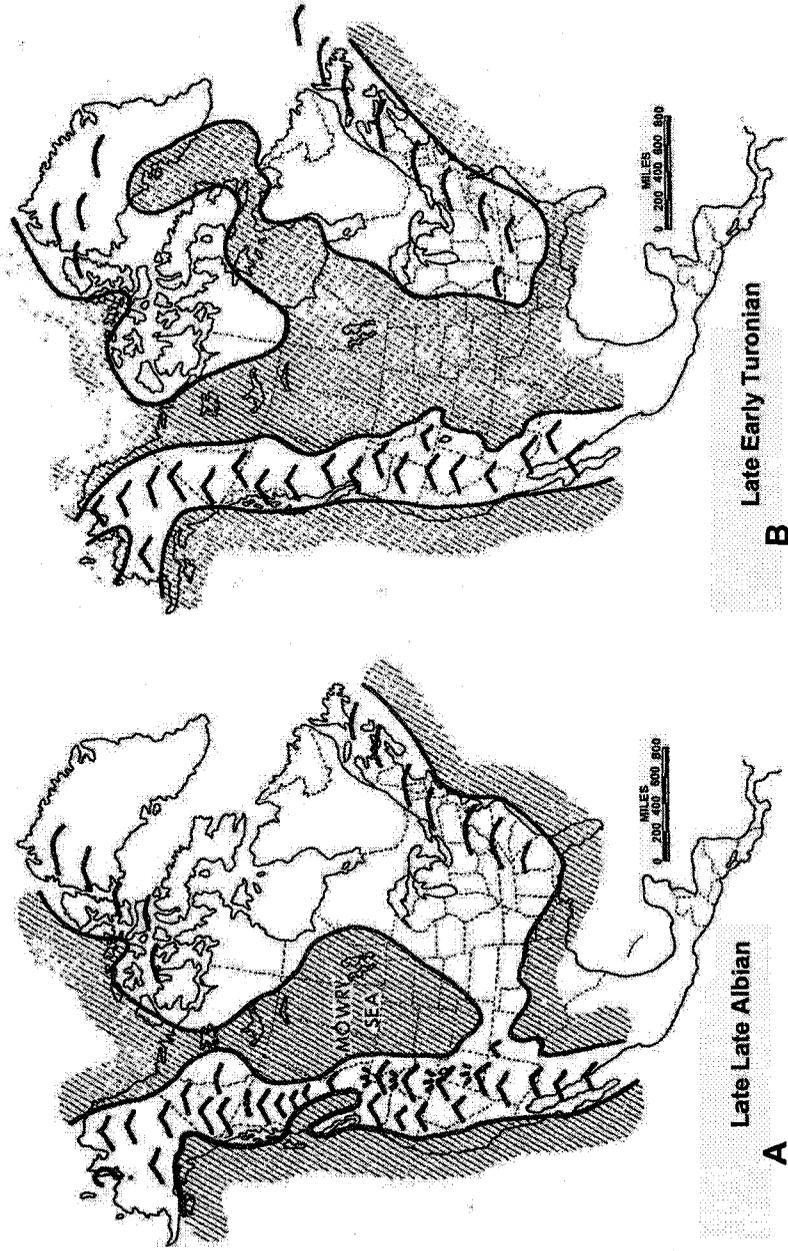


Figure 2: Paleogeographic maps showing the extent of epeiric sea coverage during A) the Late Late Albian and B) the Late Early Turonian (modified from Williams and Stelck, 1975).

connecting the Boreal Sea to the north with the proto-Gulf of Mexico (the Tethyan Sea) to the south (Stelck and Koke, 1987). This initial connection was relatively short-lived, terminating in the Late Albian with the formation of the restricted Mowry Sea (Fig. 2a). Renewed transgression during the Greenhorn Marine Cycle in the latest Albian/earliest Cenomanian (Hattin, 1962; 1964; Kauffman, 1977a) culminated with peak transgression in the early Turonian (Figs. 2b, 3). A near-peak flooding shoreline, known from the latest Cenomanian of South Dakota, indicates that the Greenhorn Sea may have flooded as much as approximately 300 m above current sea level (McDonough and Cross, 1991). The Greenhorn Cycle, in addition to being the greatest of the transgressive-regressive cycles in the basin, was dynamic, encompassing two to three third-order cycles recognized in the late Albian, one third-order cycle in the lower Cenomanian, another third-order cycle in the middle Cenomanian, and two third-order cycles (overprinted by four to five fourth-order cycles) in the late Cenomanian (summarized in Kauffman and Caldwell, 1993). Indeed, recent work in northern Alberta (Plint and Kreitner, 2007) and southwestern Utah (Laurin and Sageman, 2007) in upper Cenomanian and lower Turonian strata have revealed a dozen or more transgressive-regressive events covering that time span, where sea-level changed by up to 10 m on a time scale varying from 9-74 thousand years (kyr) in Alberta, and 20-40 kyr (for short-term sequences), 65-160 kyr (for medium-term sequences), up to 800 kyr (for long-term sequences) in Utah.

After the Greenhorn Cycle (Fig. 3), sea-level continued to rise and fall throughout the Niobrara (Kauffman, 1969, 1977a), Claggett and Bearpaw (Gill and Cobban, 1973; Kauffman, 1977b) and Fox Hills (Waage, 1978; Kauffman and Caldwell, 1993) marine cycles (and the numerous smaller-order cycles within them), providing a continuous,

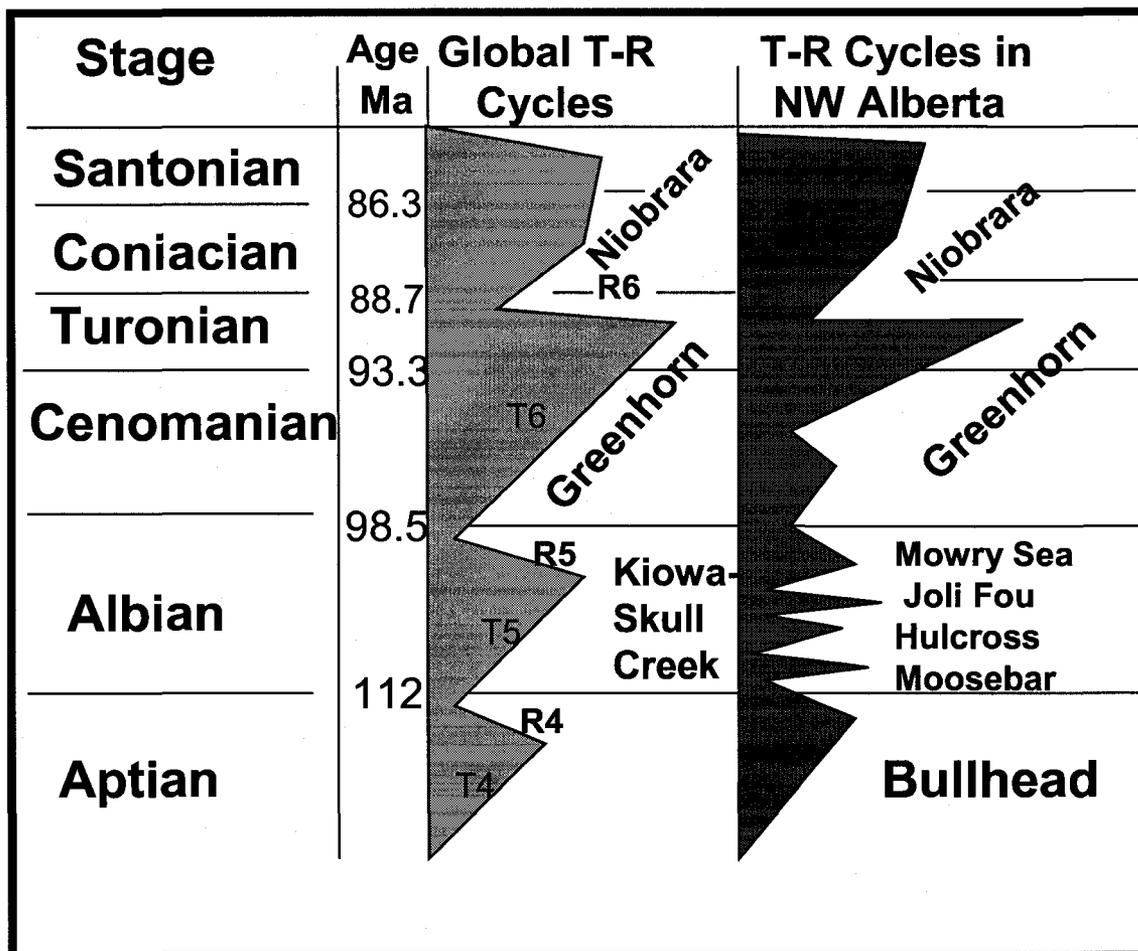


Figure 3: Global transgressive-regressive cycles and transgressive-regressive cycles in the northwest Alberta portion of the Western Cretaceous Sedimentary Basin during the Cretaceous (Aptian to Santonian) and radiometric ages at the stage boundaries. Modified after Kauffman (1977b), Obradovich (1993) and Mans (2007).

though variable, epeiric connection between the Boreal and Tethyan seas until middle Maastrichtian time (spanning over 32 million years). Followed by rapid draining of the basin, the seaway ultimately retreated from the Western Interior Basin, with no marine sediments begin preserved within the Western Interior after late Palaeocene time (Hoganson and Cvancara, 1989; 1991; Cvancara and Hoganson, 1993; Hoganson and Murphy, 2002).

Paleoenvironmental Conditions

Relatively long periods of episodic watermass density stratification occurred throughout the history of the basin (during the Kiowa-Skull Creek, Greenhorn, Niobrara and Claggett cycles) due to sluggish oceanic circulation and the interaction of northern and southern water masses (Kauffman, 1988; Hay, 1989; Hay et al., 1993). Poor circulation and abundant terrestrial runoff are thought to have contributed to salinity stratification in the blind-ended seas of the late Albian, whereas thermal stratification is thought to have played a larger role in the later seas (Late Cenomanian to Santonian) formed by the mixing of cool-temperate, somewhat brackish Boreal-derived waters and warm-temperate to sub-tropical, normal saline Tethys-derived waters (e.g. Kauffman, 1988; Hay, 1989; Caldwell et al., 1993; Glancy et al., 1993; Hay et al., 1993; Kyser et al., 1993; Schröder-Adams et al., 1996). These conditions, combined with possible northward incursions of an expanded oxygen-minimum zone into the bottom waters of the Western Interior Sea from the Tethys Sea during peak-transgression periods, all contributed to the density stratification, reduced downward mixing of oxygenated surface waters, reduced benthic oxygenation and organic-carbon accumulation during the Late Cretaceous (e.g. Kauffman, 1988; Hay, 1989; Caldwell et al., 1993; Glancy et al., 1993; Hay et al., 1993;

Kyser et al., 1993; Schröder-Adams et al., 1996; Leckie et al., 1998; White and Arthur, 2006). These dysoxic to anoxic mid- to bottom-water environments, combined with brackish waters originating from high terrestrial runoff and cool, dense northern waters further limited the biota, at times to a low diversity assemblage lacking many groups typical of open marine conditions altogether (Kauffman and Caldwell, 1993). However, despite these relatively stressed living conditions, particularly for benthic organisms, the Western Interior Seaway still supported a relatively diverse assemblage of vertebrates through time (e.g. Nicholls and Russell, 1990; Russell, 1988; 1993; Cumbaa et al., 2006; Shimada et al., 2006; Cook, 2007).

The Manitoba Escarpment

The Manitoba Escarpment is a southeast-northwest trending series of uplands extending from south-central Manitoba/north-central North Dakota to east-central Saskatchewan (Fig. 4). The Escarpment comprises (from north to south) the Pasquia Hills, the Porcupine Hills, Duck Mountain, Riding Mountain, and Pembina Mountain, extending a distance of approximately 675 km. In Canada, the Manitoba Escarpment represents the eastern erosional margin of both the Western Canadian Sedimentary Basin and the Western Interior Seaway; at times of sea-level highstand the eastern coastline of the Western Interior Seaway would have been further east (Nielsen, 2003). Cretaceous sequences are thin in comparison to correlative strata in the foredeep of Alberta and British Columbia. Frequent unconformities are sedimentologically difficult to detect due to the lack of pebble beds, but indicated by biostratigraphic analysis (McNeil and Caldwell, 1981). These strata were deposited on the stable eastern platform referred to as the backbulge (using the nomenclature of Decelles and Giles, 1996) (again, see Fig. 1) in

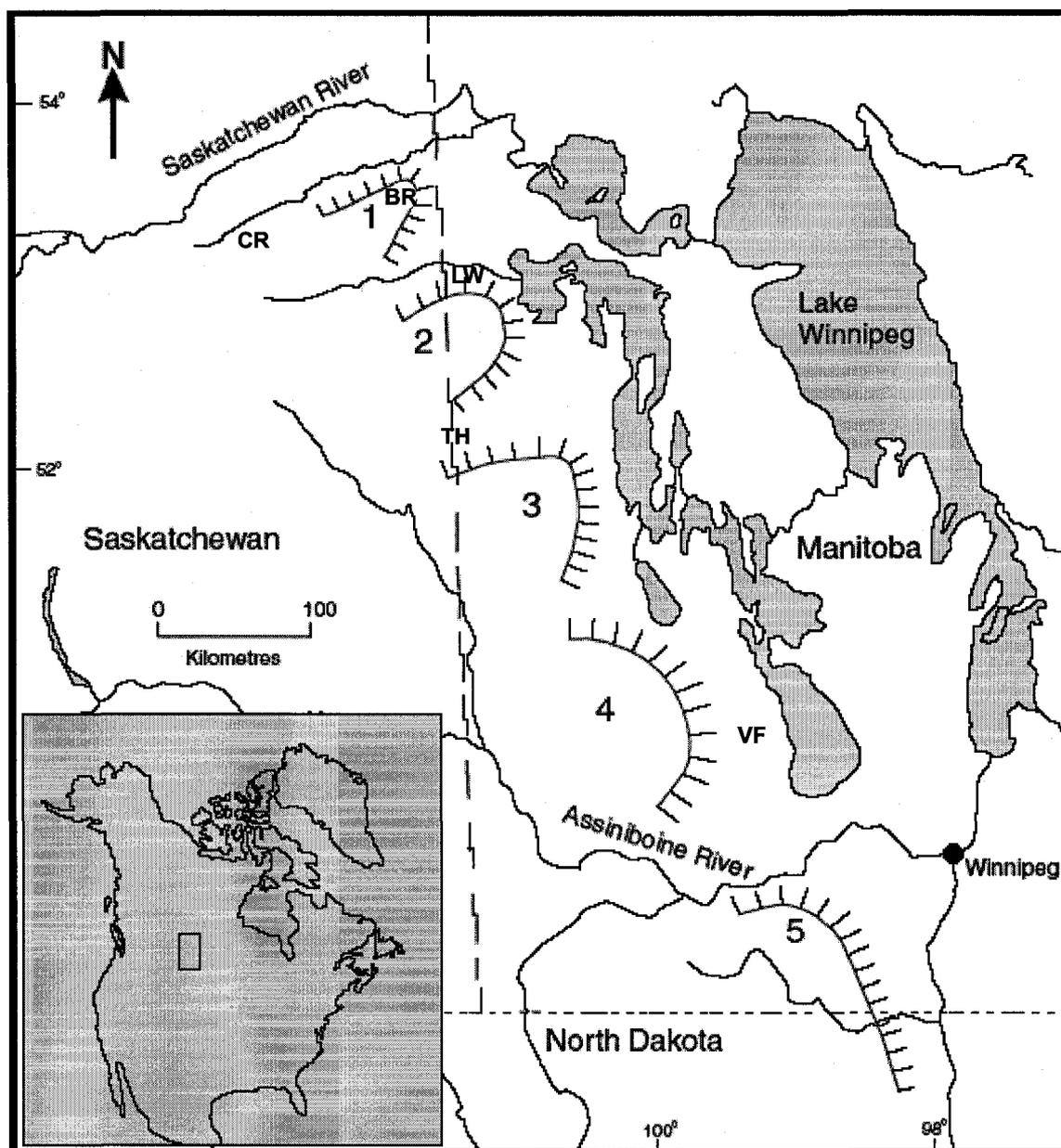


Figure 4: Map of the Manitoba Escarpment, modified from McNeil and Caldwell (1981) and Schröder-Adams et al. (2001). The major uplands of the escarpment include (1) the Pasquia Hills, (2) the Porcupine Hills, (3) Duck Mountain, (4) Riding Mountain, and (5) Pembina Mountain. Field localities pertinent to this study are the Carrot River (CR), Bainbridge River (BR), Little Woody River (LW), Thunder Hill (TH), and Van der Voort Farm (VF) localities.

waters that rarely exceeded 100 m in depth even at maximum transgression (Kauffman, 1969; Hattin, 1975). In this region both sedimentation and subsidence rates were low, and the resulting strata are condensed and lack substantial coarse-grained terrigenous siliciclastic material compared to the coarser expanded sections resulting from increased accommodation space in the rapidly subsiding foredeep (McNeil and Caldwell, 1981; Tyagi et al, 2005).

The current classification of the strata of the Manitoba Escarpment was established by McNeil and Caldwell (1981) and can be characterized broadly as condensed strata composed primarily of fine-grained terrigenous clastic and pelagic carbonate sediments (McNeil and Caldwell, 1981). Differing somewhat from this generalization are the horizons most pertinent to this study, which are found within the Belle Fourche Member of the Ashville Formation (Fig. 5).

Stratigraphic Relationships of The Belle Fourche Member

After examining the Belle Fourche Shale at its type locality near Belle Fourche, South Dakota (Collier, 1920; 1922), and correlating it in the subsurface northwards to the Manitoba Escarpment, McNeil and Caldwell (1981) designated the upper carbonaceous shales of the Ashville Formation as the Belle Fourche Member. Stratigraphically, the member unconformably overlies the Westgate Member of the Ashville Formation and is overlain by the Keld Member of the Favel Formation (Fig. 5). The contact between the upper Belle Fourche Member and the Keld Member is gradational in the Riding

Cretaceous		Stage	Southern Plains Alberta <i>modified after Bloch et al., 1993; Nielsen et al., 2003</i>	Central Saskatchewan <i>modified after Bloch et al., 1993</i>	Manitoba Escarpment <i>(this study) modified after McNeil & Caldwell, 1981; Bloch et al., 1993</i>	Eastern Montana <i>modified after Dyman et al., 1994</i>	Black Hills <i>modified after Dyman et al., 1994</i>		
						W	E	S	N
Cretaceous	Upper	Santonian	Niobrara Formation	First White Speckled Shale	Niobrara Fm	Telegraph Creek Fm ?	Niobrara Fm	Niobrara Fm	
		Coniacian			Calcareous Mbr		Niobrara Fm		
		Turonian	Carlile Formation	Morden Shale	Morden Shale	Carlile Shale	Carlile Shale	Carlile Shale	Sage Breaks Mbr
			Second White Specks Fm	Second White Specks Fm	Assiniboine Mbr	Assiniboine Mbr	Greenhorn Fm	Greenhorn Fm	Turner Sandy Mbr
		Cenomanian	Belle Fourche Fm	Belle Fourche Fm	Favel Fm	Belle Fourche Mbr	Belle Fourche Shale	Belle Fourche Shale	Belle Fourche Shale
	Fish Scales Fm		Fish Scales Fm	Ashville Fm	Keld Mbr	Westgate Mbr	Westgate Mbr	Mosby Sandstone Mbr	
	Westgate Fm		Westgate Fm			Mowry Shale	Mowry Shale	Muddy Sandstone	
	Albian	Viking Fm	Viking Fm		Newcastle Mbr	Newcastle Mbr	S. Cr. Sh. Mbr unnamed	Newcastle Sandstone	
		Joli Fou Fm	Joli Fou Fm		Skull Creek Mbr	Skull Creek Mbr	Skull Creek Mbr	Skull Creek Shale	
	Lower								

Figure 5: Regional stratigraphic nomenclature of selected early-Late Cretaceous strata of the Canadian Western Interior Basin and correlative rock units in the northern United States. Abbreviations are as follows: S. Cr. Sh. Mbr, Shell Creek Shale Member; Pool Cr. Mbr, Pool Creek Member.

Mountain and Duck Mountain areas; however, it becomes unconformable in the northwest; a fact recognized due to the progressive disappearance of abundant, readily correlated bentonite beds found throughout the Belle Fourche Member (McNeil and Caldwell, 1981). The Belle Fourche Member is correlative with the Belle Fourche Formation in the subsurface of central Saskatchewan and the central plains of Alberta (Bloch et al. 1993) and the Belle Fourche Shale in North and South Dakota (McNeil and Caldwell, 1981). The upper part of the Belle Fourche Member likely correlates with the lower Lincoln Limestone Member of the Greenhorn Formation in Colorado/Kansas and adjoining areas (Fig. 5 and McNeil and Caldwell, 1981).

Deposited during the Greenhorn transgression (Fig. 3), the Belle Fourche Member along the eastern margin is composed predominantly of uniform, greyish-black or black, carbonaceous, noncalcareous shale interbedded with numerous bentonite beds and thin beds or lenses of siltstone, fine-grained sandstone or calcarenite (McNeil and Caldwell, 1981). Additionally, it carries a distinctive sequence of stratigraphic marker beds of regional significance, described below.

Lower Belle Fourche Member of the Ashville Formation

Regional Correlation and Significance of the "Fish Scale Marker Beds": The stratigraphically lowest regional marker is what will here be referred to as the "fish scale marker beds". In the subsurface of central Saskatchewan and the central plains of Alberta, Bloch et al. (1993) described the Fish Scales Formation by including strata previously referred to as Base of Fish Scales, Fish Scale Marker Bed, Fish Scale Sandstone and Fish Scale zone. They also recommended that the correlative and distinct "fish remains zone" of the Shaftesbury Formation in the northwestern Alberta plains (Gleddie, 1954; Wall,

1967), where the term “fish scales bearing” was first used to describe shales in the WCSB (Selwyn, 1877), be assigned member status within the Shaftesbury Formation. In this study I retain the term “fish scale marker beds” to correlate to McNeil and Caldwell’s (1981) comprehensive study of the stratigraphy along the Manitoba Escarpment.

The significance of the Fish Scales Formation and its correlatives lies in its basin-wide recognition in subsurface well log data (Fig. 6). The contact between the underlying Westgate Formation and the Fish Scales Formation (which is commonly referred to as the “Base of Fish Scales”) is expressed in wireline logs primarily as a sharp increase in gamma-ray and resistivity response, and it is commonly used as a marker horizon for the Early and Late Cretaceous (i.e. Albian-Cenomanian) boundary (Leckie et al., 1992; Bloch, et al., 1993). Though barren of foraminifera (Leckie et al., 1992; Bloch et al., 1993), dinoflagellate assemblages within these strata (Singh, 1983; Leckie et al., 1992, 1999; Schröder-Adams et al., 1996) support an early Cenomanian age. The transition to the overlying Belle Fourche Formation in central Saskatchewan and the central plains of Alberta is gradational and is characterized by the appearance of the *Verneuilinoides perplexus* Zone of middle Cenomanian affinity (Bloch et al., 1993, Schröder-Adams et al., 1996, Tyagi et al., 2007).

Lithology and Biostratigraphy: In the Manitoba Escarpment, the base of the fish scale marker beds were recognized by McNeil and Caldwell (1981) to be coincident with the base of the Belle Fourche Member, and identified in outcrop by the occurrence of abundant fish fragments as well as silty lenses and laminae within the lowermost six to ten metres of the unit; fossiliferous beds or lenses composed largely of fish debris occur in

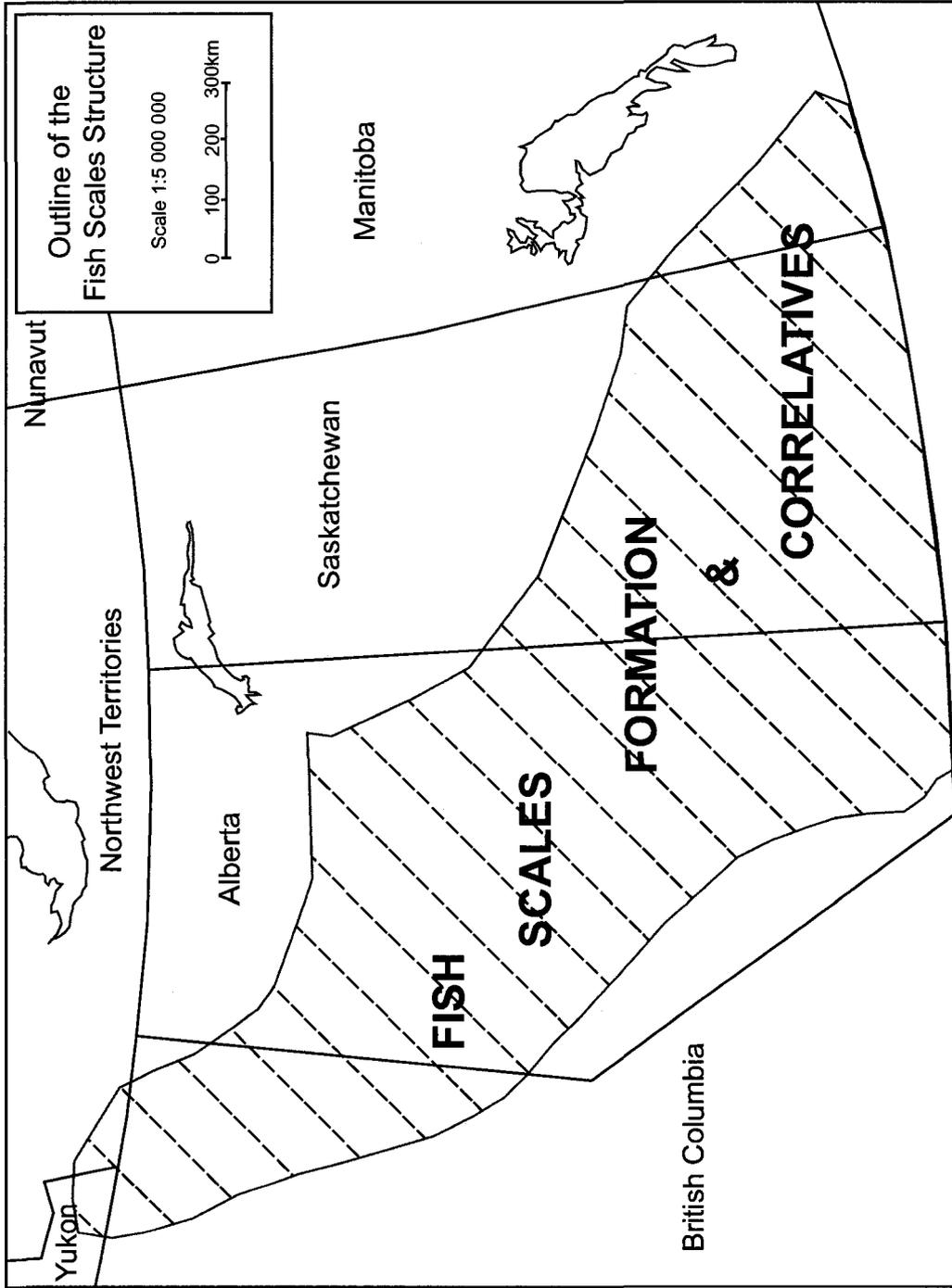


Figure 6: Generalized outline of the Fish Scales Formation (sensu Bloch et al., 1993) and its correlatives in Canada, including the “fish scale marker beds” of the Manitoba Escarpment described by McNeil and Caldwell (1981). Modified from Leckie et al., 1994; Jowett et al., 2007.

the lowest five metres. The contact of the Belle Fourche Member and the fish scale marker beds with the underlying Westgate Member of the Ashville Formation is typically sharp, while the upper boundary was assigned arbitrarily as the top of a distinctive, widespread, silty, calcarenitic unit (McNeil and Caldwell, 1981).

The lowest three metres of the fish-scale marker beds along the escarpment are not barren of foraminifera as in the western part of the basin, but instead reveal components of the *Miliammina manitobensis* Zone (McNeil and Caldwell, 1981). McNeil and Caldwell (1981) interpreted this as an indication that the lower portion of the Belle Fourche Member and the fish-scale marker beds within it are of latest Albian age in the Manitoba Escarpment and that the unit is diachronous across the basin, while other authors (e.g. Bloch et al., 1993) debate the possibility of reworking of late Albian foraminiferal assemblage into the early Cenomanian shales.

In comparison, further west in the basin the equivalent Fish Scales Formation is described as being composed primarily of well laminated claystones and mudstones generally less than 20 m thick (Bloch et al., 1993). In the central foothills of Alberta, equivalent strata occur with a thin (up to 3.5 m thick) sandstone capped with chert pebbles, while in central Saskatchewan it can be recognized by the occurrence of a thin (<5 cm) coarse sandstone or pebble layer overlain by organic-rich shale (Bloch et al., 1993; Schröder-Adams et al., 1996; Leckie et al., 2000; Ridgely and Gilboy, 2001; Ridgely et al., 2001; Tyagi et al., 2007). Though abundant disarticulated vertebrate skeletal material is disseminated throughout the unit, it is particularly concentrated in the coarse, basal, erosional layer (Leckie et al., 1992; Bloch et al., 1993).

The vertebrate assemblage of the lower Cenomanian bioclastic conglomerate within the Shaftesbury Formation of the northwestern Alberta plains contains abundant teleost fish scales belonging predominantly to *Osmeroides transversus*. Remains of unidentified ichthyodectids and enchodontiforms have been noted, as well as vertebral centra attributed to ichthyosaurs (Leckie et al., 1992). Teleost vertebral centra (Leckie et al., 1992) and the remains of the earliest known North American paracanthopterygian fish, *Xenyllion zonensis* (Wilson and Murray, 1996) have also been described from this formation. Whether it is the small size of the preserved remains or their fragmentary nature that is to blame, relatively little work has been done on assessing the diversity of the vertebrate fauna of the Fish Scales Formation, and what little has been described has all come from Albertan exposures (Leckie et al., 1992; Wilson and Murray, 1996). An examination of the literature revealed no attempt to describe vertebrate remains from the correlative fish scale marker beds in the Manitoba Escarpment.

Depositional Environment of the Fish Scales Formation: In Alberta, the deposition of the Fish Scales Formation has been interpreted as the result of marine transgression and/or of deeper water current-winnowing, with the coarsest bioclastic-hash layer at the base of the formation representing a transgressive lag deposit (Leckie et al., 1992; Bloch et al., 1993). Overlying laminae within the formation are interpreted as representing a shallow water condensed section (Leckie et al., 1990; 1992). Sparse bioturbation, the complete absence of benthic microfossils, high accumulation of organic matter, the absence of benthic vertebrate fossils and the abundance of pelagic algal cysts have all contributed to the interpretation of deposition of the Fish Scales Formation under anoxic conditions (Leckie et al., 1990; 1992; Bloch et al., 1993; Schröder-Adams et al., 1996).

The abundant vertebrate remains, on the other hand, are thought to have accumulated due to long-term, natural accumulation; their concentration in the Fish Scales Formation being interpreted as a taphonomic artifact of transgression rather than representing a mass death assemblage (Leckie et al., 1990; Wilson and Murray, 1996).

Upper Belle Fourche Member

Bio- and Chronostratigraphy: With the exception of the apparent latest Albian age of the lowest portions of the Belle Fourche Member of the Ashville Formation (and the uppermost portion, which is barren of foraminifera), the remainder of the member was further characterized as Middle Cenomanian in age by McNeil and Caldwell (1981) due to the presence of the *Verneuilinoides perplexus* Zone, as well as the presence of the paired *Ostrea beloiti* and “X” bentonite marker beds. *O. beloiti* is a biostratigraphic marker for the mid-Cenomanian (McNeil and Caldwell, 1974; Kauffman et al., 1993, Tyagi et al., 2007), and can be found in the upper part of the Belle Fourche Member in 10-15 cm thick lenses and beds of bioclastic calcarenite that are composed of *O. beloiti* valve fragments and calcitic prisms originating from disaggregated inoceramid bivalves (McNeil and Caldwell, 1981).

The *O. beloiti* beds in the upper Belle Fourche Member are found immediately below, above, or even straddling, a prominent bentonite bed, which compared favorably enough with the associations of *O. beloiti* and the “X” bentonites as originally observed in the Western United States. There these markers occur near the top of the Cenomanian Graneros Shale and its equivalents (e.g. Hattin, 1965; Cobban and Scott, 1972; Kauffman et al., 1977; Cadrin et al., 1996; Fisher et al., 2001). $^{40}\text{Ar}/^{39}\text{Ar}$ dates of this bentonite delivered a variety of ages including 93.3 (Cadrin, 1992), 94.93 ± 0.53 Ma (Obradovich,

1993) and 94.96 ± 0.5 Ma (Cobban et al., 2006). Together with the *O. beloiti* beds, the “X” bentonite provides a marker traceable for at least two-thirds the length of the Western Interior Basin (Tyagi et al., 2007), and its position in the stratigraphic framework of the Manitoba Escarpment by McNeil and Caldwell (1981) has been used in subsequent studies of these strata (e.g. Cumbaa and Bryant, 2001; Schröder-Adams et al., 2001; Cumbaa et al., 2006). Work is currently in progress to process select bentonites, including the “X” bentonite, from the Manitoba Escarpment for radiometric dates.

Bonebeds: Within this upper portion of the Belle Fourche Member, there are dense bioclastic and bonebed horizons, discovered primarily in outcrops along the Carrot and Bainbridge rivers in the Pasquia Hills (Cumbaa and Tokaryk, 1999). The most thoroughly described of these bonebed deposits is from the Bainbridge River locality, which occurs as discontinuous lenses 12-15 cm thick, composed of completely disarticulated, randomly oriented fossil remains of chondrichthyans, actinopterygians, marine reptiles and birds (Tokaryk et al., 1997; Cumbaa and Tokaryk, 1999; Cumbaa and Bryant, 2001; Schröder-Adams et al., 2001). The most abundant vertebrate remains within this bonebed are teeth (especially those of the teleost *Enchodus*), followed by vertebrae. The abundance of well-preserved, little-distorted avian post-cranial elements is unique (Tokaryk et al., 1997; Cumbaa et al., 2006). Other common components in bonebeds from the Bainbridge River include abundant, relatively undeformed coprolites thought to be of piscine origin and bentonite rip-up clasts rimmed with diagenetically-precipitated calcite (Cumbaa and Tokaryk, 1999). With more than 40 vertebrate taxa identified, the fauna from the Carrot River and Bainbridge River deposits are interpreted

as a diverse, shallow marine community (Cumbaa et al., 2006), including the earliest diverse avifauna known from North America (Tokaryk et al., 1997).

Stratigraphic Placement of Bonebeds: At the Bainbridge River locality, the primary (lensoid) bonebed is found almost immediately above the condensed, calcarenitic horizon marking the *O. beloiti* bed and approximately two metres below a 31 to 33 cm thick bentonitic horizon identified as the “X” bentonite (Cumbaa and Bryant, 2001). The Carrot River bonebed, meanwhile, was discovered in the upper third of a one metre thick section, and consisted of a pavé of small, contiguous to separated blocks capped by a 3-5 cm thick bentonite (Cumbaa et al., 2006). Samples below the bonebed contain the benthic foraminiferal *Verneuilinoides perplexus* Zone (while samples from above the bonebed were found to be barren of foraminifera) confirming a middle to late Cenomanian age for the deposit (McNeil and Caldwell, 1981; Schröder-Adams et al., 2001).

MATERIALS & METHODS

This study is based on samples of bonebed/bioclastic horizons collected from six localities found along the length of the Manitoba Escarpment on both sides of the Manitoba/Saskatchewan border (see Table 1). Collection of samples from the Bainbridge and Carrot River localities has been ongoing since the joint field project of the Royal Saskatchewan Museum (RSM) and the Canadian Museum of Nature (CMN) began in the Pasquia Hills region of Saskatchewan in 1991 (Cumbaa and Tokaryk, 1999). Samples from these localities used in this study for comparative purposes were collected several years ago, prior to the author's involvement with this research. Samples used in this study from the Thunder Hill, Van der Voort Farm, and Little Woody River localities, meanwhile, were collected in July of 2006 by the author and other members of the 2006 field expedition. The Thunder Hill and Little Woody River localities, originally described by McNeil and Caldwell (1981), had previously been visited by field parties from the Canadian Museum of Nature (Cumbaa, pers. comm., 2006), and the newly discovered Van der Voort Farm locality was visited based on information provided to the field party by the Manitoba Museum. This study ultimately focused on the calcarenitic samples collected from the Van der Voort Farm locality, however, additional bonebed material collected from other localities along the Manitoba Escarpment was utilized in order to characterize and contextualize the Van der Voort Farm samples stratigraphically, paleoecologically and paleoenvironmentally.

Table 1	
Pertinent outcrop locations along the Manitoba Escarpment	
<i>Bainbridge River (Saskatchewan)</i>	
BR-1	N 53° 33.949' W 102° 07.926' elev. 1158 ft.
BR-3	N 53° 33.912' W 102° 08.064' elev. 1164ft.
<i>Carrot River (Saskatchewan)</i>	
DH-1	N 53° 10' 30.72"
Royal Saskatchewan Museum Locality #63E4-0001	W 103° 29' 43.11"
<i>Little Woody River (Manitoba)</i>	
	N 52° 47.526' W 101° 33.880'
<i>Thunder Hill (Saskatchewan)</i>	
McNeil & Caldwell (1981) Loc. #51	N 52° 01' 49.40" W 101° 36' 34.43"
<i>Van der Voort Farm (Manitoba)</i>	
	N 50° 34' 15.5" W 99° 23' 42.8"

The Van der Voort Farm Calcarenite

Mr. Henry Van der Voort reported that in the process of excavating a dugout for water for the family's cattle approximately 25 years previous to the 2006 field season, the backhoe struck a resistant layer around seven feet below the surface (pers. comm., 2006). Dr. Stephen Cumbaa, Richard Day, Dr. Charles Underwood and the author collected samples of this layer from spoil piles on the surface of the north and south banks of the dugout (Fig. 7).

Acid Preparation

Samples used for taxonomic and taphonomic (biostratinomic) surveys were disaggregated via soaking in baths of dilute acetic acid (5 to 11% CH₃COOH) following the methods of Cumbaa and Tokaryk (1999). The acid baths were buffered using calcium orthophosphate [Ca₃(PO₄)₂] as an added precaution against dissolution of apatitic vertebrate remains. Conducted at the CMN, acid disaggregation of bonebed/bioclastic horizon samples began with measuring both the weight and volume of the selected specimens (Appendix I). Samples were subsequently soaked in tap water for 24 hours prior to acid immersion in order to limit the breakage of small vertebrate elements by the relatively violent reaction of the acid against dry pore space surfaces. Initially, samples from both the Van der Voort Farm and Thunder Hill localities were placed in acid immersion, however, only the former was successfully disaggregated; samples of the Thunder Hill material appeared unchanged even after four months of continuous immersion, and acid treatment was therefore terminated. An additional attempt was made to disaggregate the Thunder Hill material by placing specimens already treated in acid into an ultrasonic bath. This approach was also unsuccessful.

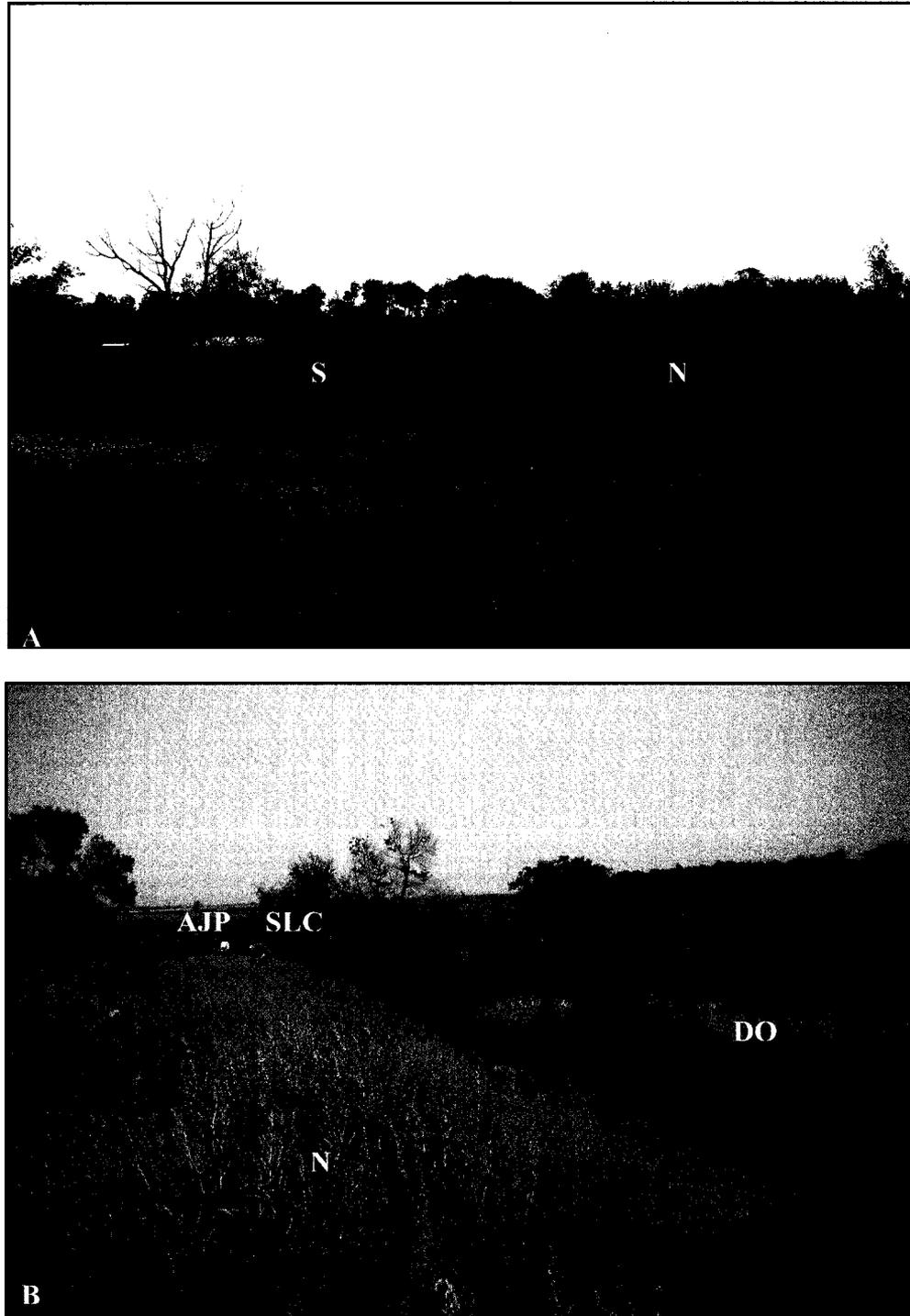


Figure 7: The Van der Voort Farm locality, near Riding Mountain, Manitoba, visited during the 2006 field season. (A) A view of the site from the southeast, with the north (N) and south (S) banks labeled (Photo by author). (B) A view of the site looking east-southeast across the site from the north (N) bank. The dugout pond (DO) is visible below, with Dr. Stephen L. Cumbaa (SLC) and the author (AJP) hard at work above (Photo courtesy of Dr. Charles Underwood).

Acid baths were changed on a weekly basis, and continued (in the case of the Van der Voort Farm material) until the samples were completely disaggregated. The acid solution was carefully decanted through an extremely fine mesh sieve (No. 270 – 0.053 mm) in order to prevent the loss of any fine suspended particles. Once disaggregated, samples were rinsed and/or soaked in tap water until their pH returned to close to neutral (target pH was approximately 6.7, based on the measured pH of the water surrounding a block of Van der Voort Farm material soaked in tap water for 24 hours), measured with an Orion 210 APlus portable pH meter. Once neutrality was achieved, samples were transferred to a mesh screen for air drying. Dried samples were then ready for taxonomic and taphonomic analyses.

Taxonomic Survey

At Carleton University, the five dried samples of disaggregated Van der Voort farm material were weighed (Appendix I) and sorted by sieve into four size fractions (coarse: No.10 sieve = 1.68mm; medium: No.20 sieve = 0.841 mm; fine: No. 40 sieve = 0.420 mm; and residue: < 0.420mm). The coarse and medium fractions of these samples were then examined microscopically in order to identify vertebrate remains to the least inclusive taxonomic level possible; the fine fraction and residue were deemed too small to be taxonomically informative. Microphotographs of vertebrate elements were taken primarily using a Sony Cyber-Shot Super SteadyShot DSC-H2 digital camera mounted on an Olympus SZX9 binocular microscope. Images were assembled using Helicon Focus 4.16 software as needed. For a complete list of the samples examined, see Appendix II. Fossils were identified by comparison with specimens in the collections of the CMN; through photographs of specimens in other museums (provided by Dr.

Cumbaa); and from published figures and descriptions. Welton and Farish's (1993) field guide to the Cretaceous selachians of Texas and Radu's (2005) zooarchaeological fish guide proved particularly helpful.

Comparative Taphonomic Census

In order to investigate the taphonomic history of the Van der Voort vertebrate skeletal material, a comparative taphonomic census was undertaken using selected bonebed samples. A random sample of Van der Voort Farm material was compared against a similarly sized, randomly selected sample of material from the Bainbridge River (BR-3) locality in order to better contextualize the taphonomic features. The samples drawn from these localities only included material retained by a standard sized No. 20 (0.841 mm) sieve. The number of elements procured from both samples was kept approximately constant from one locality sample to the other to facilitate meaningful comparisons of the taphonomic features and faunal diversities of the two localities. Samples of bioclasts were only taken from the Van der Voort and Bainbridge River (BR-3) localities due to the fact that these are the only bonebeds readily disaggregated via acid bath preparation. These elements were then assessed in terms of their size, shape, abrasive state and taxonomic affinity.

Size

Vertebrate microfossils used in this census were those collected from the standard size No. 10 (1.68 mm) and No. 20 (0.841 mm) sieve fractions. Elements that passed through these screens were not included in the survey due to their extremely small size and the paucity of useful taxonomic information they could provide. Due to the wide range of specimen sizes that could be found in a given sieve fraction, a counting tray with

1 mm marked increments was used to sort the specimens into 1 mm size categories, measured along an element's longest linear dimension. Though this method of size categorization will inevitably result in some fossils being closer in size to fossils in size classes other than their own, these categories nevertheless provide a good overall picture of the range of fossil sizes at a site (Blob and Fiorillo, 1996).

Shape

To further study the characteristics of the bioclasts as sedimentary particles, the sedimentological particle classification scheme of Sneed and Folk (1958) was employed as in Blob and Fiorillo (1996). Bioclasts in which one dimension was distinctly flattened were categorized as plate-shaped, such as the scales and bones of the opercular series of fishes. Bioclasts in which one dimension was greatly larger than the other two were categorized as elongate; for example tubular bones such as fin spines and the elongate teeth of the genus *Enchodus*. Finally, bioclasts which were approximately equidimensional were categorized as compact, and these included most vertebrae as well as the majority of coprolites.

Abrasion

To assess abrasion, Cook's (1995) slightly modified version of Fiorillo's (1988) scheme was used (Table 2). As the processes of abrasion are continuous rather than categorical by nature, data for intermediate stages was also recorded (as per Cook, 1995). Coprolites were not assessed for abrasion states due to their predisposition towards rounded shapes with smooth surfaces, which is ultimately due more to shaping during extrusion by the organism than to taphonomic factors.

Abrasion Stage	Description
Stage 0	Very angular: the bone (or tooth) is fresh and unabraded. Processes and bone edges defined and sharp.
Stage 1	Subangular: the bone edges and processes slightly abraded and polished.
Stage 2	Subrounded: bone edges well rounded, processes recognizable. Moderate abrasion.
Stage 3	Rounded: edges show high degree of rounding, processes generally remnant.
Stage 4	Very rounded: fragments show a high degree of sphericity

Faunal Diversity and Abundance

Integration of relative faunal diversity and abundance into the survey permits the assessment of potential taxonomic biases in shape, size and abrasion trends as well as providing a means for a more meaningful comparison of the overall diversity of the two localities. The relative faunal abundance of each sample was assessed by counting all elements more than half complete as separate individuals. A slight modification of the Minimum Number of Elements protocol (Badgely, 1986); this approach permits the inclusion of broken elements into the faunal census while eliminating the possibility of counting individual elements multiple times. This is particularly important with samples, like those that have been screen-washed, where the probability of some elements being broken into multiple identifiable fragments is high (Blob and Fiorillo, 1996).

Finally, the size, shape, abrasion, and faunal/element diversity distributions were compared between the Van der Voort and Bainbridge River (BR-3) samples statistically using P.A.S.T. version 1.77 software (Hammer et al., 2001) via Chi-square tests, which provide an effective means of evaluating the similarity of distribution curves (Davis, 1986).

Petrographic Analysis

A comparative petrographic analysis was undertaken in order to further investigate the taphonomic and diagenetic history of the Van der Voort Farm calcarenites, as well as why certain biophospharenitic bonebeds broke down easily via treatment with acetic acid (e.g. Bainbridge River 3) while others did not (e.g. Bainbridge River 1, Carrot River, Thunder Hill). Polished thin sections of material collected from the Van der Voort Farm were compared against thin sections prepared from other vertebrate-rich bioclastic

horizons along the Manitoba Escarpment, including Carrot River (DH-1), Thunder Hill and two localities along the Bainbridge River (BR-1 and BR-3). Polished thin sections were prepared at Carleton University and used for electron microprobe (EM) analysis, scanning electron microscope (SEM) imaging, and petrographic point count analysis.

Electron Microprobe Analysis and Scanning Electron Microscopy

Polished thin sections were examined at the CMN using a JEOL 733 SuperProbe Electron Microprobe. Slides were carbon-coated, and examined using a 15.0 kV beam at 20 nA, with a 10 μm spot size. A ZAF correction routine was utilized to analyze the composition of the cement binding the phosphatic bioclasts, as well as to characterize any other mineral grains of interest. A Philips XL30 ESEM (set at 15.0 kV, 76 nA, 5.2 μm spot size) was subsequently used in order to produce higher resolution images of noteworthy features within the thin sections.

Petrographic Point Count Analysis

A Swift Automatic Point Counter Model E was used to conduct 500-point point count analyses from the thin sections in order to determine the relative abundance and composition of the constituent clasts and matrix.

RESULTS

Surficial Description of the Van der Voort Farm Calcarenites

These calcarenitic blocks had weathered surfaces that were brownish-yellow to orange in color, while freshly broken surfaces were more yellowish-white to medium-light grey in color. The blocks ranged up to about seven centimetres in thickness and rarely more than twenty centimetres in length. They are rich in calcareous materials, principally medium sand-sized prismatic calcite crystals that appear to have originated from the disaggregated remains of the outer layers of the shells of inoceramid bivalves. They also contain oysters and variable amounts of small vertebrate fossils which are disseminated throughout the calcarenitic blocks, with obvious shark and bony fish teeth on the surface. The blocks frequently appear massive and lack physical sedimentary structures; however vertebrate fossils occasionally appear to be concentrated along some laminae, which are also occasionally slightly inclined as though cross-laminated. Additionally, larger vertebrate fossils appear to typically lie parallel or sub-parallel to the bedding plane, however they do not appear to be preferentially aligned in that plane. This description also applies to calcarenite samples collected from along the banks of the Little Woody River (N 52° 47.526', W 101° 33.880'); calcarenite samples from this latter locality were examined briefly in order to compare them lithologically, sedimentologically, and faunally with the Van der Voort calcarenites.

Systematic Paleontology

This section describes vertebrate specimens and ichnofossils examined which could be identified to a useful taxonomic level and/or which have paleoecological significance. All other vertebrate materials examined for this study, the majority of which

can only be tenuously identified if at all, are listed in Appendix II. The vast majority of the specimens described herein originated from material collected at the Van der Voort locality, which is the prime focus of this study. Material from other localities was also examined for comparative purposes, and for the comparative taphonomic survey that forms another part of this study. Where a given taxon occurs only in a site apart from the Van der Voort locality, or in more than one of the examined sites, all the alternate or additional relevant localities are mentioned. In general however, the specimen descriptions below are intended to describe the basic characteristics of each taxon based on materials collected from the Van der Voort locality. As such, the specimens figured in Plates 1 through 11 are representative samples of each taxon from the Van der Voort locality unless otherwise indicated.

Class CHONDRICHTHYES
Subclass ELASMOBRANCHII
Order HYBODONTIFORMES
Family HYBODONTIDAE Owen, 1846
Genus *Hybodus* Agassiz, 1837
Hybodus butleri Thurmond, 1971: Plate I – Fig. 1

Description – A single, small tooth with a distally inclined cusp; the root is not preserved; and it possesses a low crown with well developed, low medial and distal blades. It lacks distinct cusplets, and the carinae deviate only slightly from a straight line to form a very broad, obtuse angle. Longitudinal ridges are present on both the lingual and labial faces of the crown, reaching up to where the tip is broken on the lingual surface but only partway up the tip on the labial surface.

Discussion – Though fragmentary, this single tooth from the Van der Voort material is assigned to *H. butleri* based on the nearly straight line formed by the mesial and distal carinae, the absence of lateral cusplets, and its small size.

Stratigraphic Remarks – The specimen described above is consistent with the description of *H. butleri* from previous work on Cenomanian marine vertebrates of the Manitoba Escarpment (Cumbaa et al., 2006), and has also been reported from Aptian-Albian deposits in Texas (Welton and Farish, 1993).

Family PTYCHODONTIDAE Jaekel, 1898

Genus *Ptychodus* Agassiz, 1835

Ptychodus cf. *P. decurrens* Agassiz, 1843: Plate I – Fig. 2

Description – A single lateral tooth recovered from the Bainbridge River (BR-3) material examined, this low-crowned specimen measures approximately 7 mm in anteroposterior length. The crown is only slightly (and asymmetrically) convex, and it is roughly elliptical in shape when viewed occlusally. It is adorned with at least five transverse enameloid ridges which bifurcate into finer ridges in the marginal area; all ridges extend across the marginal area and are oriented nearly perpendicularly to the crown border. The root is somewhat box-like in shape and is also quite low, giving the tooth a total maximum height of approximately 2.5 mm.

Discussion – In possessing a relatively low crown and in having the transverse and marginal area ridges oriented perpendicular to the crown border, this lone ptychodontid shark tooth most closely matches descriptions of the teeth of *P. decurrens* (Welton and Farish, 1993). Shimada et al. (2006) indicate that the inter- and intraspecific morphological variation of *Ptychodus* teeth is not well studied, and that identification can be further confounded due to the fact that the morphology of small, lateral teeth is

apparently conservative within the genus. Therefore, while this tooth best matches published descriptions of *P. decurrens*, these considerations lead to its more conservative classification herein as *Ptychodus* cf. *P. decurrens*.

Stratigraphic Remarks - *P. decurrens* specimens are known from late Albian through Turonian strata (Williamson et al., 1991; Welton and Farish, 1993), and are common in Cenomanian deposits from Europe and Australia (e.g. Cappetta, 1987; Siverson, 1999). Abundant also in the Cenomanian of North America (e.g. Williamson et al., 1991; Cicimurri, 2001a; Shimada et al., 2006), *P. decurrens* is notably found in the Cenomanian-aged Pasquia Hills bonebeds, at both the Bainbridge River and Carrot River localities (Cumbaa and Tokaryk, 1999; Cumbaa et al., 2006), as well as in late Cenomanian deposits from northwestern Alberta (Cook, 2007).

Order LAMNIFORMES Berg, 1958
 Family ANACORACIDAE Casier, 1947
 Genus *Squalicorax* Whitley, 1939

Squalicorax volgensis Glickman in Glickman and Shvazhaite, 1971: Plate II – Fig. 1-6

Description – As with other species of *Squalicorax*, the teeth of *S. volgensis* possess anaulacorhizous roots, and lack both a nutrient groove or pit. On the labial side of the crown, the crown foot forms a prominent basal ledge overhanging a correspondingly deep basal concavity. The general pattern of an increasing distal inclination of the cusp moving distally along the tooth series is followed as in other members of the genus; anterior teeth possess the most erect cusps (Plate II, Fig. 1) and parasymphyseals(?) possess a mesio-distally compressed cusp and root, with the root being asymmetrical (where the mesial root lobe is slightly longer than the distal lobe) (Plate II, Fig. 2). The antero-lateral teeth of *S. volgensis* possess distally inclined cusps, which are inclined at

an angle more reminiscent of the closely related *S. curvatus* than *S. falcatus* (Plate II, Figs. 3, 4a). Distal inclination of the cusp is most pronounced in lateral tooth specimens (Plate II, Figs. 5, 6). All teeth are low crowned, and the apex forms an acute angle. The mesial cusplet is essentially continuous with the main cusp, while the distal cusplet forms a well defined heel (e.g. Plate II, Fig. 3). The cutting edge is continuous along the mesial and distal sides of the crown, and unlike other species within the genus, the cutting edges tend to be smooth; limited and/or irregular serrations are occasionally present, as seen in the inset in Plate II, Fig. 4b.

Discussion – In the Van der Voort deposits the “crow sharks” of the genus *Squalicorax* are the third most common family-level taxonomic group of chondrichthyans represented after the odontaspidids and the cretoxyrhinids, and the vast majority of those specimens identified are of *Squalicorax volgensis*. Teeth of *S. volgensis* were also found in the material collected from the Little Woody River locality. First identified in Russia (Glickman and Shvazhaite, 1971), this species has also been described from elsewhere in Europe (Müller and Diedrich, 1991), Texas (Welton and Farish, 1993; Cappetta and Case, 1999), Saskatchewan (Cumbaa and Tokaryk, 1999; Cumbaa et al., 2006) and in northwestern Alberta (Cook, 2007). It has been noted as “conspicuously absent” from the Cenomanian Tobe locality in Colorado (Shimada et al., 2006).

Stratigraphic Remarks - Considered to be the most primitive member within the genus, *S. volgensis* ranges from the upper Albian to Santonian in the Cretaceous of North America (Shimada and Cicimurri, 2006).

Squalicorax falcatus (Agassiz, 1843): Plate II – Fig. 7, 8

Description – As previously described in *S. volgensis*, the teeth of *Squalicorax falcatus* possess anaulacorhizous roots, lack both a nutrient groove or pit, and the crown foot forms a prominent basal ledge overhanging a correspondingly deep basal concavity on the labial side of the crown. The main cusp tends to be narrow and erect in anterior teeth, while being low and distally inclined in lateral teeth. In general, the cusp is more erect than that seen in *S. curvatus* or *S. volgensis*. The cutting edges are finely to coarsely and regularly serrated continuously along the mesial and distal edges of the crown (Plate II, Fig. 8b).

Discussion – Due to the fragmentary nature of the serrated *Squalicorax* teeth recovered, it is difficult to discern whether they are representative of *S. falcatus* or *Squalicorax curvatus* (Williston, 1900). In Williston's (1900) original description of *S. curvatus*, however, he notes that one observable feature of the teeth is that they exhibit a convex labial crown surface. As the fragmentary teeth described here display flat labial crown surfaces, I therefore refer these specimens, along with those in the Little Woody River material, to *S. falcatus*. This species is known from many localities throughout the Western Interior (Russell, 1988), including Texas (Welton and Farish, 1993; Cappetta and Case, 1999), Kansas (Shimada and Fielitz, 2006), northwestern Alberta (Cook, 2007), and from further north along the Manitoba Escarpment (Cumbaa et al., 2006).

Stratigraphic Remarks - The chronological range of this species in North America is considered to be from the middle Cenomanian to Lower Campanian (Shimada and Cicimurri, 2006).

Family CRETOXYRHINIDAE Glickman, 1958
Genus *Archaeolamna* Siverson, 1992
Archaeolamna sp.: Plate III – Fig. 1-6

Description – Parasymphyseal teeth are relatively small and possess an erect, mesio-distally compressed crown with divergent accessory cusplets (Plate III, Fig. 1). The root is also mesio-distally compressed, as well as asymmetrical, with the mesial extremity of the root being longer than the distal one. In all teeth, the root lacks a nutrient groove, and generally possesses one or two nutritive pits near the centre of the lingual protuberance. Anterior teeth also possess one pair of broad, divergent and triangular cusplets and a high main cusp that is slightly inclined distally in upper teeth and symmetrically erect in lower ones (Plate III, Figs. 3, 4). The roots of the anterior teeth tend to be quite symmetrical in upper teeth, slightly asymmetrical in lower teeth, and in both cases possess rounded extremities. Intermediate teeth are significantly smaller than those of adjacent files, and display a very narrow, distally inclined cusp (Plate III, Fig. 2). Lateral and postero-lateral teeth exhibit a more distinct distal inclination of the cusp, with the extremities of the root becoming shorter and more divergent distally along the tooth series (Plate III, Figs. 5, 6).

Discussion – Specimens assignable to *Archaeolamna* sp. account for the second most common identifiable chondrichthyan taxon in the Van der Voort material. The teeth described here as *Archaeolamna* sp. compare very favorably with those figured as *Cretodus* sp. by Case et al. (1990) as well as with those from the Pasquia Hills in the Manitoba Escarpment (Cumbaa et al, 2006). As with those from the latter locality, these teeth are found to differ from Siverson's (1992) description of *A. kopingensis* in their relative crown height and width, as well as in the orientation of the accessory cusps on

the lateral teeth. Furthermore, while weak longitudinal folds in the enamel on the labial basal crown surface can be seen on lateral teeth (Plate III, Fig. 5b, inset), they would be expected to be more strongly developed in postero-lateral teeth than is seen here (Plate III, Fig. 6b, inset) in keeping with Siverson's (1992) description. These considerations, as well as the difference in geological age from Siverson's specimens (which were Campanian in age), lead me to agree with Cumbaa et al. (2006) in stating that this is likely a new species of *Archaeolamna*, though it will not be described here.

Stratigraphic Remarks - The type species of the genus *Archaeolamna*, *A. kopingensis* (Davis, 1890) was described by Siverson (1992) from an early to middle-late Campanian fossil shark assemblage in the Köpings Sandstone in Sweden. It has since been identified from upper Campanian (Beavan and Russell, 1999) and upper Cenomanian (Cook, 2007) strata in Alberta, as well as misidentified as *Cretodus* sp. (in Case et al., 1990; corrected by Siverson, 1992) from strata in Saskatchewan which Case et al. (1990) originally misinterpreted as Coniacian, but which were later determined to be of Turonian age (Cumbaa and Tokaryk, 1999). It has also recently been tentatively identified from a Cenomanian deposit in Colorado (Shimada et al., 2006).

Genus *Cretalamna* Glickman, 1958

Cretalamna appendiculata (Agassiz, 1843): Plate III – Fig. 7, 8

Description – Generally, teeth of this species are moderately large and exhibit an erect and narrow cusp. The crown is smooth, with a strongly convex lingual face; an almost flat labial face; and a single pair of low, closely attached, divergent, and broadly triangular lateral cusplets. The crown is separated from the root by a narrow lingual dental band, and the root itself is strongly bilobate with flat, broad root lobes. It generally

exhibits a low lingual protuberance that lacks a nutrient groove but that generally possesses a nutritive pit.

Discussion – This genus is commonly referred to in the literature as *Cretalamna*, however, a growing number of researchers (Siverson, 1999, Shimada et al., 2006) have pointed out that the original spelling by Glickman (1958) is *Cretalamna*, and so that usage is followed here.

Similar to the Tobe, Colorado and Pasquia Hills localities, *C. appendiculata* is a rare taxon among material collected from the Van der Voort locality, and those specimens collected here do differ somewhat from typical specimens of *C. appendiculata*. These differences include the more rounded shape of the extremities of the roots (e.g. Plate III, Fig. 7) and, in one instance, what appears to be evidence for an incipient second mesial cusplet (Plate III, Fig. 8). However, in all three specimens recovered, the roots and crowns appear to be significantly abraded, which may contribute to the rounded appearance of the roots, and the poorly defined second mesial cusplet may only be a pathological artifact. The lateral cusplets are significantly lower than specimens figured by Welton and Farish (1993), but are consistent with those figured from the Tobe locality (Shimada et al., 2006). Despite these differences, the smooth, erect, narrow cusp and the narrow lingual dental band are characteristic of *C. appendiculata*. The U- and V-shaped interlobe areas of the figured specimens are the basis for their identification as upper and lower teeth (Plate III, Figs. 7, 8) respectively.

Stratigraphic Remarks - *Cretalamna appendiculata* has a long stratigraphic range (Albian to Ypresian) and a cosmopolitan distribution (see Shimada et al., 2006 for summary). More pertinent to this study, this taxon is especially abundant in upper Albian

and Cenomanian strata in Texas (Welton and Farish, 1993; Friedman, 2004); present in the late Cenomanian Dunvegan Formation in northwestern Alberta (Cook, 2007); and rare in the Cenomanian Tobe locality in Colorado (Shimada et al., 2006) and in the Cenomanian/Turonian strata of the Pasquia Hills in the Manitoba Escarpment (Cumbaa and Tokaryk, 1999; Cumbaa et al., 2006).

Genus *Cretoxyrhina* Glickman, 1958
Cretoxyrhina mantelli (Agassiz, 1843): Plate III – Fig. 9

Description – A single anterior tooth found in material collected at the Little Woody River locality measuring 25 mm in total tooth height, which possesses a robust, triangular, smooth-crowned cusp and no accessory cusplets. The razor-like cutting edges are continuous to the crown foot, and a broad dental band is present lingually. The root is strongly bilobed with a pronounced lingual protuberance marked by a single, pit-like nutritive foramen.

Discussion and Stratigraphic Remarks – *Cretoxyrhina mantelli* has been found globally in Cenomanian- through Campanian-aged strata (e.g. Cappetta, 1987; Müller and Diedrich, 1991; Siverson, 1992) including various Cenomanian deposits from the Western Interior Seaway of North America (e.g. Shimada and Martin, 1993; Welton and Farish, 1993; Cappetta and Case, 1999; Everhart et al., 2004; Siverson and Lindgren, 2005; Shimada et al., 2006; Cook, 2007). In the Pasquia Hills, teeth of *C. mantelli* are more common from Turonian-aged strata, however they are known to occur uncommonly in the Cenomanian-aged Carrot River bonebed (Cumbaa et al., 2006).

CRETOXYRHINIDAE *incertae sedis* (“Cretoxyrhinid A”): Plate IV – Figs. 1, 2

Description – These fragmentary teeth have convex lingual and slightly convex to flat labial crown faces. The cutting edges are non-serrated, and continuous from the cusp to the cusplets. The main cusp is relatively tall, erect, and narrow, and the crown possesses a single pair of high, erect cusplets. The roots, though incomplete, display a single nutrient foramen at the centre of the moderately high lingual protuberance and there is a moderately developed labial basal shelf.

Discussion – These teeth are similar to both *Archaeolamna* and *Cretolamna* in some respects, however they possess cusps and cusplets that are higher, narrower, and more erect (as opposed to divergent) than in either of these taxa. They are classified here as “Cretoxyrhinidae *incertae sedis*” on the basis the absence of a nutrient groove (Welton and Farish, 1993), and are therefore designated as “cretoxyrhinid A”. They approximate *Archaeolamna* most closely, and could in fact be either a new species or subspecies thereof; however, specimens are too few and fragmentary to say with certainty.

Stratigraphic Remarks – No informative stratigraphic remarks can be made regarding this taxon.

CRETOXYRHINIDAE *incertae sedis* (“Cretoxyrhinid B”): Plate IV – Figs. 3, 4

Description – Fragmentary teeth that are characterized by narrow primary cusps and a single pair of widely set, low, broadly triangular and erect cusplets. Both the lingual and labial crown faces are convex (with the labial face being less so than the lingual one) and the cutting edges are better defined on the main cusp than on the accessory cusplets. The root is very low and mesiodistally elongate. The lingual protuberance is low, there are no visible nutrient grooves, and the nutritive pits are small.

Discussion – The distinctively wide set, broad, low, erect cusplets and the mesiodistally elongate and low root set these teeth apart from the other chondrichthyan taxa observed in the Van der Voort material. They are considered to be of cretoxyrhinid affinity based on the absence of a nutrient groove (Welton and Farish, 1993), and are therefore designated as “cretoxyrhinid B”.

Stratigraphic Remarks – No informative stratigraphic remarks can be made regarding this taxon.

CRETOXYRHINIDAE *incertae sedis* (“Cretoxyrhinid C”): Plate IV – Fig. 5

Description – This taxon exhibits a narrow, erect primary cusp and very small accessory cusplets. The smooth cutting edges are continuous across the entire crown, and the primary cusp displays a convex lingual face and a flat labial face. The base of the crown is slightly constricted at the base, and marked by a prominent lingual dental band. There is no nutrient groove, and two small nutritive foramina are found on the lingual protuberance. The root is very high, with broad, tabular lobes and a V-shaped interlobe area.

Discussion – At 15 mm in length, this single specimen is one of the largest shark teeth recovered from the Van der Voort locality. The crown morphology, in particular the reduced accessory cusplets, is reminiscent of *Cretoxyrhina mantelli* (Agassiz, 1843), and while the primary cusp of “cretoxyrhinid C” is somewhat narrower than some figured *C. mantelli* (e.g. Welton and Farish, 1993), it is generally similar to other published descriptions (see Siverson and Lundgren, 2005; Shimada et al., 2006) The root morphology, however, is strongly at variance with previously described specimens of *C. mantelli*, in that the root lobes of “cretoxyrhinid C” are much more tabular, and the root

overall is much larger (root height even exceeds crown height). The absence of a nutrient groove is the basis for the designation of this taxon as “*Cretoxyrhinidae incertae sedis*”, and while it is possible that a designation of *Cretoxyrhina* sp. could be in order, the author hesitates to do so based on a single specimen; therefore this specimen is conservatively designated as “cretoxyrhinid C”.

Stratigraphic Remarks – No informative stratigraphic remarks can be made regarding this taxon.

Family ODONTASPIDIDAE Müller and Henle, 1839

Genus *Carcharias* Rafinesque, 1810

Carcharias amonensis (Cappetta and Case, 1975): Plate IV – Figs. 6-11

Description – Teeth of this species can be moderately large, with a broad-based cusp and generally one pair of cusplets in anterior teeth (e.g. Plate IV, Fig. 6) and up to two pairs on lateral teeth (e.g. Plate IV, Fig. 10). The lingual and labial faces are weakly convex, smooth, and bounded by smooth cutting edges, which are continuous onto the accessory cusplets. The cusp and cusplets alike typically exhibit some degree of distal inclination even in anterior row groups (e.g. Plate IV, Fig. 7), which becomes most pronounced in distal lateral teeth (e.g. Plate IV, Figs. 10, 11). The lingual dental band is well developed, and the relatively low root is marked with a nutrient groove in all cases. The lobes of the root are broad and tabular, and tend to converge in a V-shaped configuration.

Discussion and Stratigraphic Remarks – The teeth of *Carcharias amonensis* are the most abundant identifiable chondrichthyan remains from the Van der Voort locality. In Texas it may occur as early as the Late Albian (Welton and Farish, 1993), and is common in Cenomanian deposits from Texas (Welton and Farish, 1993; Cappetta and

Case, 1999), from Minnesota (Case, 2001) and from the Belle Fourche and Mowry shales of South Dakota (Cicimurri, 2001b; 2004), as well as from Africa (Antunes and Cappetta, 2002) and Europe (Vullo et al., 2003), though it is notably rare in the lowermost Greenhorn Limestone at the Tobe locality in Colorado (Shimada et al., 2006). The first identification of *C. amonensis* in Canada was from the Bainbridge River material collected in the Pasquia Hills (Cumbaa et al., 2006), and it has also been subsequently recognized in the Dunvegan Formation of northwestern Alberta (Cook, 2007).

Carcharias cf. *C. saskatchewanensis* (Case et al., 1990): Plate V – Figs. 1-4

Description – *Carcharias saskatchewanensis* teeth are small and consist of a triangular main cusp and one pair of lateral cusplets (though paired mesial cusplets sometimes occur in lateral teeth). The main cusp is quite massive and the smooth cutting edge is continuous along the whole length of the crown. The lingual crown face is typically smooth, though it may occasionally have weak longitudinal ridges restricted to an area just apical of the well defined lingual dental band at the crown foot. The labial crown face may also exhibit longitudinal ridges near the crown base (e.g. Plate V, Fig. 2b, 2c). The root is bilobate with rounded extremities, and bears a deep, well developed nutrient groove incising its lingual protuberance.

Discussion – The teeth in this sample closely resemble *Carcharias saskatchewanensis*, however, where they do differ is primarily in that the accessory cusplets of *C. saskatchewanensis* are typically described as high and narrow or “needle-like” (Case et al., 1990; Welton and Farish, 1993; Shimada et al, 2006), while the specimens examined in this study possessed cusplets that are lower and more broadly triangular (e.g. Plate V, Fig. 1). Additionally, the strong labial basal ledge described by

Welton and Farish (1993) is not observed in the Van der Voort specimens, and the main cusp appears to be slightly less massive here than in the Texan examples as well. However, the presence of sparse longitudinal ridges occurring on the labial crown foot and rarely on the lingual crown foot, and the overall similarity to other members of the genus *Carcharias* suggest that an assignment of *Carcharias* cf. *C. saskatchewanensis* is appropriate for these specimens, as well as for some examined from the Little Woody River sample. Another, similar looking species of odontaspimid known from Cenomanian deposits in the Western Interior that displays longitudinal ridging along the labial crown face is *Carcharias tenuiplicatus* (revised to *Cenocarcharias tenuiplicatus* in Cappetta and Case, 1999) (Welton and Farish, 1993; Cumbaa et al., 2006; Shimada et al., 2006); Shimada et al (2006) note that lateral teeth of *C. saskatchewanensis* could be mistaken for *C. tenuiplicatus*. The specimens described herein, however, show a distinct absence of the narrow crown, the two pairs of lateral cusplets, and the numerous, well-marked and sharp longitudinal ridges extending midway up the crown from the crown base that typify specimens of *C. tenuiplicatus*. An additional specimen referred to this taxon is noteworthy for its pathologically abnormal split cusp (Plate V, Fig. 4).

Stratigraphic Remarks - Described originally from Early Turonian (Cumbaa and Tokaryk, 1999) strata in Saskatchewan (Case et al., 1990), *Carcharias saskatchewanensis* has subsequently been found only in Cenomanian strata, from Texas (*Carcharias* sp. A of Welton and Farish, 1993; Friedman, 2004), Colorado (Shimada et al., 2006), Kansas (Shimada and Martin, 1993), South Dakota (Cicimurri, 2001a; 2001b) and northwestern Alberta (Cook, 2007). Cumbaa et al. (2006) also hypothesized that *C. saskatchewanensis*

is likely counted among a number of *Carcharias*-like odontaspidid teeth from the Bainbridge and Carrot River localities that remain as yet unidentified to species level.

Carcharias sp. A and *Carcharias* sp. B: Plate V – Figs. 5, 6

Description – Teeth designated here as species of the genus *Carcharias* other than *Carcharias amonensis* and *Carcharias* cf. *C. saskatchewanensis* are differentiated from the aforementioned taxa based on the morphology of their roots. *Carcharias* sp. A is recognized on the basis of a mesio-distally elongate root that is slightly asymmetrical, with the mesial lobe being more elongate than the distal lobe (Plate V, Fig. 5). The lobe extremities are rounded and the nutrient groove relatively weakly developed. *Carcharias* sp. B is recognized by the distinctively pronounced angle at which the root lobe angles away from the lateral cusplets (Plate V, Fig. 6). It also possesses very erect and broad triangular cusps and cusplets, and, as with *Carcharias* sp. A., rounded root lobe extremities and a weakly developed nutrient groove.

Discussion – *Carcharias* and *Carcharias*-like teeth constitute the second most abundant identifiable vertebrate remains within the material collected from the Van der Voort locality after teeth assignable to the teleost *Enchodus*. The presence of a nutrient groove on the roots of these teeth is suggestive of affinities with the odontaspidids, and while their overall cusp and root morphology is not unlike the species of *Carcharias* identified above, significant enough differences exist to warrant their exclusion from those species. Cumbaa et al. (2006) noted the presence of many *Carcharias*-like teeth in the Cenomanian deposits of the Pasquia Hills as well, and here as there they remain unidentified to species level.

Stratigraphic Remarks - No informative stratigraphic remarks can be made regarding this taxon.

ACTINOPTERYGII
Order AMIIFORMES Hay, 1929
Family CATURIDAE Owen, 1860
unidentified caturid: Plate VI – Fig. 1-4

Description – The remains herein ascribed to an unidentified caturid include vertebrae and vertebral fragments as well as scales. Most of the vertebral remains are preserved as the broken dorsal or ventral halves of distinctively hollow vertebral centra (referred to as “caturid vertebral arch elements” in the taphonomic survey portions of this study). These structures are generally characteristically bipartite, with distinctive inner and outer surfaces. The inner surfaces appear to be composed of relatively solid looking bone, roughly circular in outline, and are notably concave, giving them a somewhat saddle-like appearance (Plate VI, Fig. 1). The outer surface meanwhile has an almost rice paper-like texture and coloration, and it encompasses the “saddle” dorsally/ventrally and laterally (Plate VI, Fig. 1). Where preserved, the neural and/or haemal arches tend to be low and nearly horizontal (Plate VI, Fig. 2). Entire vertebrae are rarely found, however, in all cases these do not possess the saddle-like structures on the inner surfaces of the centrum (i.e. encompassing the notochordal canal), but are instead composed solely of the rice-paper textured bone (Plate VI, Fig. 2).

Scales of this taxon occur commonly in the Van der Voort material, and are generally ellipsoid in shape, occasionally slightly concave on the interior surface, and thicker around the margins than in the centre (Plate VI, Figs. 3, 4). They exhibit a distinctive pattern of parallel, slightly undulating longitudinal ridges that fan out posteriorly along

the scale from the ossification centre (Plate VI, Fig. 3). This ossification centre is the most massive point on the scale and is marked by a relatively rugose patch situated near the anterior margin of the scale, which may also occasionally possess small, raised tuberosities. In some instances, rather than the typical rugose patch, this location is instead marked by a raised canal, which opens as a pore on the inner surface of the scale and posteriorly on the outer surface (Plate VI, Fig. 4).

Discussion – The broad haemal arches inclined to an almost horizontal position characterizes these vertebrae as a member of the superfamily Caturioidea, and the presence of paired, block-like neural arch ossifications place it in the family Caturidae (Grand and Bemis, 1998). These vertebrae are essentially identical to those of an articulated specimen of an unnamed caturid [Canadian Museum of Nature; CMNFV 17462] described from Turonian strata from the shores of Lac des Bois, Northwest Territories (Cumbaa and Murray, in press) (Fig. 8a, b, c). Fish scales preserved alongside the Lac des Bois specimen are clearly associated, and these too are an identical match for those found in the Van der Voort material, and are the basis for the inclusion of these scales within this taxon (Fig. 8a, d, e). Those scales that possess a pore are interpreted as lateral line scales.

Caturid fossils are generally rare in North America, but in addition to the material from the Northwest Territories, some caturid material has also been described from the Bainbridge River locality in the Pasquia Hills (Cumbaa et al., 2006). There, teeth with distinctively arrowhead-shaped tips and premaxillae have been found and assigned to an unidentified caturid. In the course of examination of material from the Bainbridge River (BR-3) locality for the purposes of comparative taphonomy for this study, further

evidence for an unidentified caturid at the Bainbridge River (BR-3) locality was discovered in the form of two broken vertebral halves complete with saddle-shaped interior surfaces; one complete vertebra, and one very small scale inclusion within a coprolite.

Stratigraphic Remarks - No informative stratigraphic remarks can be made regarding this taxon.

Order PYCNODONTIFORMES Berg, 1940
Family PYCNODONTIDAE Agassiz, 1833
Pycnodontidae *incertae sedis*: Plate VI – Fig. 5

Description – Small fragments of plate-shaped bone with raised, enameloid ornamentation on the external surface.

Discussion – In addition to a number of small, characteristic teeth, Cumbaa et al. (2006) describe scattered fragments of bone with raised ornamentation from the Bainbridge River bonebed that compared favorably with that found on cranial bones of *Micropycnodon* Hibbard and Graffham (1945) from Kansas. Unlike the Bainbridge locality, however, no teeth have been found at the Van der Voort locality. While these few specimens are similar to those found from the Bainbridge River (Cumbaa, pers. comm.), their rarity and extremely fragmentary nature lead to their conservative designation as pycnodontidae *incertae sedis*.

Straigraphic Remarks - Though known from other Cenomanian-aged deposits in the Western Interior of the U.S. (e.g. Shimada et al., 2006), they are rare in Canadian deposits and have to date only been reported from the Bainbridge River bonebed (Cumbaa et al., 2006). No other informative stratigraphic remarks can be made regarding this taxon.

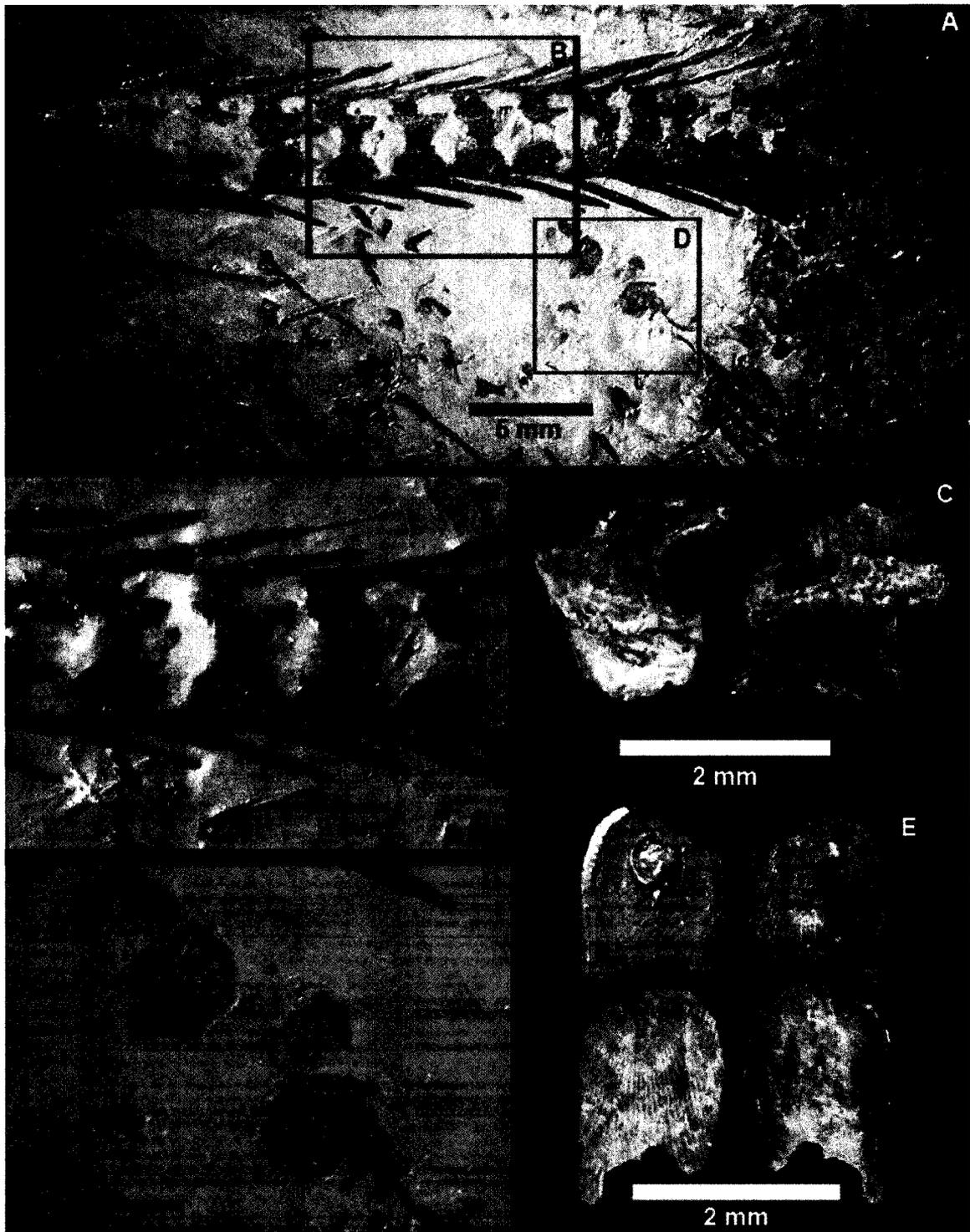


Figure 8: Comparison of an unnamed caturid specimen (CMNFV 17462) described from Turonian strata near Lac des Bois, Northwest Territories (Cumbaa and Murray, in press) with material recovered from the Van der Voort locality, Manitoba. A - Post-cranial section of articulated specimen CMNFV 17462. B and D - present magnified views of areas of CMNFV 17462 (B - vertebrae; D - scales) relevant for comparison with C (partial vertebrae - MM V-2958, left; MM V-2957, right) and E (MM V-2963, top - lateral line scale; MM V-2962, bottom - non-descript scale) respectively. CMN - Canadian Museum of Nature; MM - Manitoba Museum

Order PACHYCORMIFORMES Berg, 1940
Family PACHYCORMIDAE Woodward, 1895
Genus *Protosphyraena* Leidy, 1857
Protosphyraena sp.: Plate VI – Fig. 6

Description – The distinctive rostral teeth of this species are long, flat, wide-bladed and triangular, with non-serrated edges and are very laterally compressed. The cutting edges on the tooth margins are gently concave, and both the lingual and labial faces of the teeth are also gently concave equally, making a distinction between the two faces of the teeth impossible based solely on isolated specimens.

Discussion – Unfortunately, species of *Protosphyraena* cannot be distinguished on the basis of isolated teeth. Though fragmentary, the specimens recovered here are at the least assignable to *Protosphyraena* sp. on the basis of their distinctive morphology. *Protosphyraena* is known from numerous places around the world (e.g. Woodward, 1908; Diedrich, 2001; Shimada et al., 2006), including the Manitoba Escarpment (Bardack, 1968; Cumbaa and Tokaryk, 1999). In addition to the Van der Voort specimens, *Protosphyraena* sp. was also discovered amongst the material collected from the Little Woody River locality.

Stratigraphic Remarks - Its earliest known occurrence in North America is from the mid-Cenomanian in the Graneros Shale (Everhart et al., 2004) and the Lincoln Limestone in Kansas (Stewart, 1898a). The youngest strata from which the genus is known are Campanian in age (Stewart, 1988b).

Order ICHTHYODECTIFORMES Bardack and Sprinkle, 1969
Family ICHTHYODECTIDAE Crook, 1892
Genus *Xiphactinus* Leidy, 1870
Xiphactinus audax: Plate VI, Figs. 7, 8

Description – A small number of conical teeth were found that were oval in cross section and lacked carinae. They exhibited smooth surfaces covered with numerous, very fine longitudinal crack-like striations. Though not visible on all specimens due to adhering matrix, it was clear from select specimens that these teeth possess an oval-shaped pulp cavity (e.g. Plate VI, Fig. 7).

Discussion – *Xiphactinus* teeth are morphologically very similar to those of their sister taxon *Ichthyodectes* Cope, 1870, however, Bardack (1965) notes that the teeth of *Ichthyodectes* do not exceed 8 mm in height. The longest tooth preserved here is approximately one centimeter in length (Plate VI, Fig. 8), while the others are 6.5 mm or less. These smaller teeth are, however, clearly fragmentary, and despite their shorter length they almost all exceed the longest specimen in circumference. This observation, in addition to the stratigraphic ranges of the known North American species of *Xiphactinus*, leads to the assignment of these specimens to *Xiphactinus audax*.

Stratigraphic Remarks - *Xiphactinus audax* is a Late Cretaceous ichthyodectiform, which was one of the largest teleostean fishes in North America (e.g. 5.1 m in total length, Shimada and Everhart, 2004). Of the two North American species of *Xiphactinus*, *X. audax* is the stratigraphically older taxon, ranging from the Middle Cenomanian to the Lower Campanian of the Western Interior Sea, while *X. vetus* Leidy, 1856a, ranged temporally from the Middle Campanian to Lower Maastrichtian and geographically from the Atlantic Coastal Plain to the eastern Gulf of Mexico (Schwimmer et al, 1997b; Everhart et al., 2003, 2004). Though relatively few have been found, teeth assignable to

Xiphactinus audax are not unknown from the Cenomanian-aged bonebeds of the Pasquia Hills (Cumbaa and Tokaryk, 1999; Cumbaa et al., 2006).

Unidentified ichthyodectid: Plate VI - Fig. 9

Description – A very small number of vertebrae were found possessing a distinctively wide anterior-posterior bar on the sides of the centrum.

Discussion – The strong anterior-posterior bar on the sides of the centrum compare favorably with the vertebra of ichthyodectiform teleosts, and with those described by Cumbaa et al. (2006) from the Pasquia Hills bonebeds.

Stratigraphic Remarks - Known with certainty to occur in deposits ranging in age from the Kimmeridgian to the Campanian (Patterson, 1993), ichthyodectiform fishes were inhabitants of shallow seas with a near worldwide distribution (Alvarado-Ortega, 2004). More specific stratigraphic remarks cannot be made regarding this taxon.

Order CROSSOGNATHIFORMES Taverne, 1989

Family PACHYRHIZODONTIDAE Cope, 1872b

Genus *Elopopsis* Heckel, 1856

Elopopsis sp.: Plate VI – Fig. 10

Description – Specimens consist of wide-based, laterally compressed, triangular teeth that curve lingually at the tips. They exhibit regular and distinctive longitudinal striations that extend from the base of the root almost to the apex.

Discussion and Stratigraphic Remarks – *Elopopsis* is relatively common in Africa and Europe (e.g. Taverne, 1976), and, though less common, is also known from North America. Cumbaa et al. (2006) note that it is not unusual to find teeth and jaw fragments of *Elopopsis* sp. in material from the Bainbridge River (BR-3) locality.

Order SALMONIFORMES Greenwood et al., 1966
unidentified salmoniform: Plate VII – Figs. 1, 2

Description – The identification of an unidentified salmoniform within the Van der Voort material is based on the presence of numerous vertebrae (e.g. Plate VII, Fig. 1), which are round and relatively short in anterior-posterior length. The vertebrae possess a distinctive woven texture with many small fenestrae covering much of the vertebral surface that is characteristic of living salmoniformes, such as salmon and trout.

Discussion – Relatively complete specimens of these vertebrae are moderately common amongst those vertebrae collected here, and fragments of vertebrae bearing the unmistakable woven texture are even more common. Due to the completely disarticulated nature of these remains, it is at this point impossible to determine whether any of the variety of other unidentified teeth, jaw fragments, cranial elements, or opercular series elements could belong to this taxon; however the relative abundance of these vertebrae would make it likely. One basioccipital morphotype (Basioccipital Morphotype #3) in particular stands out (e.g. Plate VII, Fig. 2). This basioccipital is closely associated with the vertebral column, acting as the osseous anchor between it and the cranium, and though relatively uncommon, these basioccipitals possess a woven pattern of small fenestra on parts of their surface. This feature, combined with the overall robusticity of these particular basioccipital elements, suggest a potential affinity with the unidentified salmoniform(s). Comparable unidentified salmoniform vertebrae are also known from both the Bainbridge and Carrot River localities (Cumbaa et al., 2006).

Stratigraphic Remarks – No informative stratigraphic remarks can be made regarding this taxon.

Order AULOPIFORMES Rosen, 1973
Suborder ENCHODONTOIDEI Berg, 1940
Family ENCHODONTIDAE Woodward, 1901
Genus *Enchodus* Agassiz, 1835
Enchodus cf. *E. gladiolus* (Cope, 1872): Plate VII - Figs. 3-5

Description – Teeth of *Enchodus* cf. *E. gladiolus* are triangular and moderately long, and exhibit a slightly sigmoidal curvature (Plate VII, Fig. 3). The mesial and distal carinae are unserrated, and the mesial edge tends to be better defined than the distal one (Plate VII, Fig. 4). Both the lingual and labial faces tend to be finely striated, and the faces are subequally convex (with the lingual face being slightly more convex).

Palatine bones of this species are anteroposteriorly elongate, and the largest collected from the Van der Voort locality measures approximately 14 – 15 mm in estimated anteroposterior length (Plate VII, Fig. 5). The palatine tooth of this specimen is approximately one-quarter to one-third complete, and is directed slightly anteroventrally. It is finely striated on both the lingual and labial faces.

Discussion – Goody (1976) diagnosed *E. gladiolus* based on the following: "...depth of palatine bone less than one-fourth its length; anterodorsal extent of maxillary grooves meets dorsal edge of palatine bone some distance behind tooth base; palatine tooth symmetrical in cross-section and laterally compressed; single, full-length, unserrated cutting edge anteriorly, posterior edge present only as a postapical barb; length of palatine tooth just more than one-half length of palatine bone; depth of palatine bone approximately one-third length of palatine tooth; dentary and palatopterygoid teeth moderately long and slightly sigmoidal, teeth finely striated on inner and outer faces...". The specimens from the Van der Voort locality are all disarticulated and mostly incomplete; making comparison with these characters difficult at times (though none of

the *Enchodus* teeth found in the Van der Voort material possess a postapical barb). However, of the known North American species, these specimens most closely resemble *E. gladiolus* and are therefore referred to *Enchodus* cf. *E. gladiolus*. Teeth of *Enchodus* cf. *E. gladiolus* are the most common, specifically identifiable *Enchodus* teeth found at the Van der Voort site.

Stratigraphic Remarks - *Enchodus* is a genus with many nominal species ranging stratigraphically from the Albian to the Maastrichtian (Forey et al, 2003), while the known stratigraphic range of *E. gladiolus* is from the Turonian to the Upper Maastrichtian (summarized in Shimada et al., 2006). It has additionally been identified conservatively as *Enchodus* cf. *E. gladiolus* from the Cenomanian-aged deposits of the Tobe locality in Colorado (Shimada et al., 2006) and of the Bainbridge River bonebeds in the Pasquia Hills, Saskatchewan (Cumbaa et al., 2006).

Enchodus cf. *E. petrosus* Cope, 1874: Plate VII - Figs. 6, 7

Description – Teeth of *Enchodus* cf. *E. petrosus* are moderately long, triangular, and lanceolate (Plate VII, Fig. 6). The mesial and distal carinae are unserrated and are both well defined, extending right to the base. Both the lingual and labial faces are finely striated, and the faces are subequally convex (with the lingual face being slightly more convex).

Palatine bones of this species are relatively anteroposteriorly elongate, though less so than in *Enchodus* cf. *E. gladiolus* (Plate VII, Fig. 7). The palatine tooth of this specimen appears to be complete; it is directed ventrally and is characteristically asymmetrical in cross-section.

Discussion – Goody’s (1976) diagnosis for *E. petrosus* included the following criteria: “...palatine tooth asymmetrical in cross-section; smooth cutting edges placed anteriorly and laterally; length of palatine tooth greater than three-fourths length of palatine bone; palatopterygoid teeth and dentary teeth moderately long and straight with smooth outer faces and striated inner faces; teeth without postapical barbs...”. Goody (1976) notes that the symphyseal tooth of the dentary of *E. petrosus* is the largest tooth on the dentary (though still smaller than the pterygoid teeth), and that they alone have two clear cutting edges (while the other dentary teeth appear to only have a well-defined anterolateral cutting edge). This suggests that it is possible that at least the teeth figured here (Plate VII, Fig. 6) represent symphyseal teeth. They do, however, bear fine striations on both the lingual and labial surfaces, whereas Goody’s (1976) description of *E. petrosus* states that only the lingual faces bear striations. Goody (1976) further elaborates that while the one cutting edge of the palatine tooth lies in the anterior midline, that the second begins near the apex of the tooth at the posterior midline but passes into a posterolateral position near the base. The palatine figured here (Plate VII, Fig. 7) compares favorably with those figured by Goody (1976; e.g. Plate I, Fig. 9) in terms of overall shape, in the palatine-palatine tooth length ratio, and in the asymmetry of the cutting edges. Taking this comparison into account, and considering the relatively small number of these specimens recovered, along with the incompleteness of the remains, the conservative assignment of these fossils to *Enchodus* cf. *E. petrosus* seems warranted.

Stratigraphic Remarks - *Enchodus petrosus* is known from Turonian through Maastrichtian strata of the Western Interior Seaway (Goody et al., 1976; Everhart et al., 2003). Cumbaa and Tokaryk (1999) also reported *E. petrosus*, along with *E. gladiolus*

and *E. shumardi* from the mid- to late Cenomanian-aged Bainbridge River bonebeds, however, Cumbaa et al. (2006) reported that further study of the Bainbridge River *Enchodus* palatines failed to confirm its presence.

Enchodus cf. *E. shumardi* Leidy, 1856b: Plate VII - Figs. 8, 9

Description – Teeth of *Enchodus* cf. *E. shumardi* are straight and needle-like and typically relatively small (Plate VII, Fig. 8). Carinae are well marked and smooth, and continue to the base. The labial and lingual surfaces may or may not be striated.

Palatine bones of this species are anteroposteriorly shorter than those of either *E. gladiolus* or *E. petrosus* relative to the length of the palatine tooth (Plate VII, Fig. 9). Unlike in *E. gladiolus*, the palatine tooth points ventrally.

Discussion – Goody (1976) gave the following diagnosis for *E. shumardi* based on the morphology of the teeth and palatine bones: “length of palatine tooth greater than length of palatine bone; . . . palatopterygoid and dentary teeth straight and needle-like; postapical barb present on certain teeth...”. Goody (1976) also stated that *E. shumardi* tends to be smaller in size than most other species of *Enchodus*. Of the many straight *Enchodus* teeth found in the Van der Voort samples, some are decidedly more needle-like in morphology than others. It is on this basis that I am conservatively distinguishing between the teeth of *Enchodus* cf. *E. shumardi* and *Enchodus* cf. *E. petrosus*. Also, as with the dental characters, the palatine characters can be difficult to apply to incomplete, disarticulated specimens. The palatine figured here (Plate VII, Fig. 9) is larger than would be expected, however, despite the tooth being broken the palatine bone itself appears to be whole, in which case the palatine-palatine tooth length ratio most closely resembles

that described for *E. shumardi*, and is therefore here designated as *Enchodus* cf. *E. shumardi*.

Stratigraphic Remarks - *Enchodus shumardi* has been reported from strata ranging in age from Upper Cenomanian to mid-Maastrichtian from the Western Interior Seaway (e.g. Leidy, 1873; Stewart, 1900; Goody, 1976). Shimada et al. (2006) and Cumbaa et al. (2006) both report *Enchodus* cf. *E. shumardi* from the Cenomanian Tobe locality and Pasquia Hills bonebeds, respectively.

Enchodus sp.: Plate VIII - Figs. 1-4

Description – Included here are a variety of elements assignable to the genus *Enchodus* but that lack characters permitting specific designation.

Ectopterygoid fragment (Plate VIII, Fig. 1) – Broken posteriorly, this fragment preserves only the anterior portion of the original element. It is a relatively narrow lamina displaying the broken bases of four teeth along its lateral edge, and one large tooth at the extreme anterior end (the terminal ectopterygoid tooth).

Dentary fragments (Plate VIII, Fig. 2) – These fragments, which only preserve one small tooth each, present trios of distinctive finger-like processes that extend ventrally and medially to reinforce the symphysis.

Additional jaw fragments (Plate VIII, Fig. 3) – Fragments of jaw elements represented by thin laminae of bone bearing small, striated teeth.

Scales (Plate VIII, Fig. 4) – Consists of a broad, shield-shaped base, which is widest approximately one third of the way back from the anterior tip. Its outer surface is bisected longitudinally down the midline by a posteriorly-projecting flange that extends beyond the posterior margin of the base. Two pores are visible; one on the anterior tip of

the scale on the dorsal surface, at the base of the anterior margin of the midlateral flange; the other in the midline and near the posterior margin of the base on the ventral surface. These two pores appear to communicate with one another via a simple tube.

Discussion – Remains of the genus *Enchodus* are the most common identifiable vertebrate remains collected from the Van der Voort locality, and were also present in the Little Woody River sample. While these consist primarily of teeth and their distinctively toothed palatines in the Van der Voort sample, there are also other elements that are much less frequently found. The ectopterygoid, dentary, and other jaw fragments described above and figured here generally match descriptions of the corresponding elements from *E. petrosus* (Goody, 1976), however they are considered here to be too fragmentary to warrant specific designation. The only literature describing the squamation of *Enchodus* that could be found by the author was also by Goody (1976), and the scale figured herein matches his description well. *Enchodus petrosus* possessed only two scales, represented by scutes, which in life would have lain on either side of the caudal peduncle, with the large base embedded in the body wall (Goody, 1976). Goody (1976) interprets these scutes as modified terminal lateral line scales, which explains the presence of the sensory pore allowing communication between the outer and inner surfaces.

In addition to belonging to any one or a combination of the species of *Enchodus* discussed above, it is equally possible for these additional elements to belong to another, as-yet-unknown, species of *Enchodus*. It is also possible that there are representatives of other, unknown species of *Enchodus* among the teeth and palatine specimens as well, considering they do not all match the descriptions of *Enchodus gladiolus*, *E. petrosus*,

and/or *E. shumardi* exactly. As with the enchodontids of the Pasquia Hills (Cumbaa et al., 2006), the enchodontids of the Van der Voort locality will require further study.

Stratigraphic Remarks – No further informative stratigraphic remarks can be made regarding this taxon.

Order ANGUILLIFORMES Regan, 1909
cf. unidentified anguilliform: Plate VIII - Figs. 5-8

Description – Remains of this taxon from the Van der Voort locality consist entirely of the unfused halves of neural arches. These small elements range from somewhat ovoid or “ear-shaped” to sub-rectangular in shape, and curl anteromedially to form a process, which would articulate with the centrum. Most specimens feature a posterodorsally-oriented ridge on their lateral surface representing fused epineural elements.

Discussion – In their extensive review of the earliest known eel-like fossil fishes, Belouze, Gayet and Atallah (2003a, b) describe neural arches that consist of paired, autogenic plates that lack neural spines, and that meet at the dorsal midline but fail to fuse. This pattern was described as characteristic of the Anguilliformes, a pattern that is corroborated by the more recently described *Libanechelys* (Taverne, 2004). The elements described and figured in this study (Plate VIII, Figs. 5-8) compare favorably with the published descriptions of the neural arches of Cretaceous anguilliform taxa, however, due to their fragmentary nature as well as their lack of more specific diagnostic characteristics, they are here conservatively designated as cf. unidentified anguilliform.

Despite this open nomenclature, the discovery of cf. unidentified anguilliform from the Van der Voort locality is noteworthy from a biogeographic standpoint. The only

other published description of Cretaceous eels in North America comes from the Santonian Niobrara Formation of Kansas (Wiley and Stewart, 1981). Wiley and Stewart (1981) describe *Urenchelys abditus* on the basis of a single specimen, and though undoubtedly an eel, Belouze, Gayet, and Atallah (2003b) suggest that its inclusion within the genus *Urenchelys* may require reevaluation. Early anguilliform remains have previously been tentatively identified from the Bainbridge River bonebeds (S. Cumbaa, personal communication), but apart from very brief mentions (Cumbaa and Tokaryk 1999; Schröder-Adams et al., 2001) they have not yet been described in any detail. In the course of investigating the comparative taphonomy of fossils from the Van der Voort and Bainbridge River localities, however, the author did identify a small number of the distinctive neural arch components, comparable to those described above from the Van der Voort locality. Those neural arches from the Van der Voort locality, meanwhile, being Lower Cenomanian in age, represent the earliest evidence of eels in North America, approximating the age of the earliest fossil eels known worldwide. This raises the possibility that the anguilliform lineage may perhaps be older than previously assumed, if they are already found in such paleogeographically distant locations as Cenomanian North America and Lebanon.

Stratigraphic Remarks - Among primitive anguilliforms, six genera are recognized from the Late Cretaceous of Lebanon: *Urenchelys* Woodward (1900); *Anguillavus* Hay (1903); *Luenchelys* Belouze, Gayet and Atallah (2003a); *Abisaadia* Belouze, Gayet and Atallah (2003b); *Hayenchelys* Belouze, Gayet and Atallah (2003b); and *Libanechelys* Taverne (2004). Among these genera, all are known primarily from lower and/or middle Cenomanian-aged strata (Belouze, Gayet and Atallah, 2003a, b;

Taverne, 2004), and some (e.g. *Urenchelys*) range as late as the Santonian (Wiley and Stewart, 1981; Belouze, Gayet and Atallah, 2003b).

EUTELEOSTEI *incertae sedis*
Plate IX – Figs. 1-7; Plate X – Figs. 1-5

Description – This taxon encompasses a variety of cranial and mandibular elements found amongst the material from the Van der Voort locality which, as discussed below, are believed to be associated. The most distinctive of these will be described first, followed by those whose affinities with this taxon are less concrete.

Dentaries (Plate IX, Figs. 1-2) – The symphysis is moderately deep and strongly inturned, and moving posteriorly; the generally concave oral margin rises rather steeply. Moving further posteriorly along the dorsal margin, a large coronoid process is separated from the oral margin by a short convexity before resuming an even sharper rise, reaching its highest point anteriorly. The teeth, though missing from these specimens, were either six or seven in number, were quite small, and were restricted to a relatively small region of the anterior oral margin posterior to the symphysis. On the external surface, at the anterior edge of the base of the coronoid process and just postero-ventral to the tooth row there is a well marked depression for the insertion of the anterior maxillo-mandibular ligament. Finally, some of the specimens preserve one or two of the pores representing the mandibular sensory canal along their ventral margins.

Hyomandibulae (Plate IX, Figs. 3-5) – The head of the hyomandibular is single and the shaft is relatively narrow. The dorsal surface of the head, which articulates with the neurocranium, is angled away from the plane of the shaft by approximately 135°. The opercular process is positioned immediately beneath and behind the head and at a right

angle to the shaft, and on the external surface a thin strut of bone can also be seen to project antero-ventrally at an angle of approximately 45°. Additionally, delicate sheets of bone can be observed connecting each process to each of its neighbors.

Fragmented maxillae (Plate IX, Fig. 6) – These elements are characterized by a single row of tiny teeth along the oral margin and by a prominent strengthening ridge running antero-posteriorly along the dorsoventral midline of the bone. The more complete fragments suggest that intact elements would have curved gently (with the tooth row being born on a slightly convex surface), though most are too fragmentary to determine this with certainty.

Fragmented preopercles (Plate IX, Fig. 7) – Though a small number of suspected preopercular fragments were found, only the one figured here was complete enough to suggest any sort of taxonomic affinity. The preopercular canal can be seen within the fragment near the anterior edge of the bone, along with five, unbranching, posteroventrally-directed tubes that branch off the main canal. The posteroventral margin of the bone is not preserved in this fragment, however, so whether these additional tubes reached right to the posteroventral margin or not is difficult to discern.

Other elements probably associated with this taxon include: Angulo-articulars (Plate X, Figs. 1, 2) – These elements are the result of the fusion of the angular and articular components. The articular surface for the quadrate is relatively shallow, and the retroarticular process is short. The coronoid process of these elements rise sharply anteriorly of the articular facet and these bones extend anteriorly as tapering laminae to their contact with the dentary. Both the lateral and medial faces of angulo-articular are

marked by small, “V”-shaped depressions anterior of the articular facet, with the medial depression being the deeper of the two.

Quadrates (Plate X, Figs. 3, 4) – The fragments described here are broadly triangular in shape and possess small, robust articular condyles. The medial surfaces bear distinct grooves along their posterior margins for the reception of the symplectic.

Supraoccipitals (Plate X, Fig. 5) – A small number of these square-shaped elements were recovered, which bear a sizeable, low crest projecting posteriorly. They also possess a distinct transverse ridge, which is bounded anteriorly by two troughs which incompletely meet at the midpoint of the element.

Discussion – Many of the elements described above compare favorably with one or both of the named North American taxa of basal euteleosten fishes: *Erichalcis arcta* Forey (1975) and *Avitosmerus canadensis* Fielitz (2002). The high coronoid process and the steep anterior margin of the dentary are distinctive features of the mandible common among almost all of the Cretaceous basal euteleosts, and the mandibular tooth pattern observed here, while differing from most extant basal euteleosts, is one shared by four of the ten named genera: *Avitosmerus*; *Erichalcis*; *Gaudryella gaudryi* Pictet and Humbert (1866), from the Middle Cenomanian of Lebanon; and *Ghabouria libanica* Gayet (1988), also from the Cenomanian of Lebanon. The tooth pattern and the prominent strengthening ridge seen in the recovered maxillary fragments also compare well with the maxillae of *Avitosmerus* (Fielitz, 2002; personal observations of specimens CMN 17427, 17458 and 17459), as well as with the published description of the maxillae of *Erichalcis* (Forey, 1975). The hyomandibular, with its single articular head for articulation with the neurocranium, is unlike the double-headed articulation observed for *Avitosmerus* (Fielitz,

2002; personal observation of specimen CMN 17427), however, it does compare well to the description for *Erichalcis* (Forey, 1975). The supraoccipital meanwhile, appears more *Avitosmerus*-like in its possession of a transverse ridge (Fielitz, 2002; personal observation of specimen CMN 17427) in addition to the low, posteriorly-projecting crest, which is seen in *Erichalcis* as well (Forey, 1975). Finally, one of the characters Fielitz (2002) uses to distinguish *Avitosmerus* from other Cretaceous basal euteleosts is that the four to five branches of the preopercular canal reach the edge of the preopercle, and though it is the author's opinion that very little of the figured preopercle's margin is missing, it is sufficiently broken to render this comparison equivocal.

In general, many similarities can be seen between the elements listed above and both *Avitosmerus* and *Erichalcis*, however, these elements do not furnish any definitive diagnostic characters. Nor do they provide any definitive diagnostic characters of the Euteleostei in general, for those pertain mostly to the caudal region (Johnson and Patterson, 1996; Arratia, 1997, 1999), and are far better suited for the diagnoses of articulated specimens. However, the similarity of these elements to those of *Avitosmerus* and/or *Erichalcis* is striking, and is suggestive that these elements do indeed belong to some manner of basal euteleostean(s), and thus that their assignment to euteleostei *incertae sedis* is warranted. It should be noted that disarticulated and/or isolated fossil material attributed to indeterminate basal euteleosts has been found in Late Cretaceous marine strata in other Canadian localities, including the Kanguk Formation (Cenomanian to Campanian) of Banks Island, Northwest Territories (Wilson, 1978) and the Turonian-aged Kaskapau Formation near Watino, Alberta (Wilson and Chalifa, 1989). Cumbaa and Murray (in press) propose that Wilson's (1978) indeterminate basal euteleostean fossils

from Banks Island may also be *Avitosmerus canadensis*. Additionally, in the course of conducting the comparative taphonomic survey portion of this study, the author did observe a single dentary fragment, among other rare fragments that compare favorably with those described above among the examined Bainbridge River material. Finally, some of the isolated bones figured by Leckie et al. (1992, figs. 9A, 9H) from the Fish Scale Marker Beds of the Shaftesbury Formation of northern Alberta (Early Cenomanian) do bear a striking resemblance to those described here, and Fielitz (2002) speculates that these may also be from basal euteleosts.

Stratigraphic Remarks - Fielitz (2002) provides an excellent table summarizing the ten monotypic genera of Cretaceous teleost fishes that have been described as basal members of the Euteleostei. They have been described from around the world, and among them there are two from the Cretaceous of North America: *Erichalcis arcta* Forey (1975), from the Lower or Middle Albian of the Northwest Territories, Canada; and *Avitosmerus canadensis* Fielitz (2002), from the Turonian-aged Lac des Bois locality, also in the Northwest Territories (approximately 870 km northwest of the locality where *Erichalcis* was collected). The majority of these taxa are known from Cenomanian strata.

TELEOSTEI *incertae sedis* ("Teleost A")
Plate X – Figs. 6-8

Description – Teeth considered here are characterized by slender, compressed and conical crowns. They have smooth surfaces and do not exhibit carinae. Typically they display a distinct lingual(?) curvature and where they are broken off at the root they reveal a very large central pulp cavity, giving the teeth an almost hollow appearance.

Where these teeth are found associated with fragmentary jaw material, the broken roots of the teeth are distinctively oval-shaped in cross-section (e.g. Plate X, Fig. 7).

Discussion – Taxonomic identification of teleosts on the basis of isolated teeth is difficult due to the lack of comparative data concerning the range of dental variation within species. A noteworthy feature of the few jaw fragments associated with this taxon is the variation of the orientation of the teeth: some specimens exhibit teeth that were clearly laterally compressed (Plate X, Fig. 8), while others show distinct mesiodistal compression (Plate X, Fig. 7); whether this indicates different tooth bearing jaw bones of one species or different species is difficult to assess. Teeth of “Teleost A” are fairly common at the Van der Voort locality, and by being relatively simple, generalized teeth it is indeed possible that more than one species may be represented.

Stratigraphic Remarks – No informative stratigraphic remarks can be made regarding this taxon.

TELEOSTEI *incertae sedis* (“Teleost B”)

Plate X – Fig. 9

Description – Teeth considered here are distinguished by broad, laterally compressed crowns, with smooth lingual and labial surfaces. They typically exhibit slight lingual curvature and the mesial and distal margins bear well-defined carinae, which are continuous from the apex to the base. Where the teeth are invariably broken at the base, they display large central pulp cavities, which give the teeth an almost hollow appearance.

Discussion – Teeth of “Teleost B” are less common at the Van der Voort locality than those of “Teleost A”, and do not appear to overlap with them morphologically. They do, however, demonstrate some similarity in structure in the large opening of the pulp

cavity at the base, and so could belong to a related species. Further comparisons with teeth of other osteichthyan taxa are needed to clarify their taxonomic identity.

Stratigraphic Remarks – No informative stratigraphic remarks can be made regarding this taxon.

REPTILIA

Order HESPERORNITHIFORMES Fürbringer, 1888
unidentified hesperornithiform(s): Plate XI – Figs. 1, 2

Description – A single tooth was found in the material examined from the BR-3 locality bearing a laterally flattened, posteriorly recurved crown with an expanded root (Plate XI, Fig. 1). The crown bears unserrated enamel edges on the anterior and posterior margins, and while the crown is strongly convex on the labial surface, it is comparatively planar on the lingual surface. The enamel stops at the base of the crown, and the tooth expands rapidly into the root. The lingual surface of the root is marked by a well-defined resorption pit.

Additionally, some scant skeletal fragments were also recovered from this same sample from the BR-3 locality (e.g. Plate XI, Fig. 2) which, based on their highly pneumatized nature, are also interpreted as avian in origin.

Discussion – Martin and Stewart (1977) note that hesperornithiform teeth are nearly planar on the lingual surface and strongly convex on the labial surface, while the teeth of *Ichthyornis*, another toothed bird common to the Late Cretaceous Western Interior Seaway of North America, are convex on both sides. While both hesperornithiform and ichthyornithiform birds have been previously identified from the Pasquia Hills bonebeds (Tokaryk et al., 1997), this tooth is interpreted as hesperornithiform on the basis of its nearly planar lingual crown surface, as well as due to

its favorable comparison with other avian teeth identified as hesperornithiform from the Bainbridge River locality (Cumbaa et al., 2006, Figs. 7.4). No avian remains have been identified from the Van der Voort locality.

Tokaryk et al. (1997) described the hesperornithiform genus *Pasquiaornis* (including *P. hardiei* and *P. tankei*) from the Carrot River locality of the Pasquia Hills based on characters relating to distinctive post-cranial material and unrelated to dentition, and thus the tooth examined here is classified as an unidentified hesperornithiform since it is at the moment impossible to discern whether this tooth is that of a species of *Pasquiaornis* or of another hesperornithiform bird that has gone as yet undetected among the Pasquia Hills' bonebed material.

The other figured bone fragment identified as avian (Plate XI, Fig. 2) is identified as such due to its highly pneumatized nature as well as the favorable comparison of its general state of preservation with other identified avian fragments from the Pasquia Hills bonebeds. It is listed in this section as hesperornithiform as a matter of convenience; apart from being avian it is too fragmentary for a more specific designation.

Stratigraphic Remarks – Species of the hesperornithiform genus *Pasquiaornis* are known only from the Cenomanian-aged Carrot and Bainbridge River bonebeds in the Pasquia Hills of Saskatchewan (Tokaryk et al., 1997; Cumbaa and Tokaryk, 1999; Cumbaa et al., 2006). Hesperornithiforms in general, meanwhile, have been found in strata spanning from the Late Albian to the mid-Maastrichtian (summarized in Rees and Lindgren, 2005).

Order TESTUDINES Linnaeus, 1758
unidentified testudine(s): Plate XI – Fig. 3

Description – A small number of largely plate shaped bones exhibit distinctive vascularization and moderately sculptured surface textures. Most are relatively small, plate-shaped bone fragments, while one particularly large piece exhibits a roughly triangular shape, with small foramina on parts of the surface and a prominent groove along one margin.

Discussion – The large, triangular bone fragment compares favorably with a marginal scute from a disarticulated carapace of a modern turtle in the comparative osteological collections of the Canadian Museum of Nature, suggesting this bone originated at the margin of the carapace. Other, plate-shaped elements exhibit surficial texturing reminiscent of turtle plastron elements, and so are tentatively assigned to “unidentified testudine(s)”. One or more species of turtle may be represented by these specimens, however, their fragmentary nature and their rarity makes this impossible to quantify. A limited number of turtle elements are known from the Carrot River bonebed, in the way of the right humerus of a protostegid (Family Protostegidae Cope, 1872) and other fragments of unknown familial designation (Nicholls et al., 1990).

Stratigraphic Remarks – No informative stratigraphic remarks can be made regarding this taxon.

Order PLESIOSAURIA Blainville, 1835
Superfamily PLIOSAUROIDEA Welles, 1943
Family PLIOSAURIDAE Seeley, 1874 (s. O'Keefe, 2001)
Genus *Brachauchenius* Williston, 1903
cf. *Brachauchenius* sp.: Plate XI – Fig. 4

Description – In the Van der Voort material, this taxon is known only from a 4 cm long impression of a tooth crown preserved on the surface of a large, unprepared block. The tooth crown that made the impression was clearly conical in shape, relatively elongate, slightly recurved, and the surface was marked by relatively fine longitudinal ridges that extended from the base of the crown almost to the apex. These ridges run more or less parallel with one another, and progressively bifurcate basally.

Discussion and Stratigraphic Remarks – No complete skeletons are known, however, *Brachauchenius* is hypothesized to have been a large pliosaurid with an estimated total body length of large individuals of about 11 metres (Carpenter, 1996). The genus is represented by a single species, *B. lucasi* Williston, 1903, where the type specimen is known from the Greenhorn Limestone, and the paratype from the Eagle Ford Group, both in Texas. In Kansas, *B. lucasi* is reported to range from the Middle Cenomanian Lincoln Limestone to the lower Middle Turonian Fairport Chalk (Schumacher and Everhart, 2005), as well as by Ligget et al. (2005) from near the Graneros Shale – Lincoln Limestone contact. Most recently, Albright et al. (2007) reported two new specimens of *B. lucasi*, one of which included the first known pectoral and pelvic elements, from the Early or early Middle Turonian of the Tropic Shale from southern Utah. Tarlo (1960) demonstrated that tooth morphology can be used reliably in order to make generic identifications among pliosaurs, and in Carpenter's review of short-necked plesiosaurs of the Cretaceous North American Western Interior (1996), he identifies "striations [=ridges]

on teeth branching toward roots” as one of the diagnostic characters for *Brachauchenius*. Considering, however, that my identification is based only on an isolated impression in the Van der Voort material, I refer it to cf. *Brachauchenius* sp. Incomplete teeth recovered from the Cenomanian-aged Tobe locality in Colorado (Shimada et al., 2006) and from Turonian deposits in South Dakota (Stewart and Martin, 1993) have been the basis of the same taxonomic treatment.

PLESIOSAURIA *incertae sedis*: Plate XI – Fig. 5

Description – The essentially square-shaped bone shows distinct articular surfaces at either end. The element is both widest and deepest at the ends and both narrows and tapers towards its midpoint, giving it a slight hourglass-like appearance. Where exposed, the internal structure of the bone is observed to be highly porous and of endochondral derivation.

Discussion – The small phalangeal element figured here represents the only plesiosaur material recovered from the Bainbridge River sample that was examined for taphonomic comparison with material from the Van der Voort locality. It is, however, not distinctive enough to assign to a more specific taxon. Plesiosaur remains, primarily teeth, have been previously described from the Pasquia Hills bonebeds (Cumbaa and Tokaryk, 1999; Cumbaa et al., 2006) and include remains assignable to elasmosaurs, pliosaurs, and polycotylids. Though small post-cranial elements such as phalanges are also known from these localities, they are often much more difficult to assign to specific taxa.

Stratigraphic Remarks – No informative stratigraphic remarks can be made regarding this taxon.

VERTEBRATA(?) *incertae sedis*: Plate XI – Figs. 6-8

Description – The specimens are represented by microcoprolites, which are preserved in the Van der Voort material as small phosphatic pebbles. They vary in shape from cylindrical to circular to spheroidal; they may rarely exhibit a faint spiral (e.g. Plate XI, Fig. 6), and can measure up to just over a centimeter in maximum dimension. They are massive, and their color varies from buff white to light brown, with the occasional specimen being medium to dark brown. Several specimens were found to have inclusions consisting of fragmented and/or whole fish bones and scales (e.g. Plate XI, Fig. 7).

Discussion – Late Cretaceous sediments deposited within the Western Interior of North America commonly preserve fecal remains (e.g. Savrda and Bottjer, 1993; Hattin, 1996; Schröder-Adams et al., 2001; Anderson and Kowallis, 2004; Friedman, 2004). Savrda and Bottjer (1993) differentiate between two types of fecal matter found in fine-grained sediments from the Western Interior on the basis of size: fecal pellets, which are generally less than four millimetres in maximum dimension, and coprolites, which are generally several centimeters in maximum dimension. They attribute the production of the former mostly to zooplankton and benthic macroinvertebrates, while the latter is generally attributed to vertebrates, especially when the coprolites contain macrovertebrate inclusions (e.g. bones, teeth and/or scales). Based on size, the majority of the fecal matter found in material from the Van der Voort locality would be classified as fecal pellets under this classification scheme. However, many of these small “fecal pellets” contain vertebrate inclusions, including bones, teeth and scales. The abundance of osteichthyan vertebrae that measure two millimetres in length or less in the samples examined here suggest that there were many fish here that would have been no more than a few

centimeters long in total length, and these fish could surely produce coprolites four millimetres or less in maximum dimension. It is on the basis of the small size of the fish known from these deposits, and the inclusion of macrovertebrate remains that this fecal material is therefore referred to here as “microcoprolites”, acknowledging both their small size and inferred vertebrate origin.

One exceptional specimen was found whose color and composition was consistent with other microcoprolites, however, it exhibits a highly sculptured “ropey” surface texture (Plate XI, Fig. 8). It is difficult to imagine how a piece of feces, assumed to have a paste-like consistency at the time of excretion (Hattin, 1996), could have survived the rigors of defecation with so much surface detail preserved intact; therefore this specimen is interpreted as an enterospira. Enterospirae from the Western Interior have been previously described from the Upper Cretaceous Niobrara Formation in Western Kansas (Stewart, 1978), where they were attributed to selachians. The twisting, spiraled texture seen in this specimen suggests it would have been formed in an intestine containing a spiral valve, which is consistent with the intestinal structure of both chondrichthyans and non-teleost osteichthyans (Kardong, 2002), while a distinct constriction at one end suggests that this fecal mass was at the distal-most end of the digestive tract at the time of the animal’s death (Hattin, 1996). Other microcoprolites displaying slight spiral morphologies could also be interpreted to be of either chondrichthyan and/or non-teleost osteichthyan origin (Stewart, 1978; Friedman, 2004), however they are relatively rare compared to those which are simply cylindrical, circular or spheroidal in shape. These latter microcoprolites, while being potentially attributable to birds, reptiles, or teleostean fishes (Hattin, 1996), are in this case interpreted to be most likely of teleostean derivation

based on the abundant remains of these fishes preserved here, in contrast to the low numbers of reptiles and birds.

Stratigraphic Remarks – No informative stratigraphic remarks can be made regarding this taxon.

Comparative Taphonomic Census

In order to assess the relative importance of biostratigraphic processes affecting the vertebrate fossils preserved at the Van der Voort Farm locality, a random sample was taken and examined for signs of abrasion and sorting by both shape and size. A second random sample, taken from material collected at the Bainbridge River (BR-3) locality, was examined in an identical manner in order to place observations made of the Van der Voort fossils into context.

Shape

Chi-square testing of the counts of elements across the three microfossil shape categories demonstrated a statistically significant difference between the two distributions (Table 3). While the two samples differed little in terms of the number or proportion of elongate-shaped elements (with the Bainbridge River (BR-3) sample having only slightly more), greater disparity was observed between plate- and compact-shaped elements (Fig. 9). The Bainbridge River (BR-3) sample was found to have a greater number and proportion of compact-shaped elements (by a difference of 5.84%), while the Van der Voort sample was found to contain a greater number and proportion of plate-shaped elements (by a difference of 7.18%) (Table 4).

Statistical Comparison of Taphonomic Indicators					
	VDV	BR-3	Deg.s Freedom	χ^2	p(same)
Comparison of Shape Distributions	N=1770	N=1805	3	19.709	0.00019499
Comparison of Size Distributions	N=1770	N=1805	16	226.04	4.1024E-39
Comparison of Abrasion Distributions	N=1707*	N=1610*	9	336.4	4.85E-67

Table 3: Statistical comparison via Chi-square tests of taphonomic indicators scored for the clasts recovered from the Van der Voort (VDV) and Bainbridge River (BR-3) samples used for the comparative taphonomic census. The column “p(same)” indicates the probability that the distribution curves from the two samples are the same. *The number of clasts used for the abrasion distributions varies from the other distribution values due to the exclusion of coprolites.

Shape Distributions

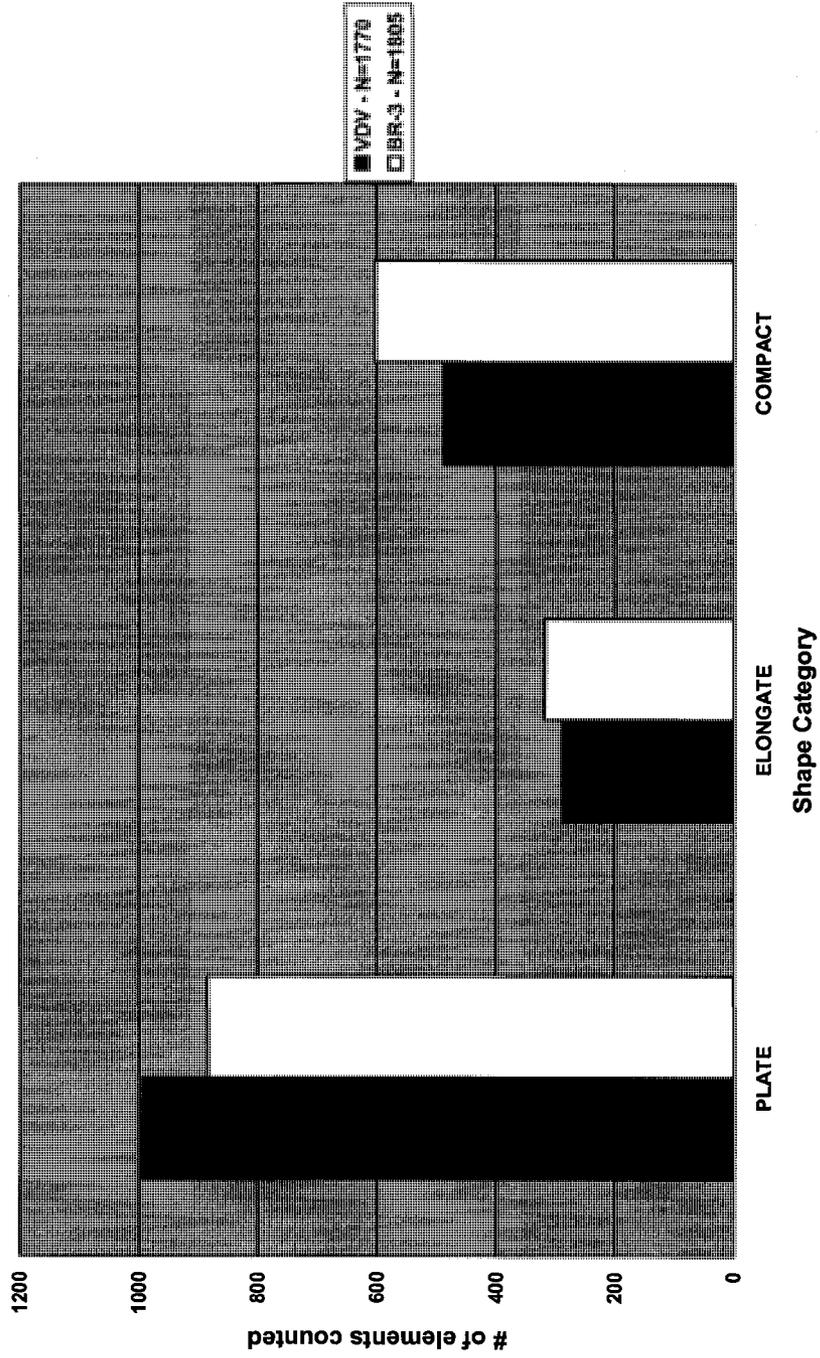


Figure 9: Comparison between the Van der Voort (VDV) and Bainbridge River (BR-3) samples of the distribution of plate, elongate, and compact shaped clasts.

Percent Differences between Taphonomic Variables				
Taphonomic Variable	Variable Category	Sample %s		Difference
		VDV	BR-3	
Shape	Plate	56.16	48.98	7.18
	Elongate	16.27	17.62	-1.35
	Compact	27.57	33.41	-5.84
Size Increment (mm)	0-1	6.05	0.00	6.05
	1-2	45.76	34.07	11.69
	2-3	30.00	35.62	-5.62
	3-4	11.86	17.06	-5.20
	4-5	2.43	5.82	-3.39
	5-6	1.41	4.32	-2.91
	6-7	1.30	1.27	0.03
	7-8	0.45	0.83	-0.38
	8-9	0.40	0.33	0.06
	9-10	0.11	0.33	-0.22
	10-11	0.00	0.11	-0.11
	11-12	0.00	0.00	0.00
	12-13	0.11	0.00	0.11
	13-14	0.06	0.06	0.00
	14-15	0.06	0.06	0.00
	15-16	0.00	0.06	-0.06
	16-17	0.00	0.00	0.00
	17-18	0.00	0.00	0.00
	18-19	0.00	0.00	0.00
19-20	0.00	0.06	-0.06	
Abrasion State	0	1.29	0.00	1.29
	0.5	19.63	2.24	17.39
	1	47.04	45.71	1.33
	1.5	18.86	28.51	-9.65
	2	9.96	16.40	-6.44
	2.5	1.41	4.66	-3.25
	3	1.41	2.17	-0.77
	3.5	0.18	0.12	0.05
	4	0.23	0.19	0.05

Table 4: Percent differences between the numbers of clasts counted for and within each taphonomic variable. Positive differences represent a comparative surplus for the Van der Voort (VDV) sample; negative differences represent a comparative surplus for the Bainbridge River (BR-3) sample. Note that $N_{VDV}=1770$ and $N_{BR-3}=1805$ for Shape and Size Increments, while $N_{VDV}=1707$ and $N_{BR-3}=1610$ for Abrasion State due to the exclusion of coprolites.

Size

A statistically significant difference was found to exist between the microfossil size increment distributions from the two samples (Table 3). Differences between elements equal to or greater than 6 mm in length were negligible, but amongst size increments smaller than 6 mm in size some distinct differences were observed (Fig. 10). The Van der Voort sample was found to contain greater numbers and proportions of elements ranked into the 0-1 and 1-2 mm size classes (by differences of 6.05% and 11.69% respectively) (Table 4). The Bainbridge River (BR-3) sample meanwhile was found to have a distinctly greater number and proportion of elements ranked into the 2-3, 3-4, 4-5 and 5-6 mm size classes (by differences of 5.62%, 5.20%, 3.39%, and 2.91% respectively).

Abrasion

Of the three taphonomic variables assessed, Chi-square testing revealed the greatest statistically significant difference exists between the abrasion state distributions of the two samples surveyed (Table 3). The number of clasts that were found to be rounded to very rounded (scoring from 3 to 4 on the abrasion scale) were rather small in both samples, and the differences from one sample to the other were minimal (Fig. 11). Both samples were dominated by subangular elements scoring a 1 on the abrasion scale (accounting for 47.04% of the Van der Voort sample and 45.71% of the Bainbridge River (BR-3) sample), though once again the difference between these two values is minimal (examples of the abrasion states can be seen in Fig. 12). The real differences lie in the number of elements scoring 0.5, 1.5, 2, and 2.5 on the abrasion scale. Elements scored as 0.5 (between “angular” and “subangular”) accounted for 19.63% of the Van der Voort

Size Distributions

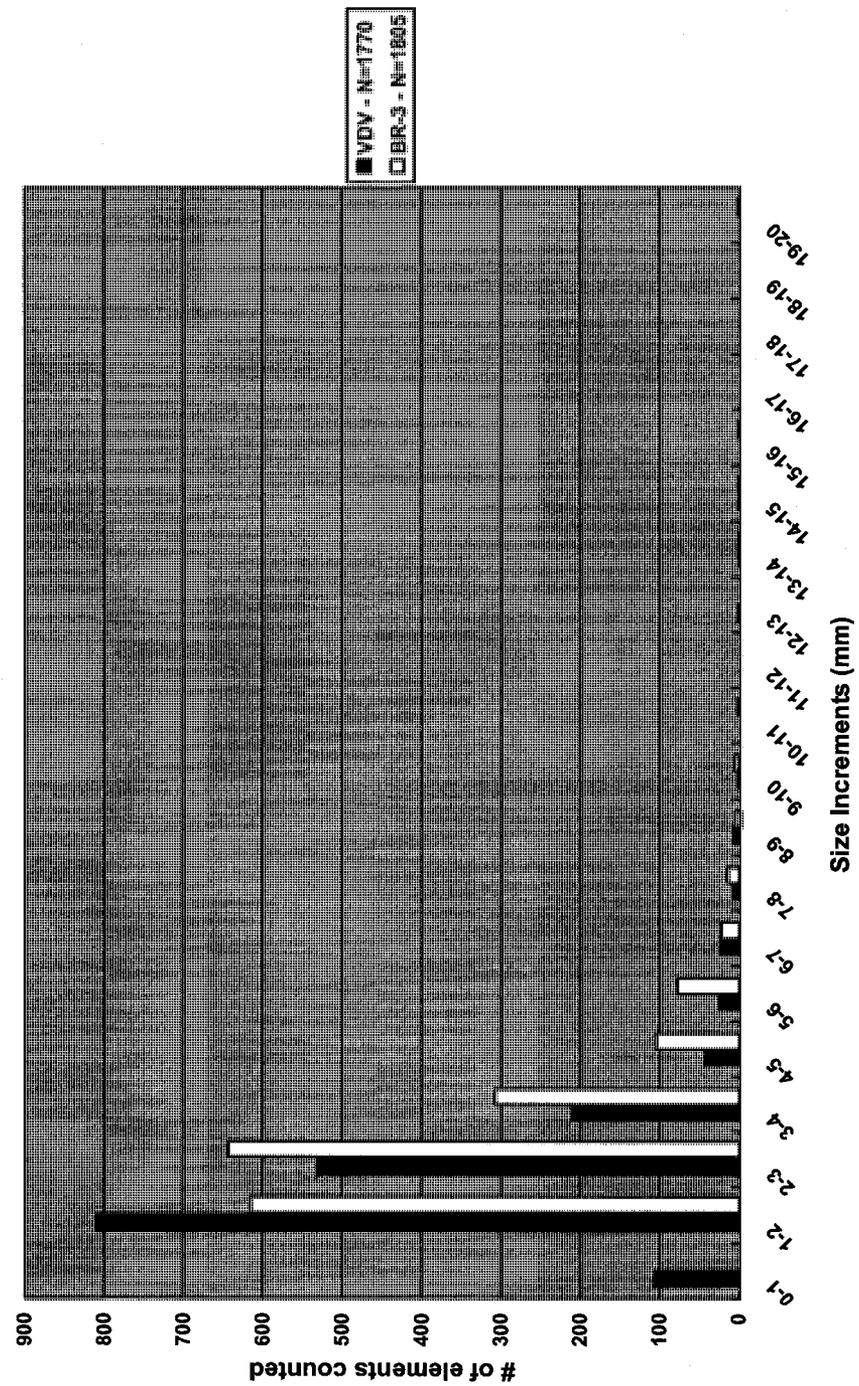


Figure 10: Comparison between the Van der Voort (VDV) and Bainbridge River (BR-3) samples of the distribution of clasts within discrete size increments.

Abrasion State Distributions

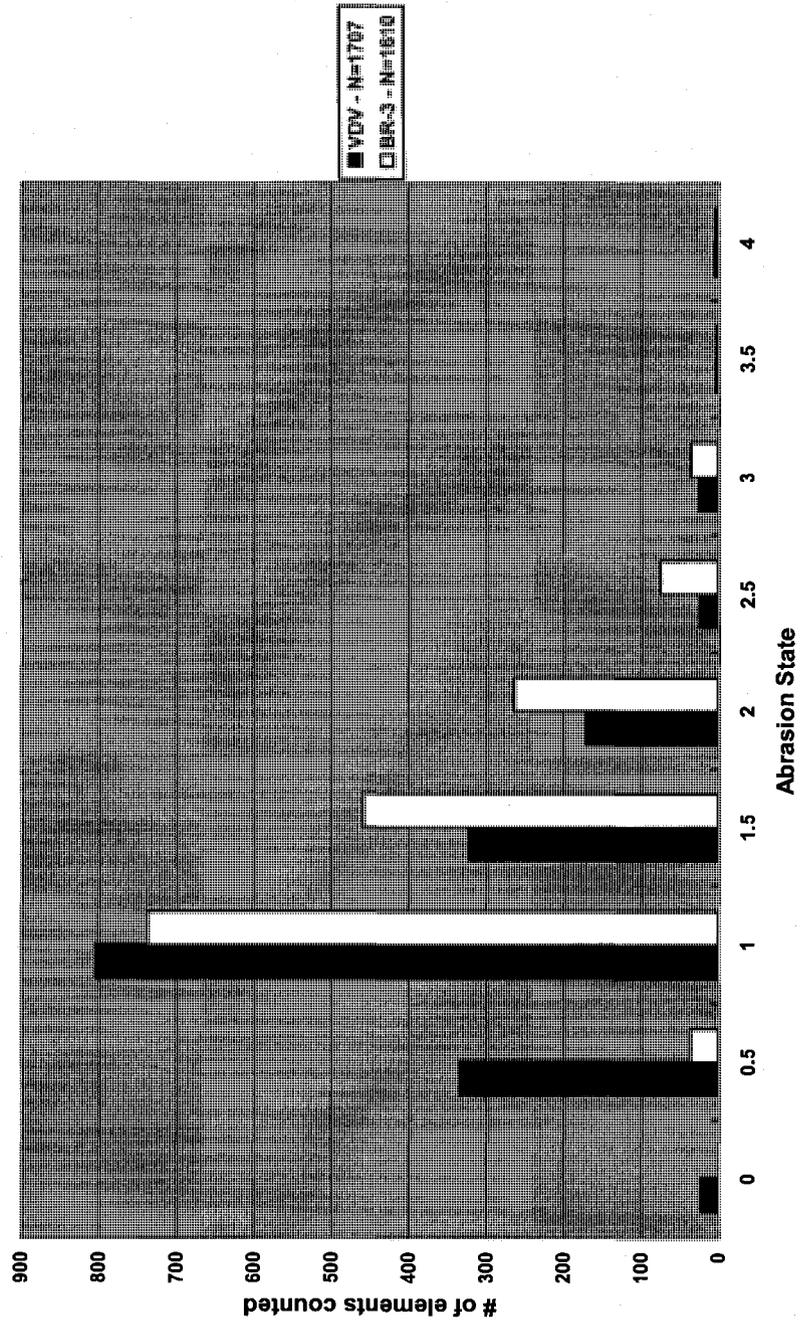


Figure 11: Comparison between the Van der Voort (VDV) and Bainbridge River (BR-3) samples of the distribution of clasts within described abrasion states. Total number of clasts included varies here from other tests due to the exclusion of coprolites.

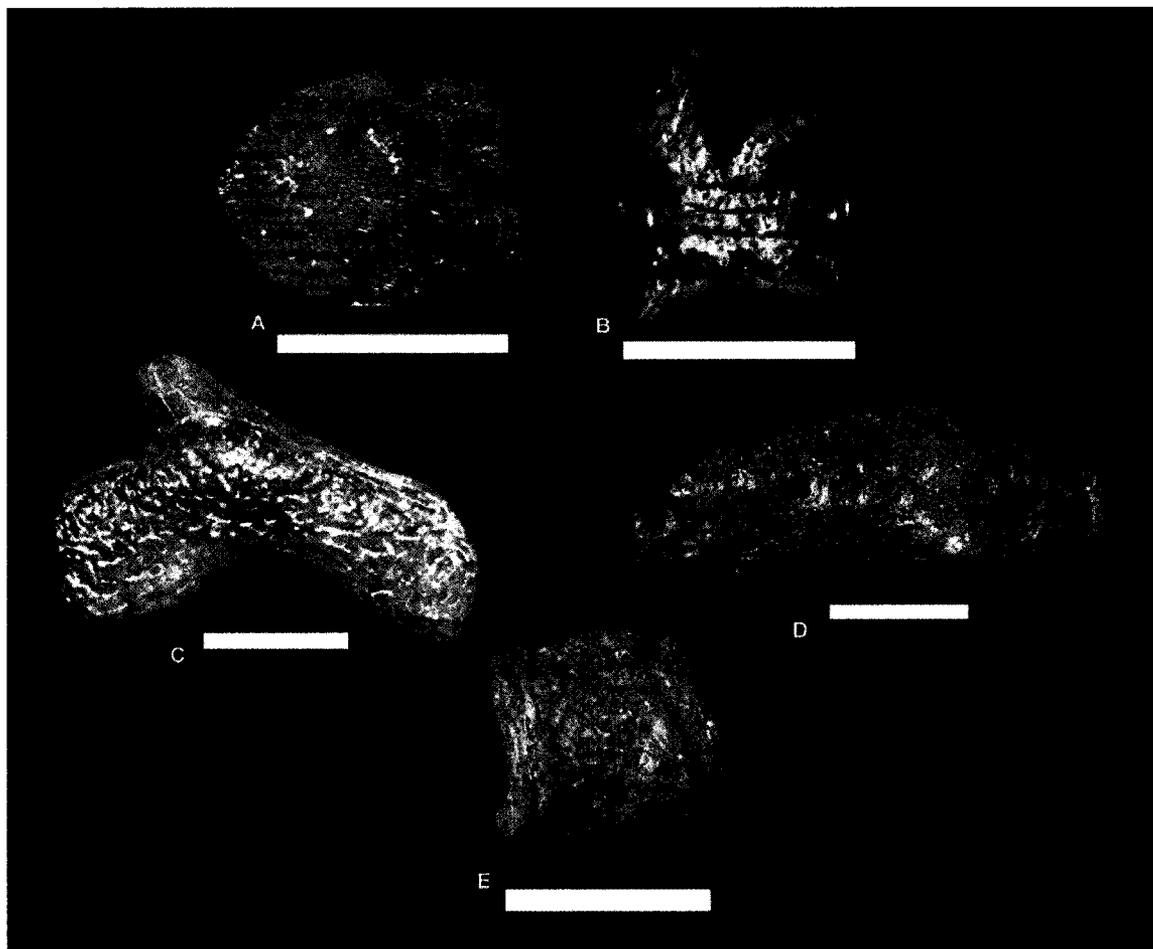


Figure 12: Representative examples of the abrasion stages used to score vertebrate-derived elements from the Van der Voort and Bainbridge River (BR-3) localities for the comparative taphonomic census. (A) Stage 0 - Very angular; (B) Stage 1 - Subangular; (C) Stage 2 - Subrounded; (D) Stage 3 - Rounded; (E) Stage 4 - Very rounded

sample, while only accounting for 2.24% of the Bainbridge River (BR-3) sample. Meanwhile, Bainbridge River (BR-3) contained proportionately more elements scoring 1.5, 2, and 2.5 than the Van der Voort sample, by differences of 9.65%, 6.44%, and 3.25% respectively (Table 4).

Diversity

Both the Van der Voort and Bainbridge River (BR-3) samples were found to be dominated by bones and bone fragments which could not be identified to element ('Indeterminate bones & fragments' in Fig. 13) and which therefore could not be assigned any particularly specific taxonomic classification. In fact, only 83 out of 1707 (or 4.86%) of the vertebrate fossils (bones, teeth, and their fragments) recovered from the Van der Voort sample were identified to Order or other less inclusive taxonomic ranking (with the Bainbridge River (BR-3) sample scoring slightly higher with 145 out of 1600, or 9.06%, of vertebrate fossils identified to Order or other less inclusive taxonomic ranking). The relatively small number of elements which were identifiable an ordinal taxonomic level or lower made statistical integration of the taxonomic data difficult. The majority of the elements that fall into the 'Indeterminate bones & fragments' category most closely resemble elements of osteichthyan derivation (though a small portion of the indeterminate material from the Bainbridge River (BR-3) sample is decidedly more "reptilian"-looking). Once this is taken into consideration, the distribution of recovered elements from both samples is overwhelmingly dominated by osteichthyan remains (Fig. 14). Chi-square test comparisons of these distributions revealed that they are significantly different, with the distribution corrected for the largely osteichthyan 'indeterminate bones & fragments' (Fig. 10) being only very slightly less significant (Table 5). A complete

Frequency of Recovered Clasts (by Category) I

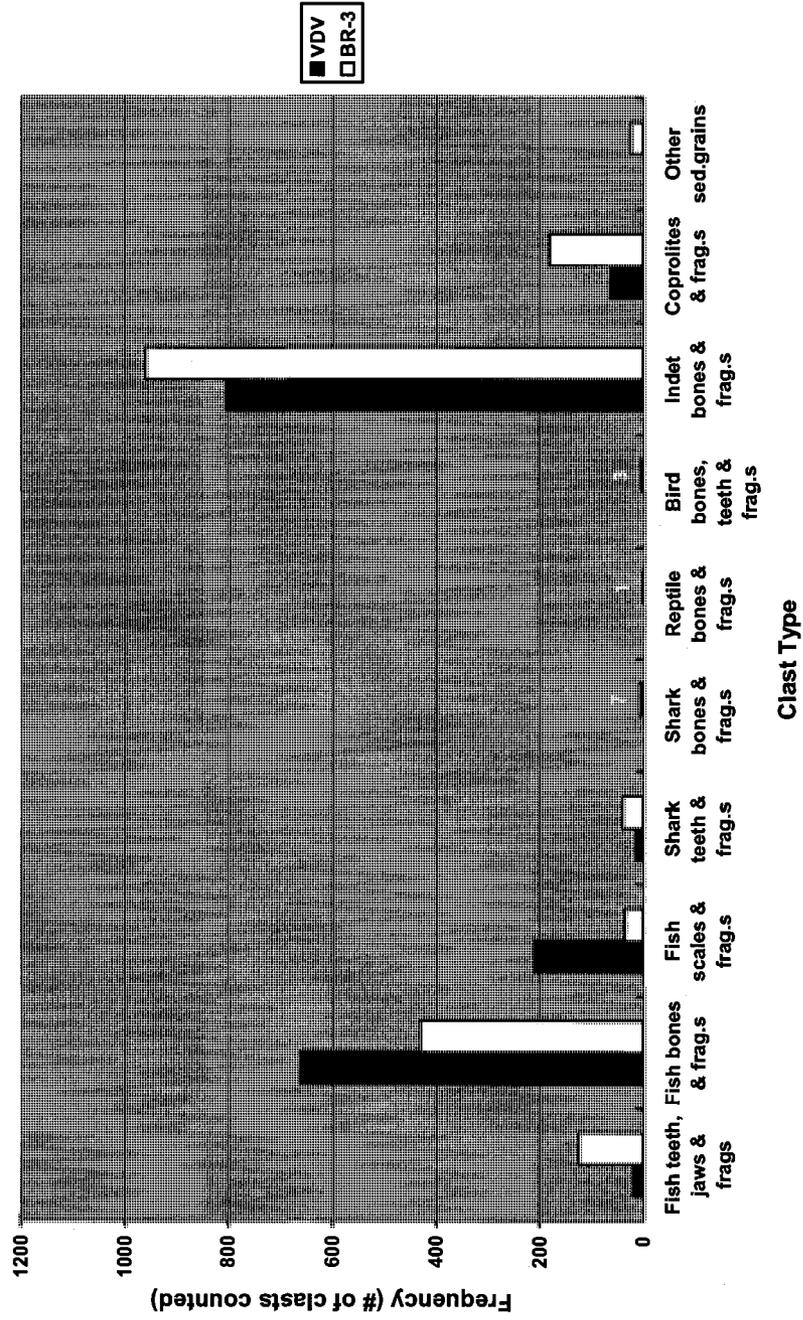


Figure 13: Comparison of the types of clasts recovered from the Van der Voort (VDV) and Bainbridge River (BR-3) samples examined for the comparative taphonomic census. $N_{VDV}=1770$; $N_{BR-3}=1805$

Frequency of Recovered Clasts (by Category) II

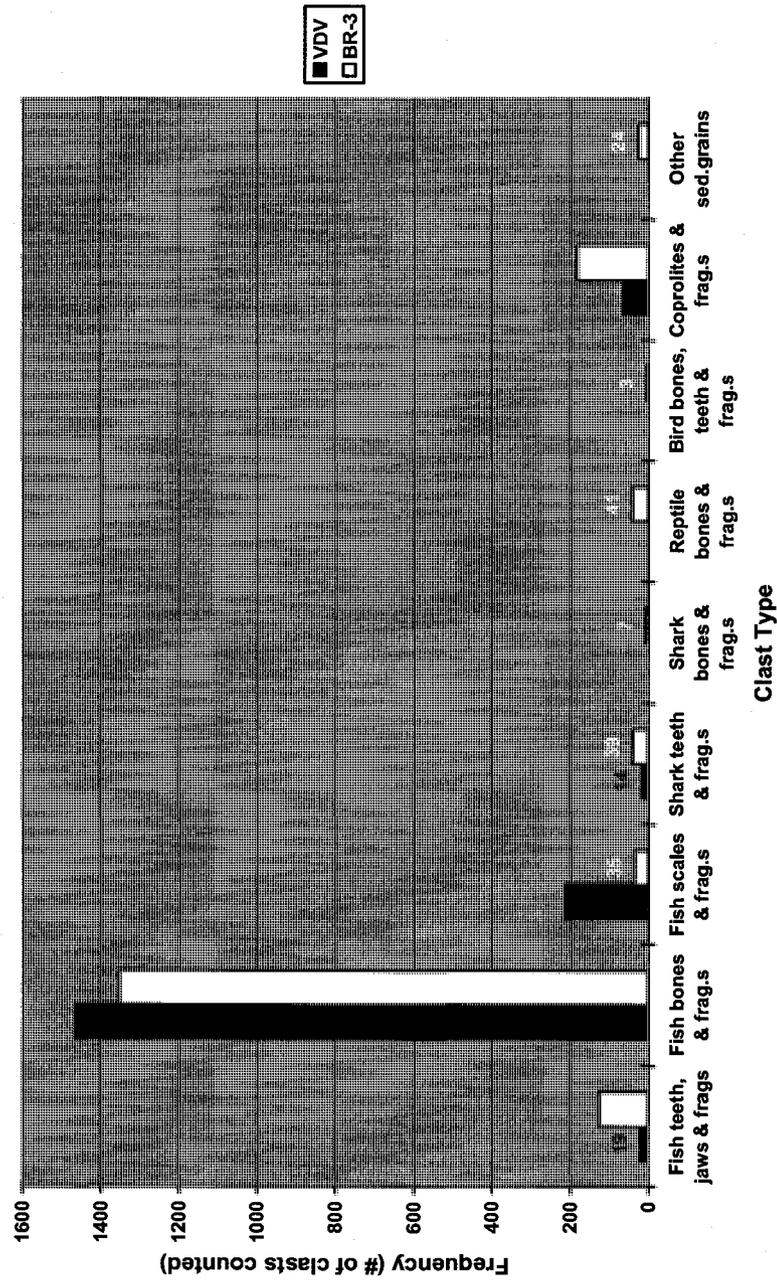


Figure 14: Comparison of the types of clasts recovered from the Van der Voort (VDV) and Bainbridge River (BR-3) samples examined for the comparative taphonomic census, after division of the anatomically unidentified 'Indet. bones and frags.' in Figure 13 along suspected osteichthyan and "reptilian" affinities.

$N_{VDV}=1770$; $N_{BR-3}=1805$

Statistical Comparison of Distribution of Recovered Clasts					
	VDV	BR-3	Deg.s Freedom	χ^2	p(same)
Comparison of Proportions of Clasts I	N=1770	N=1805	10	367.98	6.05E-73
Comparison of Proportions of Clasts II	N=1770	N=1805	9	351.02	3.75E-70

Table 5: Statistical comparison via Chi-square tests of the distribution of the clasts recovered from the Van der Voort (VDV) and Bainbridge River (BR-3) samples used for the comparative taphonomic census. The column “p(same)” indicates the probability that the distribution curves from the two samples are the same.

listing of the clasts recovered from the 0.841mm and 1.68mm sieve fraction samples used in the comparative taphonomic census can be viewed in full in Appendix II.

Summary

In summary, the vertebrate remains preserved in the Van der Voort sample exhibit signs of significant sorting (by shape and by size) and abrasion. The Bainbridge River (BR-3) sample against which the Van der Voort sample was compared also exhibits signs of significant sorting and abrasion, the difference being that the Bainbridge sample is statistically somewhat skewed towards slightly larger elements, slightly fewer plate-shaped elements, and heavier abrasion. Overall, the composition of both bioclastic concentrations are both dominated by bony fishes and sharks, while the Bainbridge River sample has the greater concentration of tetrapod remains. Though a statistical comparison of taxonomic diversity is impractical, it can be qualitatively noted that overall the taxonomic composition of the ichthyofauna of these two deposits are similar, but differing in abundance. In terms of tetrapod diversity the Bainbridge River sample contained taxa which were not found at the Van der Voort locality, specifically of plesiosaurs and birds. The paleoecological and paleoenvironmental implications of these findings will be discussed below.

Petrographic Analysis

In order to interpret varying diagenetic processes affecting Late Cretaceous bioclastic accumulations along the Manitoba Escarpment, thin sections from five bioclastic accumulations were analyzed to assess similarities and differences in the diagenetic histories of these deposits. These included samples from the Van der Voort

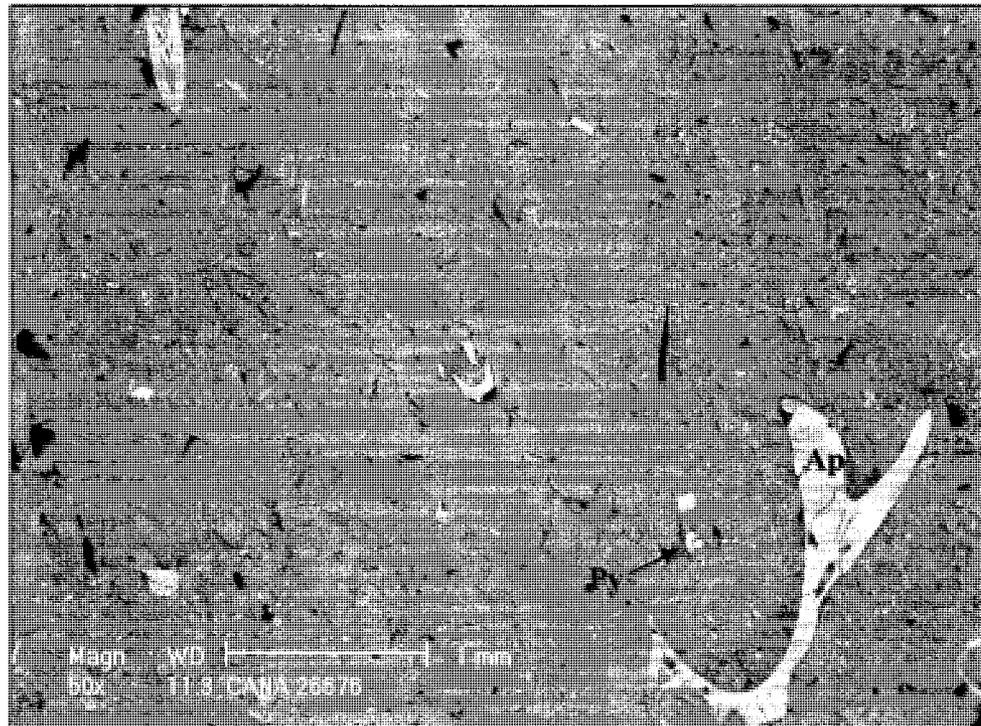
Farm, Carrot River (DH-1), Thunder Hill and two localities along the Bainbridge River (BR-1 and BR-3). Complete listings of the results of the electron microprobe analyses can be view in Appendix III, and a summary of the petrographic and sedimentological observations can be seen in Table 6.

Van der Voort

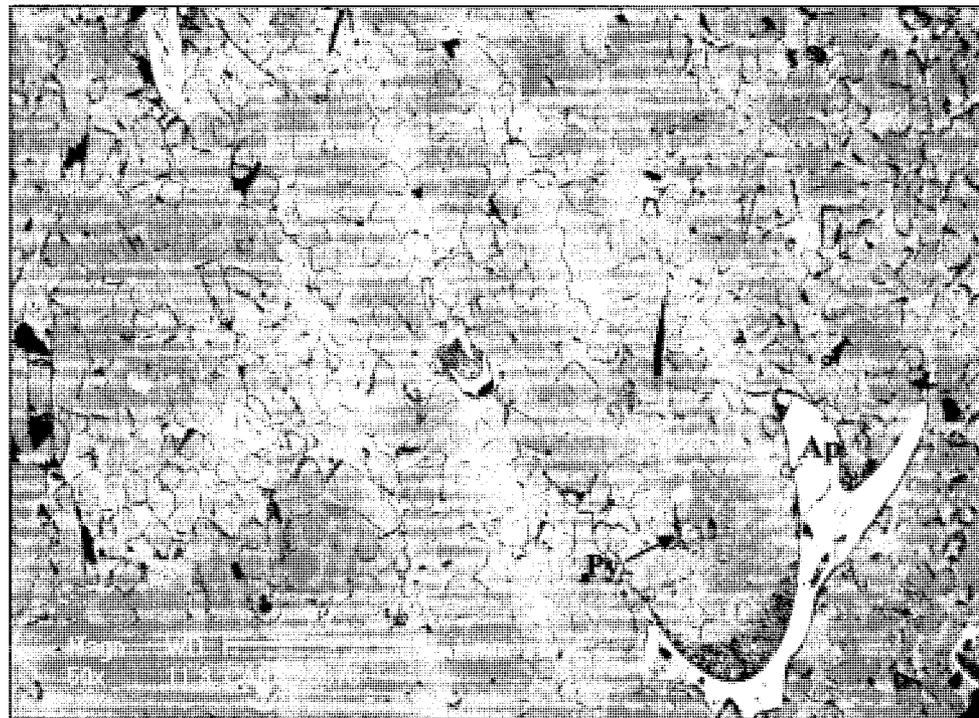
Overall grain size at the Van der Voort sample is typically small (0.3 to 0.7 millimetres) and the sample is moderately well sorted, though the phosphatic bioclasts tend to be larger (0.5 to 1.5 mm). The lithology at this locality is unique compared to those seen in any of the other samples examined (Fig. 15). Petrographically, this material is classified as a biosparite with a wackestone to packstone texture, wherein clasts consist primarily of inoceramid-derived prismatic calcite and vertebrate-derived, phosphatic bioclasts preserved amidst pervasive, sparry calcite cement. These lithologies are therefore further classifiable as “inoceramites”, as per Hattin (1975). Contacts between bioclasts are mostly point contacts, though some are relatively long relative to the size of the grains, and grains showing breakage or signs of plastic deformation were rare. Sedimentologically, point count analysis reveals that the sample consists of approximately 96.8% calcite (approximately 53% sparry calcite cement and 43.8% inoceramid prisms), while phosphatic bioclasts account for only about 2.6%. These phosphatic bioclasts include mainly tabular and/or spindle-shaped vertebrate bone and tooth fragments, with occasional ovoid-shaped pellets (some of which are recognizable as coprolites). The remainder is divided between small quantities of siliciclastic (quartz) grains (approximately 0.2%) and argillaceous (possibly smectite clay) minerals (approximately 0.4%).

Table 6: Summary of Petrographic Observations
(based on point count analysis and SEM observations)

Inoceramite	Bone-biophospharenites		
	Bainbridge River (BR-3)	Bainbridge River (BR-1)	Carrot River
Thunder Hill			
Van der Voort			
Low % (<2.6%) phosphatic bioclasts	>55% phosphatic bioclasts	>65% phosphatic bioclasts	~70% phosphatic bioclasts
Coprolites rare	Coprolites abundant	Coprolites rare	Coprolites rare to absent
Sparry calcite matrix	Sparry calcite matrix	Reduced sparry calcite matrix (compared to BR-3)	Reduced sparry calcite matrix (compared to BR-1)
Trace argillaceous material	Trace argillaceous material	Trace argillaceous material	Trace argillaceous material unobserved
Trace siliciclastic grains (quartz)	Trace siliciclastic grains (quartz)	Trace siliciclastic grains (quartz)	Trace siliciclastic grains (quartz)
>40% inoceramid-derived prismatic calcite	inoceramid -derived prismatic calcite common	Trace inoceramid -derived prismatic calcite	Trace inoceramid -derived prismatic calcite unobserved
Pyrite euhedra & frambooids common; significantly pyritized grains rare	Pyrite euhedra & frambooids common; significantly pyritized grains rare	Pyrite euhedra & frambooids common to abundant; occasional partially pyritized grains	Pyrite euhedra & frambooids very abundant; partially to completely pyritized grains abundant
Randomly oriented	Randomly oriented	Somewhat imbricated	Imbricated
Point contacts b/w grains, min. grain breakage	"Floating" grains abundant, point contacts b/w grains, min. grain breakage	Point and linear contacts b/w grains about equally common, grains frequently show breakage	Linear contacts b/w grains abundant, broken grains common
Grain size small (0.3-0.7mm)	Grain size large (1-3mm)	Grain size small (0.3-1mm)	Grain size small (0.4-1.2mm) with occasional larger clasts (> 3mm)



A



B

Figure 15: Representative SEM images of thin section material from the Van der Voort Farm. Low contrast (**A**) and higher contrast (**B**) general views of calcite-cemented wackestone to packstone with pervasive inoceramid-derived prismatic calcite. In (**A**) and (**B**), pyrite (Py) can be seen as small white flecks, while vertebrate bone (Ap) appears much brighter in (**B**). In (**B**), prismatic calcite can be distinguished as slightly darker colored than the lighter sparry calcite cement surrounding it.

Not counted in the point count analysis but relatively common in the sample are small ($\leq 5\mu\text{m}$) pyrite euhedra as well as framboidal pyrite (Fig. 16a). Where present, pyrite occurs most frequently within grains of the prismatic calcite, somewhat rarely within the intragranular pore spaces of phosphatic clasts (though rarely within or replacing the apatite itself), and was absent within the sparry calcite cement.

Higher contrast SEM images highlight the difference between the inoceramid-derived prismatic calcite and the sparry cement of the matrix, and under higher magnification the hexagonal cross-sectional form of the prisms is readily apparent (Fig. 16b). Electron microprobe analysis of the two calcites confirms the difference in brightness in the SEM images is largely due to differing amounts of iron; where the inorganically precipitated calcite cement is relatively rich in iron compared to the biologically derived prismatic calcite (Appendix III).

Bainbridge River (BR-3)

The sample appears relatively well sorted, with grain sizes typically ranging between one and three millimetres (the largest average grain size of any of the samples examined). In contrast to the Van der Voort material, thin-sectioned material from the Bainbridge River (BR-3) locality examined petrographically classifies as bone-biophospharenite (Fig. 17). It possesses a coarse grainstone to rudstone texture and pervasive sparry calcite cementation, with calcite cement accounting for approximately 39.4% of the thin-section sample examined. Phosphatic clasts appear largely "afloat" in the calcitic matrix, and include tabular, spindle, and ovoid shaped phosphatic bioclasts representing principally fish bones, fish and shark teeth, as well as coprolites; accounting together for

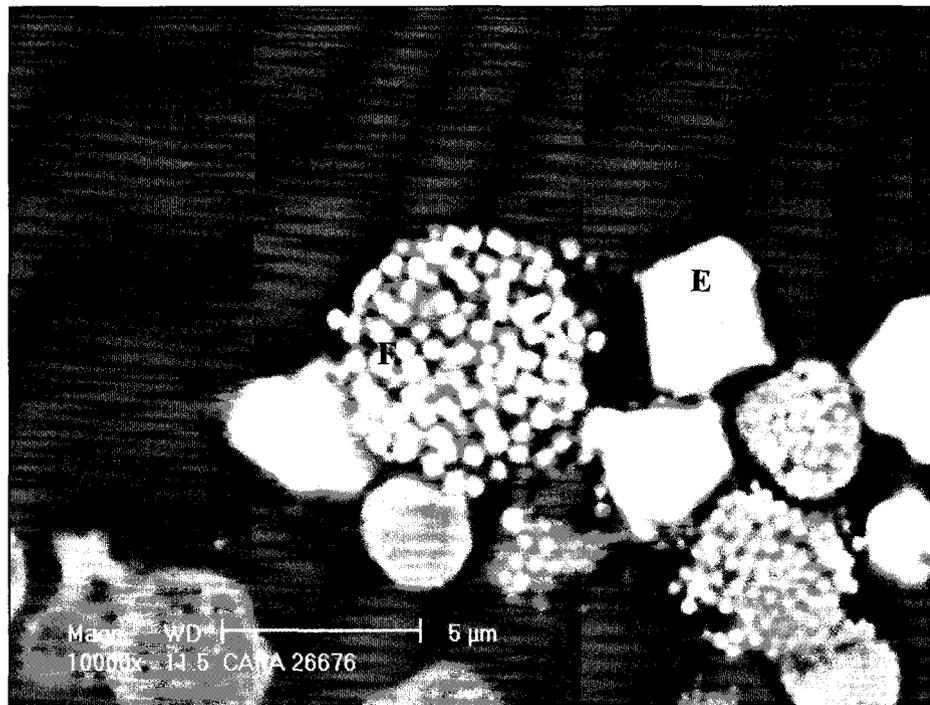


Figure 16: SEM images of thin section material from the Van der Voort Farm. (A) Framboidal (F) and euhedral (E) pyrite under high magnification. (B) Higher magnification high contrast view, highlighting the difference between sparry calcite cement (C) and inoceramid-derived prismatic calcite (P). Pyrite (Py) is visible as small white flecks, and the darker, rough-textured area in the centre of the photograph is argillaceous material (Ag). Also visible is the characteristic hourglass form of a fish vertebra (V).

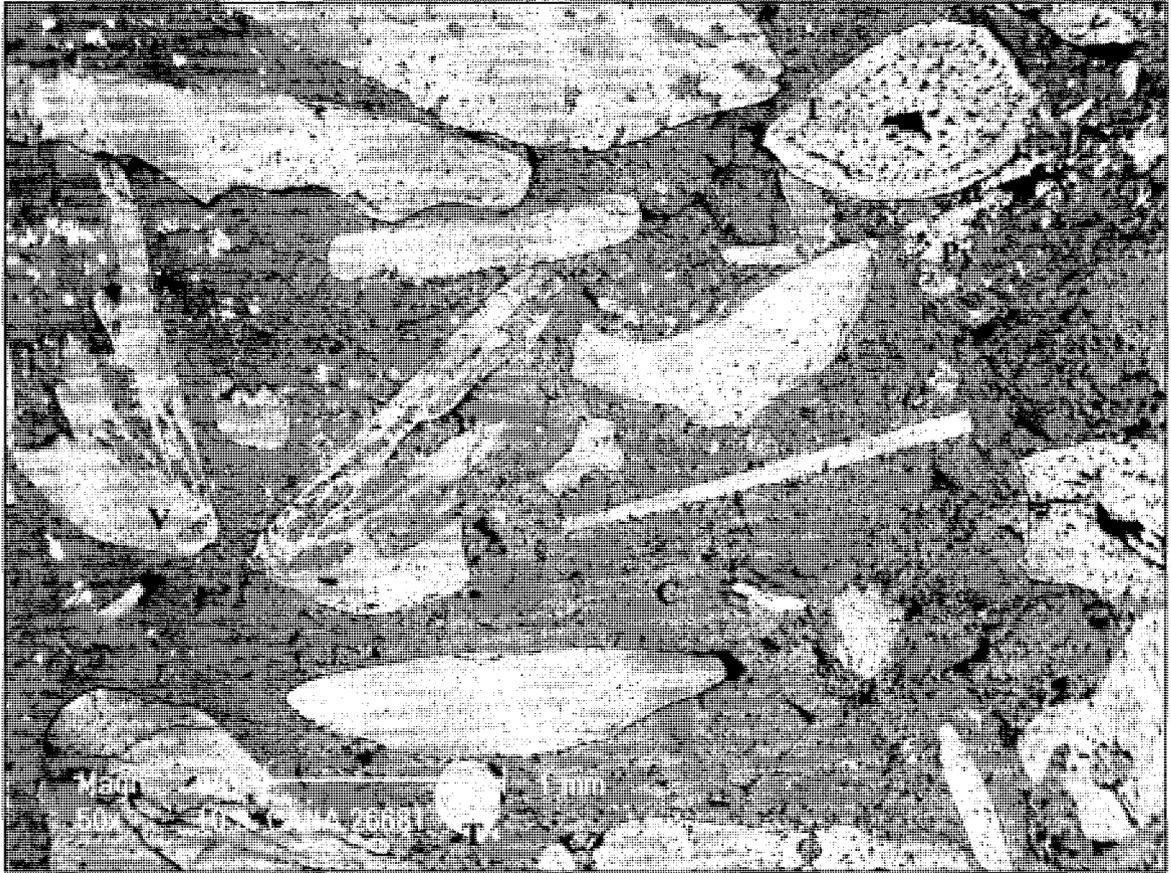


Figure 17: Representative SEM image of thin section material from the Bainbridge River (BR-3). General view of calcite-cemented (C) bone-biophospharenite with a coarse grainstone to rudstone texture. Apatitic bone and tooth fragments visible here include a fish vertebra (V) and fish teeth (T). Also visible is some pyrite as small white flecks (Py).

approximately 57.4% of the sample. Inoceramid-derived prismatic calcite was commonly visible in SEM microphotographs (Fig. 18), and in one region a set of “articulated” prisms was observed (Fig. 19a). Inoceramid-derived prismatic calcite was more difficult to discern using optical petrographic techniques, however, was relatively rare (approximately 2.6%) in the point count analysis. Electron microprobe analysis confirms that the differences between the two varieties of calcite in this sample is consistent with what was seen between inoceramid-derived prismatic calcite and inorganically precipitated calcite spar in the Van der Voort sample (Appendix III). Once again, argillaceous material and siliciclastic grains are rare to absent.

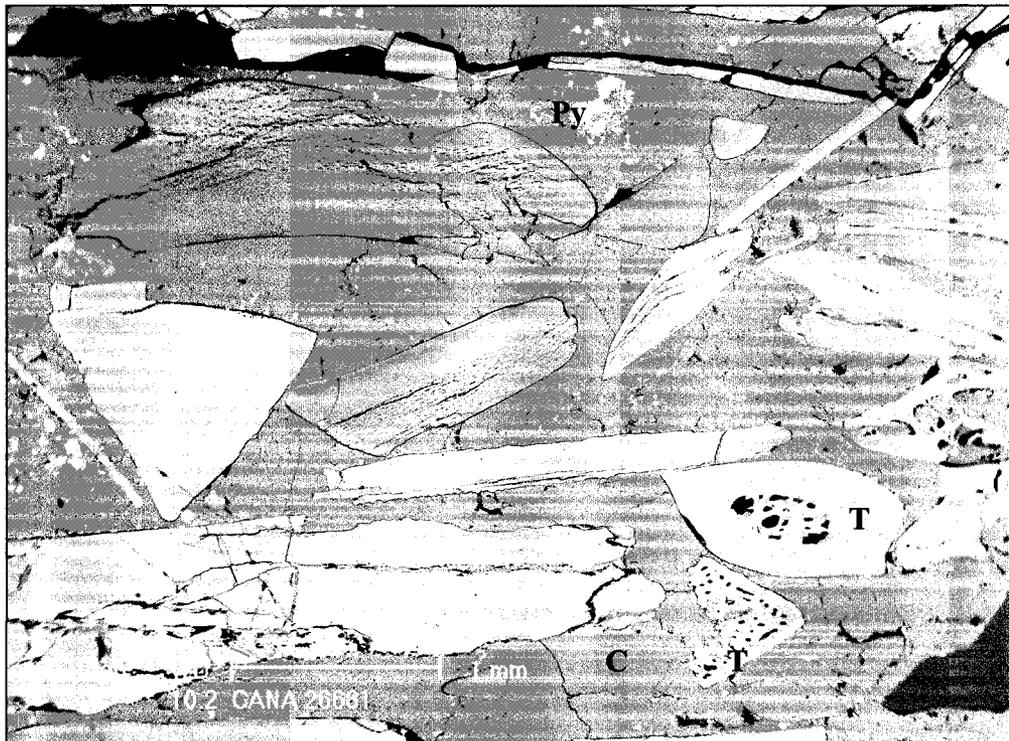
Small pyrite euhedra and framboids were observed commonly in the sample and, where present, they appear to occur primarily in and around inoceramid-derived prismatic calcite crystals and coprolites (e.g. Figs. 18, 19b). Pyrite was also observed, though less frequently, within intragranular pore spaces (e.g. dental pulp cavities). Where articulated inoceramid prisms were observed, they were virtually pyrite-free.

Bainbridge River (BR-1)

Another bone-biophospharenite thin section examined for this study comes from a second locality along the Bainbridge River (BR-1), which is texturally classifiable as a grainstone cemented by sparry calcite crystals (Fig. 20). Compared to BR-3, this sample is more poorly sorted, with grain sizes ranging between approximately 0.3 and one millimetre in length. Linear contacts between grains are more common here than in BR-3, and broken grains are common. Relative to BR-3, BR-1 contains a higher concentration of phosphatic bioclasts (approximately 67.8%) and somewhat less calcite cement (approximately 31.4%). Phosphatic bioclasts are predominantly spindle-shaped,



A

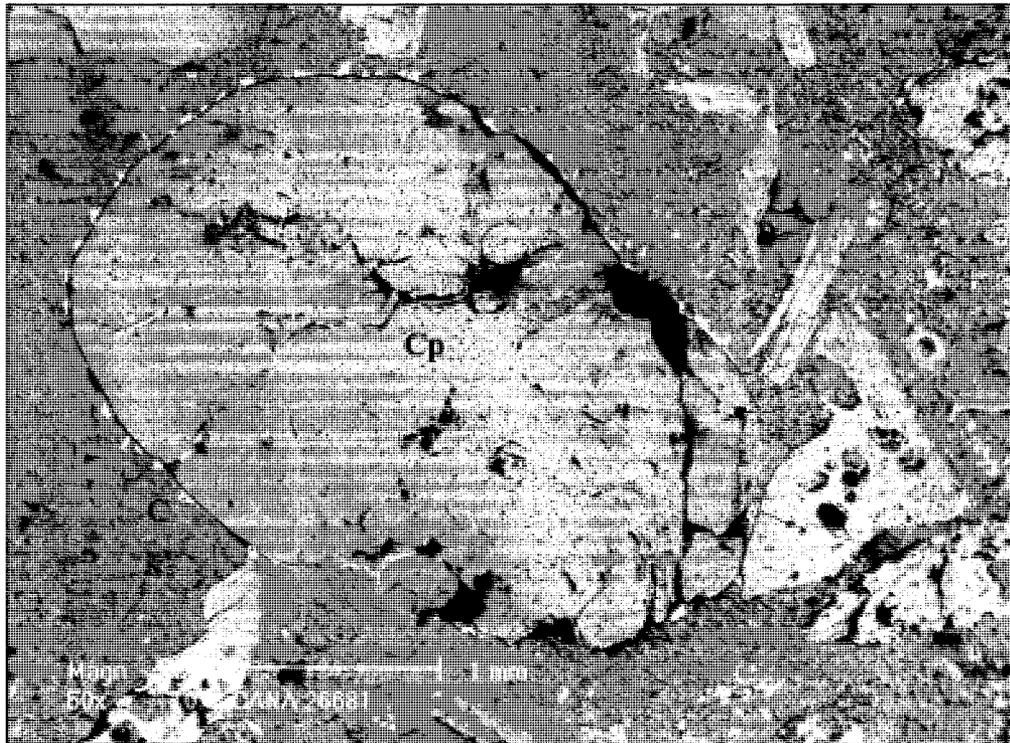


B

Figure 18: SEM images of thin section material from the Bainbridge River (BR-3). High contrast (A) and lower contrast (B) general views of calcite-cemented (C) bone-biophospharenite with a coarse grainstone to rudstone texture. Pyrite (Py) is visible as white flecks and identifiable vertebrate fragments include teeth (T). Some calcite, consistent with inoceramid-derived prismatic calcite (P), is also visible in (A), being slightly darker than the calcite surrounding it.



A



B

Figure 19: SEM images of thin section material from the Bainbridge River (BR-3). (A) High contrast image highlighting a region of ‘articulated’ inoceramid prisms (P). Calcite-cemented (C) and vertebrate bioclasts (Ap) are also visible. (B) Clusters of pyrite (visible as small white flecks) occurring around and within a coprolite (Cp) surrounded by calcite cement (C).

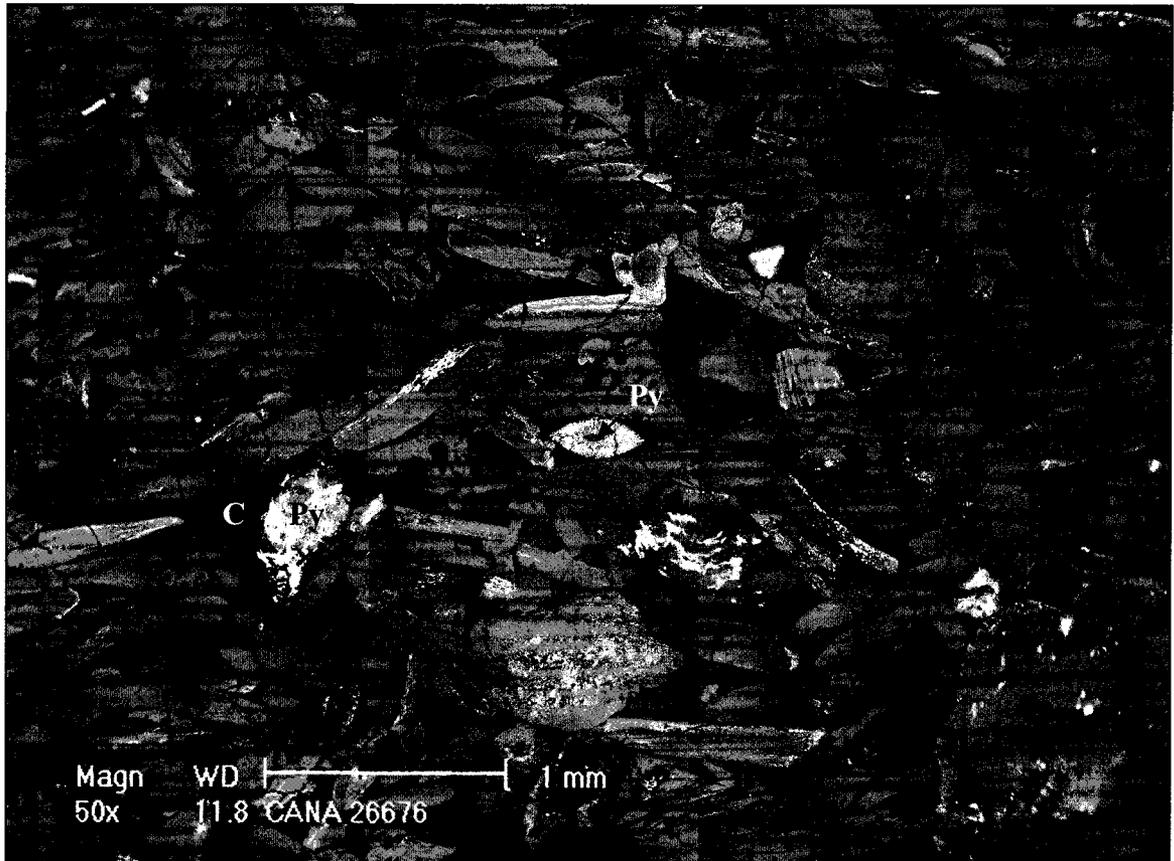


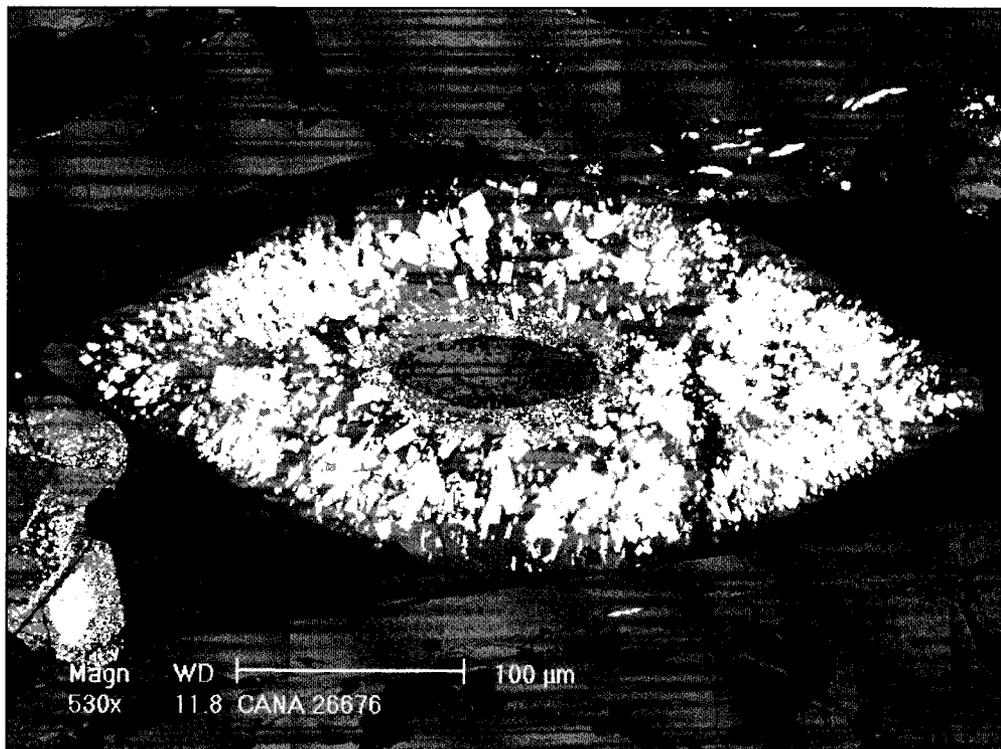
Figure 20: Representative SEM image of thin section material from the Bainbridge River (BR-1). General view of calcite-cemented (C) bone-biophospharenite with a grainstone texture. Apatitic bone and tooth fragments (Ap) are abundant, and include some partially pyritized elements (Py).

with occasional tabular- or ovoid-shaped clasts, and consist largely of bone and tooth fragments with only rare coprolites.

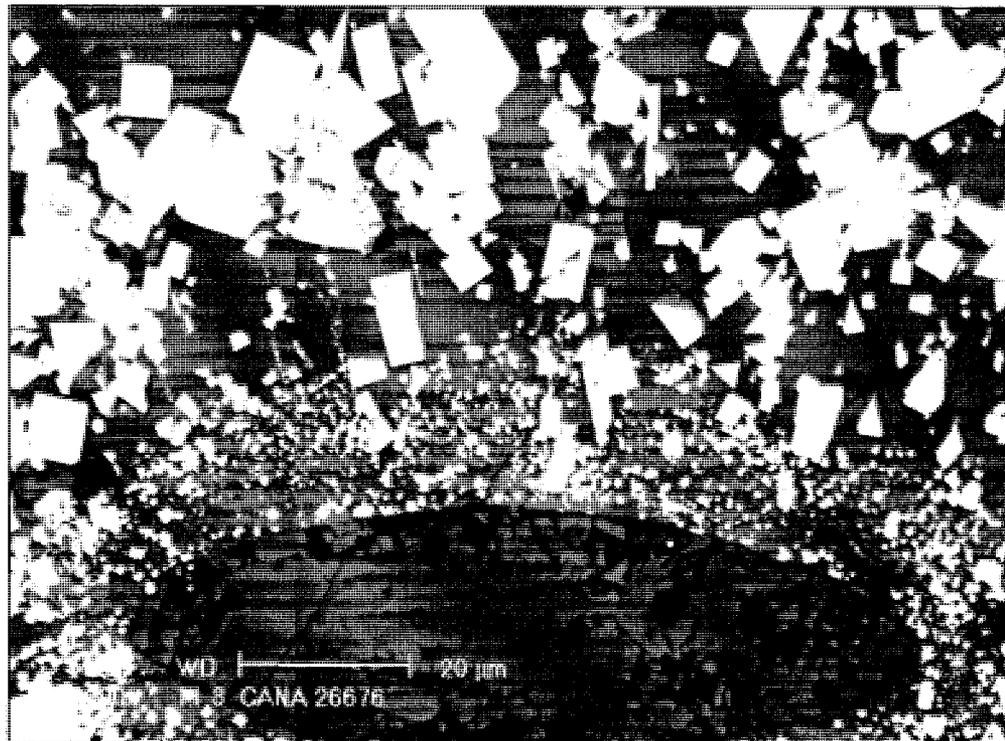
Inoceramid-derived prismatic calcite is very rare, accounting for only one out of five hundred points counted (or 0.2%). Pyrite is more common here than in any of the previous samples, and occurs predominantly as euhedral crystals with rarer framboids within the intragranular space of porous phosphatic bioclasts, and in some cases euhedra displace the apatite outright (Fig. 21), where some clasts are nearly entirely pyritized. Electron microprobe analysis confirms that the differences between the two varieties of calcite in this sample is consistent with what was seen between inoceramid-derived prismatic calcite and inorganically precipitated calcite spar in the Van der Voort sample (Appendix III).

Carrot River (DH-1)

The thin section of the sample collected at a locality along the Carrot River (DH-1) is yet another bone-biophospharenite with a calcareous matrix (sparry calcite, approximately 29% of the sample) that is dominated by mostly spindle-shaped phosphatic debris, primarily fish bones and teeth (phosphatic debris accounts for approximately 69.4% of the sample) (Fig. 22a). The sample is moderately sorted, with an average grain size of approximately one millimetre or smaller, but with occasional larger grains (Fig. 22b). The concentration of phosphatic bioclasts in this grainstone is noticeably higher than that observed in the BR-1 sample, and there is also comparatively slightly less calcareous cement. The Carrot River sample resembles the BR-1 sample, however, in that coprolites were not readily identifiable, and that linear contacts between bioclasts are quite common, as are broken grains. Inoceramid-derived prismatic calcite



A

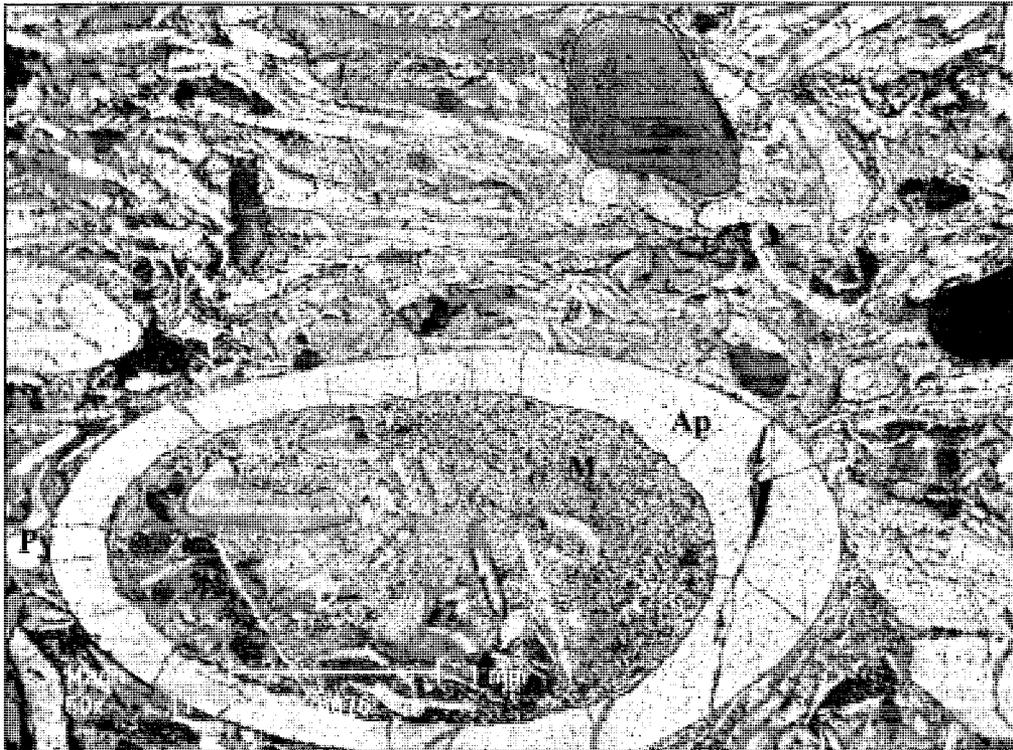


B

Figure 21: SEM images of thin section material from the Bainbridge River (BR-1). (A, B) Increasingly magnified view of pyrite crystal growth within a fish tooth (this tooth is also visible in the centre of Fig. 20).



A



B

Figure 22: Representative SEM images of thin section material from the Carrot River. (A, B) General views of calcite-cemented (C) grainstone with apatitic bone and tooth fragments (Ap), common partially pyritized bone fragments (Py) and localized micrite cement (M, in B).

was also present only in trace amounts, with only four potential prisms identified using the petrographic microscope (accounting for approximately 0.8% of the sample) and few were observed using the SEM. Pyrite is more abundant in this sample than in the previously described samples, and both euhedra and framboids appear clustered within intragranular pore spaces of phosphatic grains, with partially pyritized phosphatic grains also being fairly common. In contrast to the sparry calcite cement seen elsewhere in the sample, some of the few larger bioclasts seem to contain calcareous cement that appears more micritic (e.g. in Fig. 22b).

Thunder Hill

The bioclastic horizon from the Thunder Hill locality is classified as a bone-biophospharenite with a grainstone texture. The sample is moderately sorted, with average grain sizes ranging from approximately 0.4 to 1.2 millimetres, though larger clasts (>3mm) occasionally occur locally. It is composed primarily (73.4%) of spindle- and tabular-shaped phosphatic bioclasts, specifically fish bones and teeth (coprolites were not observed), set within a comparatively reduced (26.4%) sparry calcite matrix (Fig. 23a). Siliciclastic grains were observed in only trace amounts (~0.2%), and neither inoceramid-derived prismatic calcite, nor any argillaceous materials were observed.

The phosphatic clasts are very tightly packed within the sample, with linear grain contacts dominating and abundant broken grains (Fig. 23). Pyrite is very abundant, occurring both as framboids and euhedra (Fig. 24a) and principally within the intragranular pore spaces (e.g. Fig. 24b); partially to completely pyrite-replaced grains are abundant.

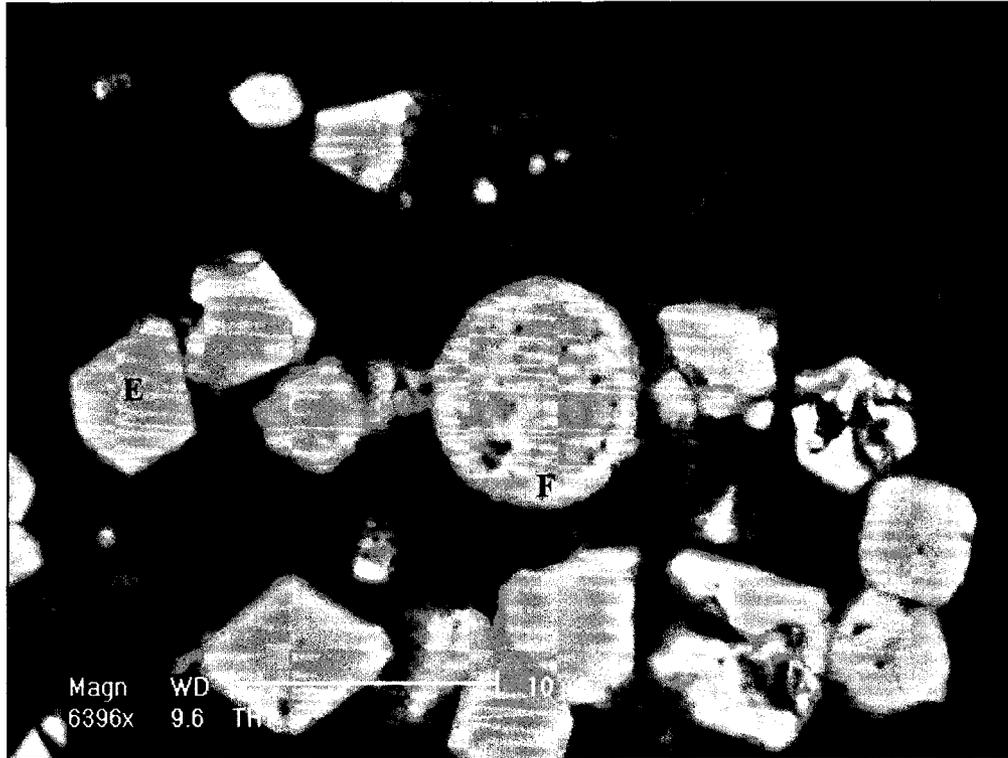


A



B

Figure 23: Representative SEM images of thin section material from the Thunder Hill. (A, B) Phosphatic bioclasts are tightly packed within a reduced calcite matrix; pyritized bone and tooth fragments are abundant. (LC) shows linear grain contacts, (BG) shows broken grains.



A



B

Figure 24: SEM images of thin section material from the Thunder Hill. (A) Pyrite occurs as both framboids (F) and euhedra (E). (B) Pyrite (Py) completely filling the internal pore space of a fish tooth (T), surrounded by calcite cement (C).

Though the Van der Voort inoceramite sample differs significantly from the other samples in terms of lithology, it still displays many of the same diagenetic features and so it can be compared to the diagenetic histories of the bone-biophospharenites. The discussion below will explore how these inoceramites can be potentially viewed as one end of a diagenetic spectrum displayed by bioclastic horizons from the Manitoba Escarpment.

DISCUSSION

Biostratigraphy

Biostratigraphic placement of the inoceramite at the Van Der Voort locality is problematic due to its isolated occurrence without a measurable section that can be sampled for biostratigraphic analysis. The stratigraphic interval of these deposits has to be narrowed then by combining numerous lines of evidence.

The localities nearest to the Van der Voort Farm from which McNeil and Caldwell (1981) describe calcarenitic horizons in outcrop along the Manitoba Escarpment occur along the Vermilion and Wilson rivers, north of Riding Mountain Provincial Park, approximately 76 and 90 km northwest of the Van der Voort locality, respectively. Along the Vermilion River, McNeil and Caldwell (1981) report calcarenites from outcrop numbers 80, 81 and 82 (Fig. 25). These outcrops stratigraphically span from the base of the Morden Shale at the top of outcrop 80, to the lower Belle Fourche Member of the Ashville Formation at the base of outcrop 82. The calcarenites are reported specifically from the Assiniboine Member of the Favel Formation (in outcrop 80), as well as from the Belle Fourche Member of the Ashville Formation (in outcrop 82). The calcarenites described from the Assiniboine Member of the Ashville Formation are comprised of the holostatotype of the Marco Calcarenite, a yellowish-brown, thin-bedded deposit composed of fine-grained fragments of bivalve-derived, prismatic calcite. Megafossils are reported to commonly include the belemnoid *Actinocamax manitobensis*, the bivalves *Inoceramus cuvieri* (common), *Pseudoperma bentonensis* (abundant), and abundant calcareous worm tubes of *Serpula semicoalita* attached to the valves of *I. cuvieri* (McNeil and Caldwell, 1981). Fish fragments are also reported to be commonly concentrated

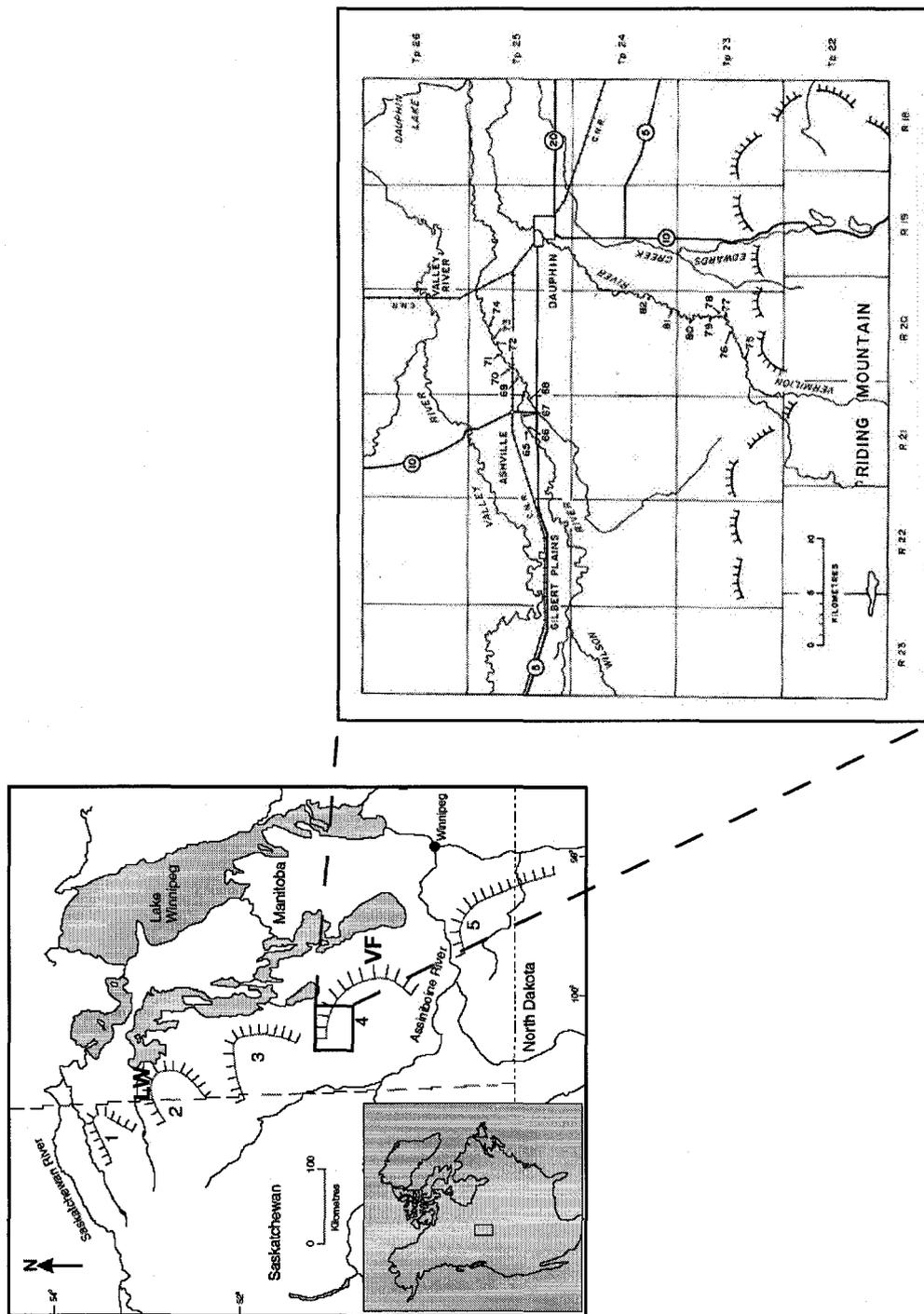


Figure 25: Index map showing McNeil and Caldwell (1981) outcrop locations 65 to 82, along the Vermilion and Wilson Rivers, north of Riding Mountain Provincial Park, Manitoba. LW - Little Woody River; VF - Van der Voort Farm. Modified from McNeil and Caldwell (1981) and Schröder-Adams et al. (2001).

along bedding planes, with rare mosasaur teeth being preserved (McNeil and Caldwell, 1981). Based, however, on the dissimilarity of the megafaunal assemblages, it seems unlikely that the Van der Voort inoceramites represent the Turonian-aged Marco Calcarenite.

Calcarenitic horizons are also described from the Belle Fourche Member of the Ashville Formation, both at locality 82 along the Vermilion River as well as at outcrops 66 through 69 along the Wilson River in the composite type-section of the Ashville Formation (Fig. 25). When comparing the calcarenites of the Belle Fourche Member of the Ashville Formation from along these two rivers, it becomes clear that there are two distinct "sets" to consider. The stratigraphically higher of the two occurs between approximately 11 and 9 metres from the top of the Belle Fourche Member (the Belle Fourche Member measures approximately 27 m at the composite type-section of the Ashville Formation; McNeil and Caldwell, 1981). This stratigraphically higher calcarenite is found both directly above and below a prominent bentonite horizon, measuring from 0.53 m in thickness in outcrop 66 to 0.79 m in thickness at outcrop 82 (McNeil and Caldwell, 1981). This bentonite was interpreted by McNeil and Caldwell (1981) to be the northern continuation of the "X" bentonite, and the calcarenites straddling it were interpreted as the *Ostrea beloiti* beds. These calcarenites are described as containing abundant *Ostrea beloiti* valves that are well indurated, set in a background matrix of very fine to fine calcite prisms, with rare to common fish fragments (McNeil and Caldwell, 1981). Comparison with specimens of the *Ostrea beloiti* beds collected from Manitoba Escarpment reveal, however, that these beds contain comparatively far more bivalve shells and have a very different appearance from the inoceramites collected

at the Van der Voort locality (compare, for example, Fig. 26 to Schröder-Adams et al., 2001, Fig. 10a). In fact, these oyster fragments, comprised exclusively of left valves (Haggart, pers. comm., 2008), have been identified as *Ostrea dunveganensis* Warren 1930, which differs from specimens of *Ostrea beloiti* collected from the Bainbridge River locality in that the *O. dunveganensis* valves are consistently more elongate, slender, regularly rounded and thinner than left valves of *O. beloiti* (Haggart, pers. comm., 2008), while *O. beloiti* also exhibits a more curved valve orientation and a more pronouncedly trigonal beak region (Haggart, 2006, G.S.C. Loc. C-307739). These bivalves also help to narrow the biostratigraphic placement of the Van der Voort inoceramites. The type material of *O. dunveganensis*, against which the Van der Voort specimens were compared, originated from the upper part of the Cenomanian Dunvegan Formation of Alberta, and Haggart (2006, G.S.C. Loc. C-307739) states that a Late Cenomanian age is preferred, and considers assignment to the Ashville Formation likely.

The second, and stratigraphically lower “set” of calcarenites from the Belle Fourche Member of the Ashville Formation were “indisputably” recognized by McNeil and Caldwell (1981) as the “fish-scale marker beds”; the eastern stratal equivalent of the Fish Scales Formation of central Saskatchewan and the central plains of Alberta and the basal fish scale-rich bed of the Shaftesbury Formation in the northwestern plains of Alberta. McNeil and Caldwell (1981) reported that the fish scales marker beds occurred within the lowermost six to ten metres, with the upper contact occurring about midway through the Belle Fourche Member. This upper contact was admittedly arbitrary due to the persistence of fish fragments upward through the remainder of the Belle Fourche Member into the overlying Favel Formation and above, however the “sandy and silty sediments



Figure 26: An example of an unprepared sample of Van der Voort Farm inoceramite that was particularly rich in disarticulated oyster valves, identified as *Ostrea dunveganensis* Warren 1930. Examples of preserved valves are indicated by arrows.

associated with the fish fragments terminate...at the top of a distinctive, widespread, silty, calcarenitic unit..." (McNeil and Caldwell, 1981). This upper calcarenitic unit is described from outcrops 68 and 69 as being grey in color, weathering to yellowish-orange or light brown, and being comprised of fine-grained calcite, commonly containing fish fragments (McNeil and Caldwell, 1981).

This same calcarenitic unit, occurring about midway through the Belle Fourche Member is also identified in outcrops 40 and 41 along the Little Woody River, just north of the Porcupine Hills, near the Manitoba-Saskatchewan border (Fig. 27). In outcrop 41, McNeil and Caldwell (1981) further describe these calcarenites as: "medium dark grey, weathering medium light grey to light brown; fine to medium grained; composed of calcite prism with fine- to coarse-sized fish fragments common; very hard; lensoid, lenses less than 0.6 m in length and 5 cm in thickness; massive to weakly laminated or cross-laminated; orientation of fish fragments is variable but majority parallel lamination...". In this study *in situ* samples of inoceramites were collected from a locality along the Little Woody River (Fig. 4 and Table 1) approximating McNeil and Caldwell's Outcrop Section 41 (1981). Both the outcrop that was examined, and the inoceramite samples collected there, compared favorably to McNeil and Caldwell's description. Finally, the inoceramite samples collected at the Little Woody River locality were examined briefly in the course of this study for comparison with the Van Der Voort samples, and were found to compare very favorably with the the Van der Voort samples lithologically, sedimentologically and in terms of the composition of the vertebrate fauna. McNeil and Caldwell (1981) also track this mid-member calcarenite in the subsurface immediately to the west of the Manitoba Escarpment using well log data.

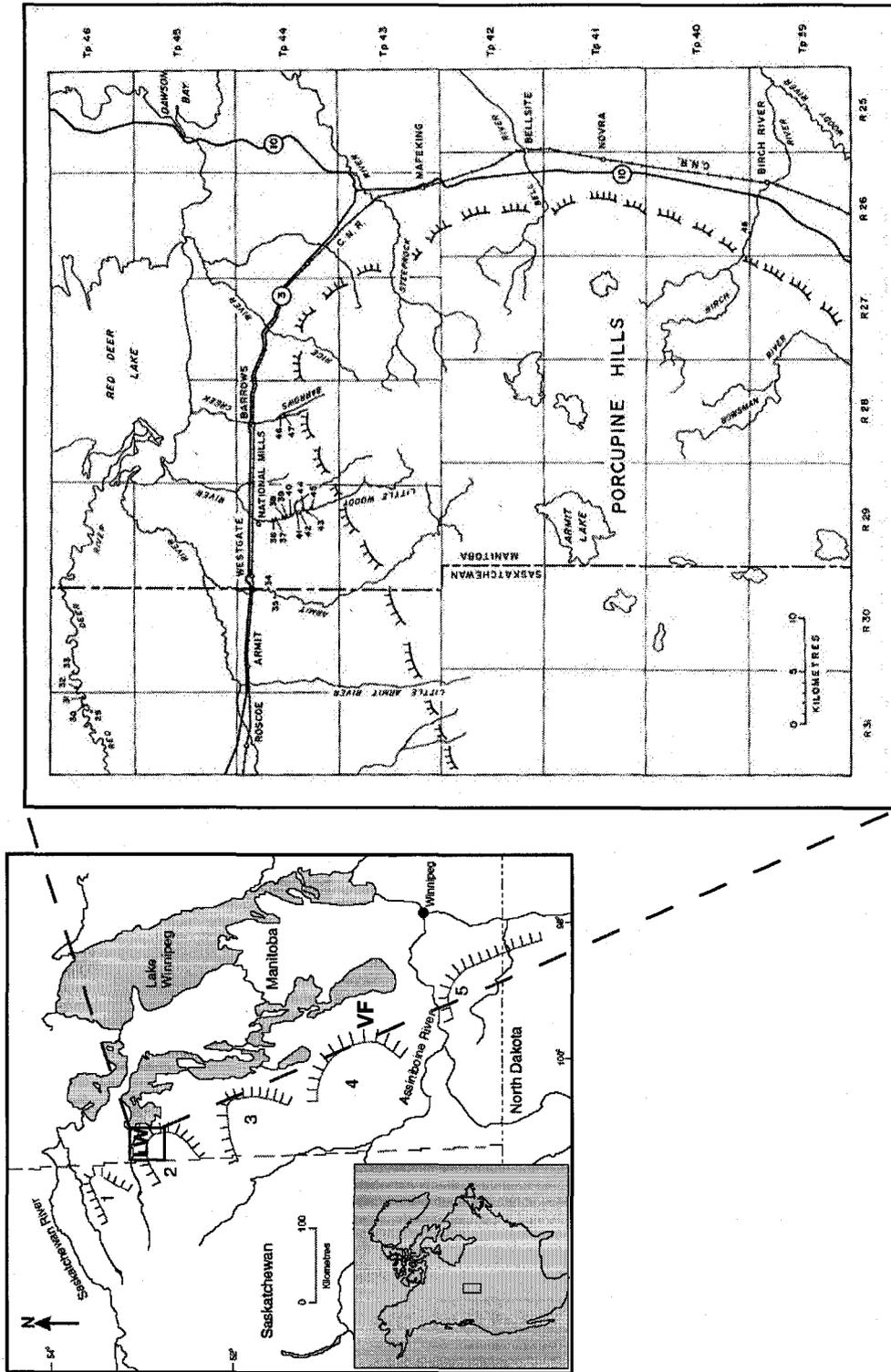


Figure 27: Index map showing McNeil and Caldwell (1981) outcrop locations 29 to 48; of note here are outcrop locations 36 to 45 along the Little Woody River, north of the Porcupine Hills, Manitoba. LW - Little Woody River; VF - Van der Voort Farm. Modified from McNeil and Caldwell (1981) and Schröder-Adams et al. (2001).

They observed (Fig. 28) that it is only prominent in the northwest (sections B-B' and C-C'), and, to a lesser extent, in the southeast (parts of sections G-G' to J-J'), and noted that this distribution corresponded to the areas closest to the escarpment where the Belle Fourche Member is consistently thinner. The log section G-G' matches favorably with the location of the Van der Voort site, and the C-C' section matches favorably with the Little Woody River site.

The vertebrate fauna of the Van der Voort locality also provides some evidence for the narrowing of the biostratigraphic placement of these deposits: for example, *Carcharias saskatchewanensis*, though originally described (Case et al., 1990) from strata determined to be Early Turonian (Cumbaa and Tokaryk, 1999) in age, has subsequently only ever been found in Cenomanian strata (Shimada and Martin, 1993; *Carcharias* sp. A of Welton and Farish, 1993; Cicimurri, 2001a; 2001b; Friedman, 2004; Shimada et al., 2006; Cook, 2007). Similarly, *Carcharias amonensis*, though it may be known as early as the Late Albian (Welton and Farish, 1993), is otherwise also exclusively known from Cenomanian-aged deposits (Welton and Farish, 1993; Cappetta and Case, 1999; Case, 2001; Cicimurri, 2001b; 2004; Antunes and Cappetta, 2002; Vullo et al., 2003; Cumbaa et al., 2006; Shimada et al., 2006; Cook, 2007). Both sharks are common in the Van der Voort deposits, suggesting a Cenomanian age for these deposits. A comparison of the marine vertebrate fauna of the Van der Voort inoceramites in its entirety to the "fish scales marker" in the Shaftesbury Formation in the northwestern plains of Alberta, meanwhile, reveals distinct dissimilarities. In fact, a detailed comparison of the relevant marine vertebrate faunas (see Vertebrate Faunal Distribution in the Western Interior Seaway) reveals that the Van der Voort fauna is more readily

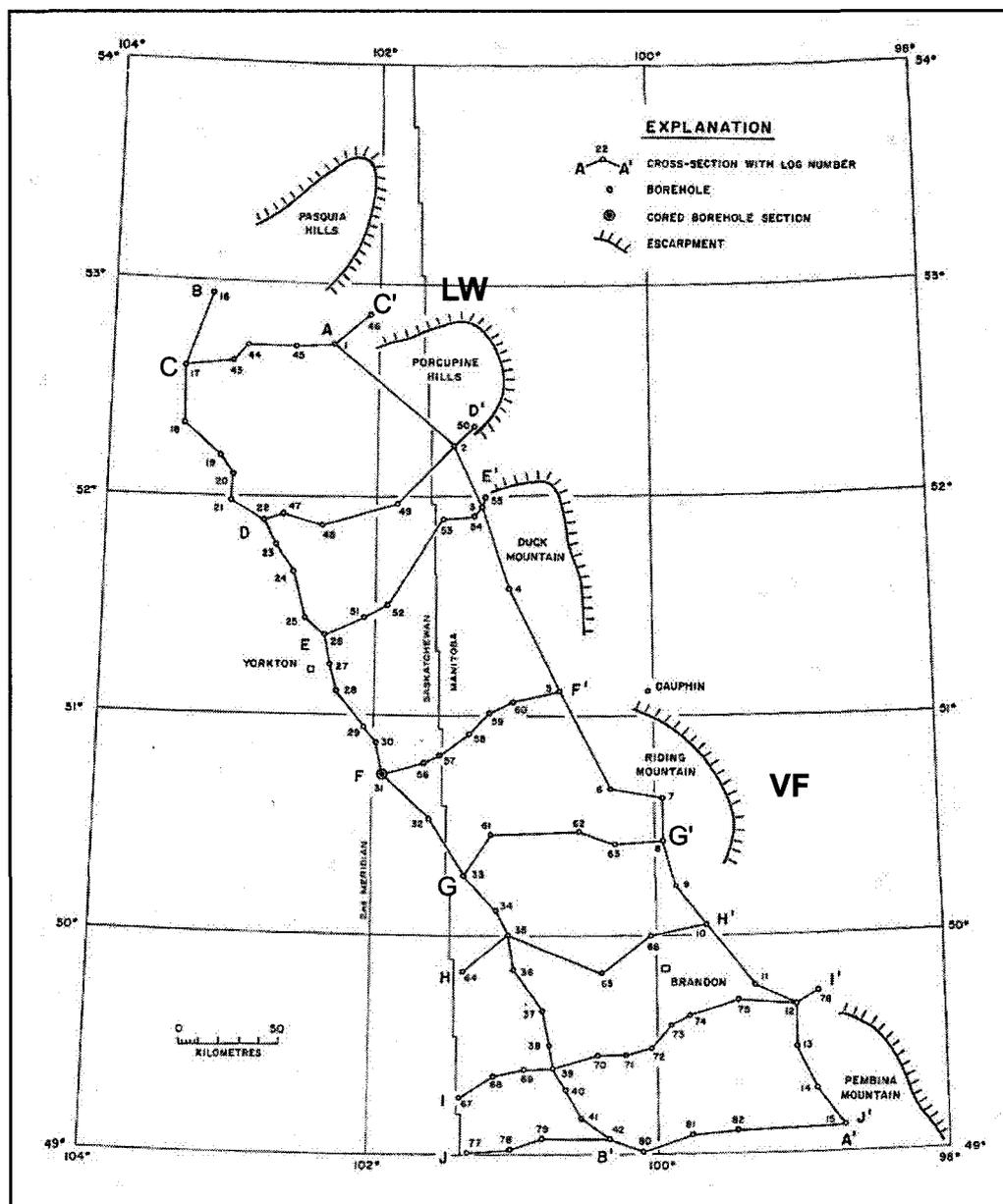


Figure 28: Index map showing McNeil and Caldwell borehole locations and lines of subsurface cross-sections. Note the proximity of section C-C' to the Little Woody River (LW) locality, and the proximity of section G-G' to the Van der Voort Farm (VF) locality. Modified from McNeil and Caldwell (1981).

compared with that of the Pasquia Hills bonebeds described from the upper Belle Fourche Member of the Ashville Formation (e.g. Cumbaa and Tokaryk, 1999; Cumbaa et al., 2006). The Alberta “fish scales marker” fauna is actually far more readily compared to marine vertebrate faunas of the Late Albian/Early Cenomanian Mowry Shale in the northern United States (e.g. Vuke, 1984; Stewart et al., 1994; Anderson and Kowallis, 2004; Stewart and Hakel, 2006).

A final line of evidence contributing to the narrowing of the stratigraphic interval in question are samples of black shales that were collected from immediately above and below the calcarenites at the Little Woody locality, visited in 2006. Micropaleontological analysis revealed the shale to be barren of foraminifera, though they did contain abundant vertebrate (i.e. fish) bone, scale and tooth fragments, inoceramid-derived prismatic calcite crystals, and algal cysts (Schröder-Adams, pers. comm., 2007). While negative evidence of foraminifera cannot be taken as proof, these observations are consistent with the micropaleontological description of the Fish Scales Formation from the subsurface of central Saskatchewan (Bloch et al., 1993; Schröder-Adams et al., 1996). It should also be noted, however, that the Cenomanian interval in the Manitoba Escarpment is one marked by numerous shales interpreted to have been deposited under inhospitable, dysoxic to anoxic conditions (e.g. Schröder-Adams et al., 1996; Schröder-Adams et al., 2001), and this alone may explain the lack of foraminifera.

To summarize, of all the calcarenites described by McNeil and Caldwell (1981), the one that seems most similar lithologically, sedimentologically, and paleontologically to the Van der Voort inoceramites are those described from the lower portion of the Belle Fourche Member of the Ashville Formation and likely originated at or near the level of

the mid-Belle Fourche Member calcarenitic horizon. McNeil and Caldwell (1981) considered the calcarenitic horizon found in the middle of the Belle Fourche Member from exposures on the Wilson River to be correlative with similar outcrop exposures on the Little Woody River, and their wireline log correlations supported this correlation; these data compare favorably with the geographic situation of the Van der Voort Farm and Little Woody River localities from which calcarenites were collected for the present study. Therefore, the Van der Voort inoceramites are interpreted to have originated within the upper part of McNeil and Caldwell's "fish scale marker beds". This, coupled with molluscan and vertebrate biostratigraphic data, support the interpretation of the Van der Voort deposits as Cenomanian in age, with a stratigraphic position below the Pasquia Hills bonebeds, the "X" bentonite, and the *Ostrea beloiti* beds.

The uppermost level of the "fish scale marker beds" is approximately 5 m below the *Ostrea beloiti* beds and the "X" bentonite (at the type locality of the Ashville Formation along the Wilson River) within the Middle to Late Cenomanian *Verneuilinoides perplexus* Zone. This horizon is also no more than 10 metres above the basal 3 metres of the Belle Fourche Member in which McNeil and Caldwell (1981) recognized the Late Albian *Miliammina manitobensis* Zone. Taking this into consideration, along with the other evidence cited above, it seems reasonable to interpret that the upper "fish scale marker beds", and thus the Van der Voort and Little Woody inoceramites, are latest Early to (more likely) early Middle Cenomanian in age.

Taphonomic Interpretations

Taphonomic Overprint at the Van der Voort Locality

The vertebrate remains preserved at the Van der Voort locality, like the Bainbridge River deposits, represent a significant concentration of vertebrate skeletal material. At the Bainbridge River (BR-3) locality, larger elements are more heavily abraded, while other lighter elements are better preserved. This, combined with the abundantly preserved, undeformed coprolites, has been taken to suggest a process of continual accumulation in an environment starved of terrigenous sediments, sufficiently shallow that some winnowing by waves could take place with the lighter fraction drifting away or slowly resettling, and the heavier fraction undergoing regular abrasion (Schröder-Adams et al., 2001).

A similar interpretation can readily be applied to the deposition of the Van der Voort inoceramites as well. In the Van der Voort, sharks are preserved exclusively as teeth, and bony fishes are preserved most commonly as either isolated teeth, superficial skull and jaw bones or vertebrae (with scales being somewhat less common), and all of the above being completely disarticulated and largely distributed at random over the bedding planes. The accumulation and preservation of such an assemblage may be due to a) the fact that articulated fishes were not settling to the bottom and/or b) that if they were settling to the bottom that they were subsequently disturbed (e.g. Leckie et al., 1992). Several mechanisms can contribute to such phenomena, including scattering of the bones by vertebrate or invertebrate scavengers (Elder and Smith, 1988); flotation-decay: where bloated, floating carcasses shed hard parts to the sea floor (Elder and Smith, 1988; Wilson, 1988); predation, which can contribute undigested bones from feces or gastric

residues (Wilson, 1987; 1988); and the activity of waves and/or currents (Elder and Smith, 1988). Scavenging and flotation-decay have been recognized in the fossil record on the basis of discoveries of fragmentary and partially-articulated fishes surrounded by randomly scattered superficial bones and scales (Wilson, 1987; Elder and Smith, 1988). Predation is recognized on the basis of partially dissolved, disarticulated bones that are randomly arranged but spatially concentrated within coprolites or gastric residues (Wilson, 1987), and current-dispersal is typified by partially articulated skeletons with the superficial bones, scales and fin rays aligned in the down-current direction (Elder and Smith, 1988).

While scavenging may be impossible to rule out entirely from contributing to the taphonomic characteristics of the Van der Voort remains, it is likely to have been limited. The lack of epifaunal elements in life position, infauna and bioturbation suggests that the water column immediately above the substrate (and the substrate itself) was relatively inhospitable to animals, thus excluding benthic scavengers and inhibiting colonization. Low oxygen levels seem a likely cause of this, which is interpreted to have been common during the deposition of the shales of the Belle Fourche Member and has been proposed as a factor in the formation and preservation of other Cenomanian bioclastic concentrations (Leckie et al., 1992; Schröder-Adams et al., 1996; Schröder-Adams et al., 2001). The predation-mechanism certainly contributed to the deposition of the vertebrate fraction, as the relative abundance of microcoprolites containing inclusions of vertebrate bone attests, though these microcoprolitic inclusions account for very little of the recognized vertebrate diversity. The contribution (or lack thereof) of the other mechanisms listed above is more difficult to assess, due to the complete lack of even

partially articulated remains. Despite the additional paucity of elements displaying current-alignment, the amount of abrasion and the relatively unimodal size distribution nonetheless argue that a significant, though not overly destructive, amount of transportation, sorting and/or reworking took place, which could very well have overprinted the signatures of other disarticulation mechanisms.

Determining whether the abundant vertebrate fossils found in the Van der Voort samples accumulated quickly (e.g. as may be caused by a mass mortality event) or over a longer period of time is also difficult to assess quantitatively. It is probable, however, that these deposits accumulated over relatively long periods of time based on the preservation of microcoprolites; the observed levels of sorting by shape and size; and the amount of abrasion observed on the individual elements. Feces can vary in hardness significantly relative to an individual producer, however, even the ground mass of fecal pellets at the harder end of the spectrum would still be expected to be no more than paste-like in consistency (Hattin, 1996), and as such would be relatively soft compared to mineral grains. For relatively soft coprolites to accumulate and be preserved intact and undeformed they would need to be deposited in an environment in which they could rest on the sea floor, undisturbed, for a period of time sufficient to harden (or lithify) enough to resist disaggregation and/or compaction by winnowing, transportation, sorting, reworking and burial. An environment prone to sufficiently long periods of calm would thus be required, as well as one which could inhibit disturbance of feces by detritivores or bioturbators.

Evidence of time-averaging, defined as “the mixing of skeletal elements of non-contemporaneous populations or communities” (Walker and Bambach, 1971), also

indicates these remains accumulated over a relatively long time period. Evidence of abrasion, fragmentation, disarticulation, and sorting by shape and size are considered to be "sensitive indicators" of time-averaging, which is also hinted at by sedimentological features which record erosion, transport, and/or low rates of sedimentation (Fursich and Aberhan, 1990). The observed levels of abrasion, fragmentation, disarticulation, sorting; the preservation of undeformed soft microcoprolites and the lack of siliciclastic grains in the Van der Voort inoceramites all fulfill these criteria. It would seem reasonable then to interpret that the vertebrate remains here accumulated over a relatively lengthy time period (possibly on the order of up to several thousand years), rather than due to a mass mortality event. While the occurrence of successive mass mortality events over a relatively long period of time are known to contribute to some substantial fossiliferous deposits (e.g. Emslie et al., 1996) and cannot be ruled out for the Van der Voort *a priori*, there is no specific evidence warranting such an interpretation here. Though they may have accumulated in a relatively low energy environment, the vertebrate fossils of the Van der Voort were undeniably subjected to moderate hydraulic transport as indicated by the moderate sorting, abrasion, fragmentation and disarticulation of the preserved elements. The low proportion of highly worn elements does, however, suggest that this hydraulic energy was neither highly vigorous nor persistent over long continuous periods of time. This suggests that original, pre-transport accumulation may have been in a deeper water environment, disturbed only infrequently by storm waves impinging on the sea floor.

The Comparative Taphonomic Census

Fursich and Aberhan (1990) state that taphonomic criteria such as the degree of articulation, fragmentation and abrasion provide a qualitative measure of the exposure time of skeletal elements at the sediment-water interface and of the frequency of reworking events. While in many regards the Van der Voort inoceramites and the Bainbridge River bonebeds have been subjected to comparable taphonomic (or more specifically, biostratinomic) processes, a detailed comparison of the two deposits did reveal subtle and informative differences. The lower comparative levels of abrasion observed for vertebrate-derived elements and the preservation of many angular to subangular inoceramid-derived calcite prisms in the Van der Voort samples could indicate less time spent exposed on the sea floor, and by corollary less opportunity to be successively reworked, as well as simply lesser transport distances. The smaller overall clast sizes (both vertebrate- and inoceramid-derived) and the skewing of the distribution of the preferentially preserved clast sizes towards smaller elements would also suggest that the Van der Voort deposits were, on average, subjected to less physical reworking and ultimately deposited in a less energetic environment. The less a fossil assemblage is taphonomically altered, the less time it is inferred to have resided in the taphonomically active zone, and therefore the less it will be time-averaged (Fursich and Aberhan, 1990). Thus, it is likely that the inoceramites at the Van der Voort Farm locality underwent comparatively less time-averaging than the Bainbridge River (BR-3) bonebed.

The difference that is inferred to exist in the intensity and/or frequency of hydraulic transport and sorting of the Van der Voort and Bainbridge River (BR-3) deposits may also have had the effect of decreasing the perceived taxonomic diversity of the latter

deposit. Blob and Fiorillo (1996) have illustrated examples of certain taxa being excluded from preservation at some localities due to the predisposition of some remains to taxonomically-controlled sizes and shapes. These taxonomic controls on the size and shape of skeletal elements can be preservationally disadvantageous within the prevailing hydraulic regime. Remains of a “basal euteleost”, an early anguilliform, and an unidentified caturid are known from both the Van der Voort and Bainbridge River (BR-3) deposits, though in the Bainbridge deposit these are far less common. While it may be that this difference in abundance does reflect differences in the vertebrate paleocommunity structure at the two localities, it is worth noting that these elements are typically of a size and fragility that are preferentially preserved at the Van der Voort locality, and not at the Bainbridge.

Diagenetic Interpretations

Petrographic examination of the bone-biophospharenite revealed informative differences, predominantly in terms of the degree of mechanical compaction and the abundance of authigenic pyrite. Despite very different mineralogy, the Van der Voort inoceramites can still be meaningfully compared to the bone-biophospharenites with regard to these parameters.

Petrographers differentiate between grain fabrics indicating early cementation and mechanical compaction on the basis of the nature of the contacts between grains and the degree to which grains have been broken and plastically deformed (Meyers, 1980; Budd, 2002). A predominance of point contacts between grains and/or “floating grains” (grains surrounded entirely by interstitial cement), as well as a lack of significant grain breakage

and plastic grain deformation are collectively taken to be indicative of early cementation, while increasing predominance of linear grain contacts and close packing, with abundant broken and/or plastically deformed grains are indicative of increasing mechanical compaction (Meyers, 1980; Budd, 2002). The vertebrate-derived clasts dominating the Bainbridge River 3 sample contact one another predominantly via point contacts, if at all, and tend to show very few signs of breakage or plastic deformation: thus they are interpreted to be indicative of early cementation. This is true also of the Van der Voort sample, though to a lesser degree, where proportionately longer contacts between inoceramid-derived calcite prisms are common while grain breakage is still rare. This is in contrast to what is observed in the other three samples where increasingly abundant linear contacts between grains, close packing, and breakage of elongate grains can be observed (in order of increasing abundance) through the Bainbridge River 1, Carrot River and Thunder Hill samples. The Thunder Hill sample in particular is very compacted, and the volume of pore-space filling cement is greatly reduced in comparison to the Bainbridge River 3 sample. The overall reduction in the volume of calcite cement in the Bainbridge River 1, Carrot River and Thunder Hill samples reduces the effective permeability of the samples with regard to the acetic acid mediated dissolution of calcite, and the increasingly grain-supported fabrics further inhibit successful disaggregation of these bonebeds using this method. The variability of the degree of compaction among the samples also contributes to interpretations of the differences in the late biostratigraphic and early diagenetic histories of these samples, which will be discussed in more detail below in combination with other factors, including the abundance of authigenic pyrite.

In order to discuss the importance of the variable amounts of authigenic pyrite in the examined samples, we must first consider some of what is known about pyrite precipitation in marine sediments. Under normal marine conditions, most authigenic pyrite precipitates within the zone of bioturbation, largely as a byproduct of the decomposition of organic matter by obligatorily anaerobic, sulfate-reducing bacteria (Bernier, 1980). Commonly using organic matter as a substrate, sulphate-reducing bacteria produce hydrogen sulfide (H_2S) as a byproduct of their metabolic activity, and this in turn reacts with iron in solution to form pyrite (Littke, 1993). In normal marine sediments (i.e. in oxygenated bottom waters), the major factors controlling the rate of bacterial sulfate reduction is the amount and especially the reactivity of the organic matter being deposited in the sediment (Bernier, 1984). This is in contrast to the situation in euxinic conditions (i.e. in anoxic bottom waters), where the reaction of H_2S with iron minerals can occur before and after burial, and even during sedimentation itself (Leventhal, 1983). Here, it is more the amount and reactivity of the detrital iron minerals that govern the amount of pyrite that forms, rather than the abundance of locally deposited organic matter (Bernier, 1984). In further contrast to normal marine sediments, appreciable pyrite can also form under euxinic conditions where deposition rates are very low (Bernier, 1984). Slow deposition, which inhibits pyrite formation in normal pelagic sediments, actually maximizes the amount of pyrite formed under euxinic conditions because slowly reacting iron compounds are given more time for reaction with H_2S (Bernier, 1984).

Research has shown that the microenvironments within pellets, invertebrate and microorganismal body chambers and algal bore holes are distinct from, and only partly

dependant on, that of the enclosing sea water, and that these internal microenvironments are distinctive in that they possess both surfaces free from abrasion and a concentration of organic tissue undergoing bacterial decay (Oppenheimer, 1960, 1961; Purdy, 1968). The same is true within vertebrate skeletal elements: Trueman et al. (2003) demonstrated that the chemical environment inside fossilized bones of shallow marine vertebrates can be distinct (low pH, reducing) from that of the surrounding sediment, and attributed the genesis of these microenvironmental conditions to the microbial metabolism of collagen initiated in relatively fresh bones. In their example, Trueman et al. (2003) further state that the maintenance of these low-pH and low-Eh conditions inhibited extensive microbial bioerosion within the bone internal pore space and enhanced rapid pyrite mineralization. They theorized that these microenvironmental conditions were responsible for the survival of their studied vertebrate material into the fossil record due to the inhibition of microbial bioerosion, which has been theorized to accelerate bone apatite dissolution by increasing the porosity and permeability of bone (Trueman and Martill, 2002). In the inoceramite and bone-biophospharenite samples examined in the present study, pyrite precipitation was observed almost exclusively within biogenic grains, which is interpreted to result from the decay of the remnant organic matter contained within fecal pellets (preserved as microcoprolites), within the internal pore spaces and organic matrix of vertebrate bones and teeth (e.g. pulp and medullary cavities, dentine tubules), and from organic filaments which may have originally been present within the inoceramid-derived calcite prisms (e.g. Pirrie and Marshall, 1990). The paucity of pyrite in the surrounding calcite cement, meanwhile, is taken as an indication that pyrite precipitation was limited in the interstitial space. This may have been due to a lack

of dissolved organic matter in interstitial waters. Indeed, the regions of teeth most frequently observed to contain pyrite were the smaller tubules within the dentine layer, rather than in the central pulp cavity or cavities (e.g. Fig. 21a), which would be consistent with ideal microenvironmental conditions forming first within those pore spaces most restricted from an external sea water source. Assuming then that the amount of organic tissue contained within these pore spaces (for example among comparable shark teeth or among comparable teleost teeth) is more or less constant (based on the similarity of the available pore space), it is difficult to imagine that it is the amount of organic matter which is the factor limiting the amount of pyrite which can be precipitated. This would suggest then that it is the amount of time exposed to the sulphate reduction zone which is the variable limiting the extent of pyrite precipitation in these samples, and that those bioclasts which contain the most authigenic pyrite (or that are themselves most thoroughly pyritized) are those that have resided within the sulfate reduction zone the longest.

All of the samples examined come from bioclastic horizons interbedded within the carbonaceous shales of the Belle Fourche Member of the Ashville Formation. These skeletal fragment-rich horizons are thought to have accumulated slowly over time on the sea floor, in relatively shallow, potentially nearshore waters characterized by low sedimentation rates and bottom water anoxia, which were concentrated by winnowing and reworking by storms and/or transgressive-regressive events (McNeil and Caldwell, 1981; Schröder-Adams et al., 2001; Cumbaa et al., 2006). Interestingly, in similar modern environments, the sulphate reduction zone can extend up to and even above the sediment-water interface (e.g. Leventhal, 1983), however it does not typically extend

more than about 20 cm beneath the surface (summarized in Reeburgh, 1983). Indeed, partially fossilized Miocene to Recent marine vertebrate remains, concentrated there due to winnowing by bottom currents, have been collected right from the surface of the Namibian shelf and have been shown to contain crystallized globules, as well as cubic and cubic-octahedral crystals of authigenic pyrite (Moroshkin et al., 1970; Baturin, 1978; Baturin and Dubinchuk, 2003; Nemliher et al., 2004). Thus, even with low sedimentation rates, the bioclasts studied here would not have to be buried very deeply before being beyond the reach of sulphate-reducing bacteria. It can be concluded, therefore, that for a given bioclast to spend a significant time within the sulphate-reduction zone would be to spend a significant amount of time at or near the sediment-water interface. This would increase the likelihood that these elements were transported and reworked by infrequent, episodic events multiple times before final burial. The distribution of coprolites (which occur abundantly in Bainbridge River 3, commonly in the Van der Voort, very rarely in the Bainbridge River 1, and were not observed at all in the Carrot River and Thunder Hill samples) throughout the samples supports the hypothesis that perhaps the Bainbridge River 1, Carrot River, and Thunder Hill spent a greater amount of time being mobilized (or remobilized) on the sea floor, since these relatively soft particles would be removed by such processes. A lesser degree of transport is also supported by the presence of fine-grained clay minerals, which are represented by macroscopic bentonite rip-up clasts in Bainbridge River 3 samples (e.g. Schröder-Adams et al., 2001). Fine-grained clay minerals were also occasionally observed packed into the “corners” of vertebrate elements seen in SEM images from the Van der Voort samples (Fig. 16b), but are absent from the other localities.

What then might have been responsible for the relatively earlier immobilization of the largely biogenic sediments of one location over another? In the samples examined it is found that as pyrite becomes more abundant, so too do signs of mechanical compaction. Therefore, the earlier cementation occurred, the less likely (and/or frequently) a given bioclastic deposit could be remobilized. Though commenting on medium- to large-sized carbonate deposits, Morse and Mackenzie (1993) note that most changes in porosity in carbonate rocks reflect the redistribution of CaCO_3 within the rocks, rather than by importation from without. As those samples which are least pyritized and least compacted are also those with the most abundantly preserved inoceramid-derived prismatic calcite, it is interpreted that these prisms provided the CaCO_3 source for calcite cementation. It is beyond the scope of this study to establish whether the rates of sedimentation varied sufficiently between these localities to effectively bury some deposits beneath the sulphate-reduction zone (thus favoring earlier cementation) more rapidly than others. However, when all the evidence is considered (Fig. 29 and Fig. 30), it appears feasible that being buried along with an ample supply of inoceramid-derived calcite prisms would have improved the chances of earlier cementation, thus limiting compaction as well as the amount of time bioclasts would have spent in (and/or being reworked in) the sulphate-reduction zone. While the difference in the number of preserved inoceramid prisms may reflect the local paleoecological abundance of these bivalves at the time of deposition, it is at least as likely that bioclasts deposited in more distal environments were exposed to less frequent episodes of reworking, which would winnow out fewer of the finer grained inoceramid-derived calcite prisms. Being exposed to fewer reworking episodes early on would facilitate earlier cementation, which in turn

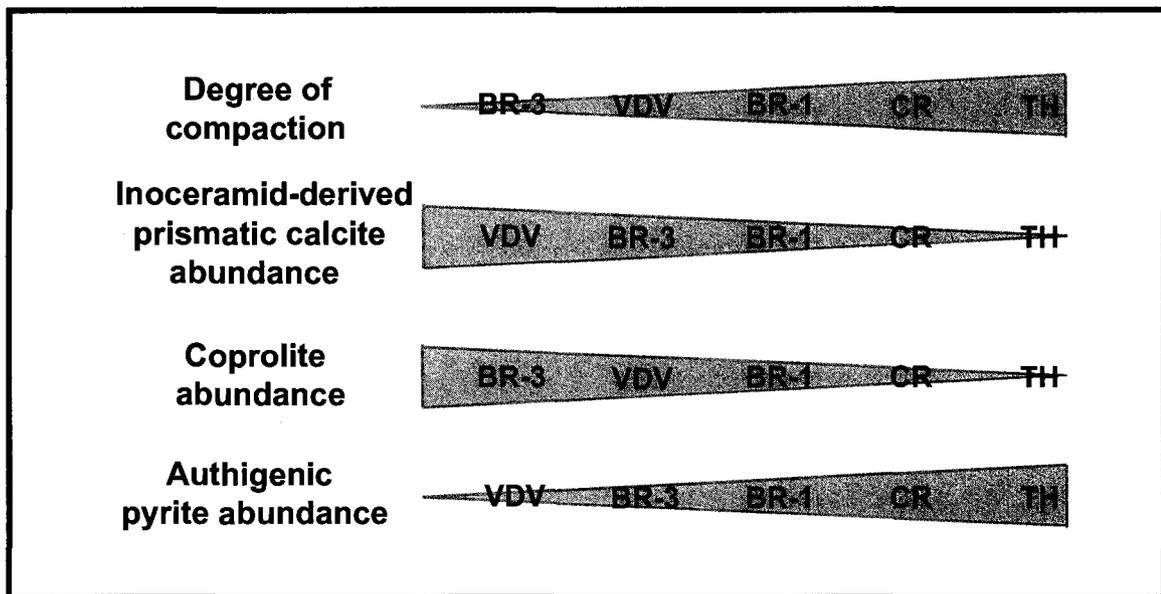


Figure 29: Summary of diagenetic trends, increasing or decreasing in degree or abundance from left to right as observed petrographically in thin sectioned samples from the Van der Voort (VDV), Bainbridge River 3 (BR-3), Bainbridge River 1 (BR-1), Carrot River (CR), and Thunder Hill (TH) localities.

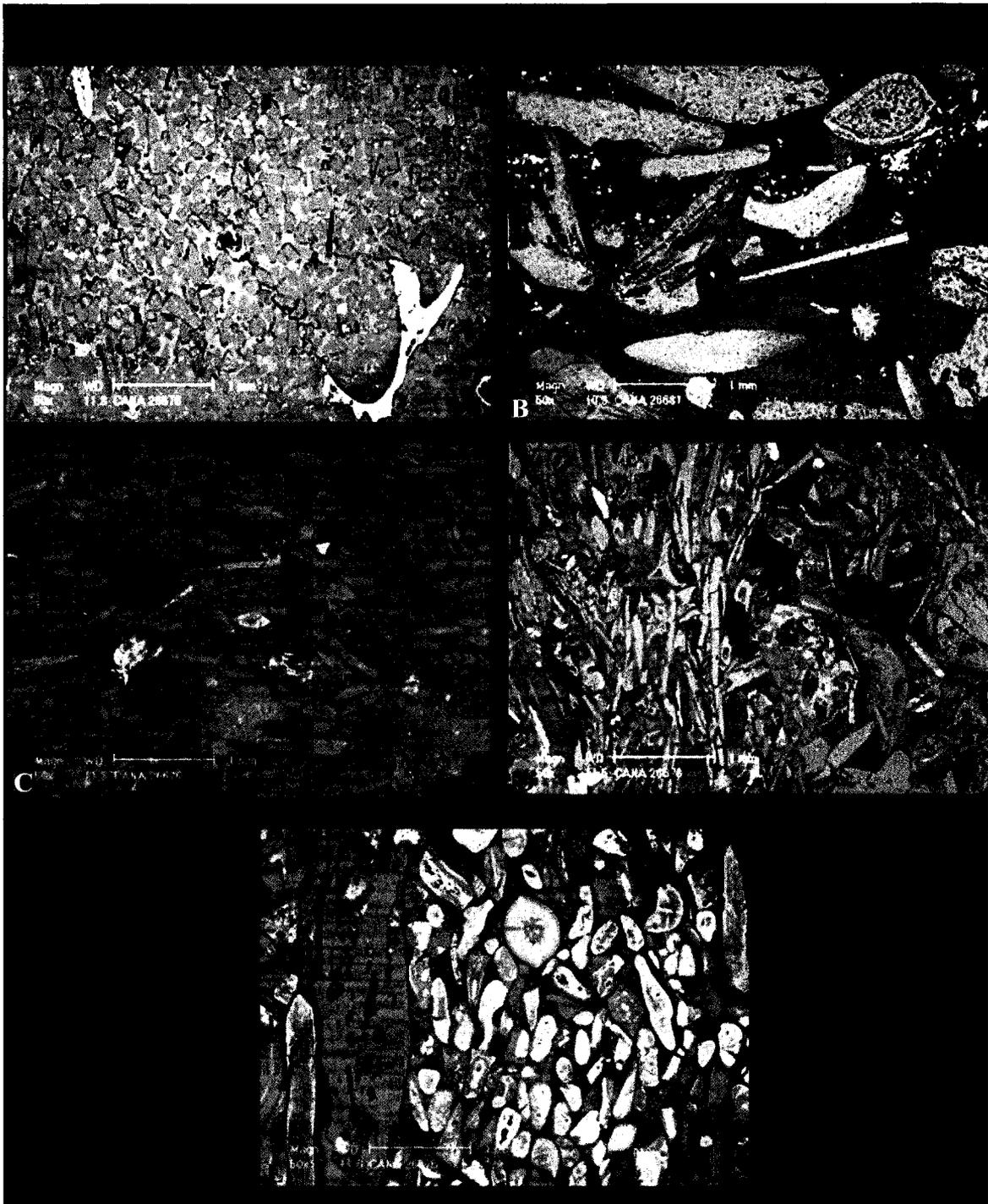


Figure 30: Comparison of representative thin sections (50X magnification) of five bioclastic accumulations from the collected from the Manitoba Escarpment. (A) Van der Voort locality: note abundant inoceramid-derived calcite prisms, sparse phosphatic elements and point contacts between grains. (B) Bainbridge River (BR-3) locality: note large “floating” phosphatic grains. (C) Bainbridge River (BR-1) locality: note increasingly linear contact between grains and increased compaction. (D) Carrot River locality: note linear grain contacts, greater compaction, and frequent splintered grains. (E) Thunder Hill locality: note rounded and abraded phosphatic elements, and high degree of pyritization.

would protect against further reworking. The inoceramites of the Van der Voort locality and the bone-biophosparenites from elsewhere along the Manitoba Escarpment may then represent something of a continuum of bioclastic preservation: where the preservational quality of vertebrate remains is enhanced by burial along with abundant inoceramid-derived prismatic calcite (relating to the abundance of inoceramids, the frequency of reworking, or both) thus affecting both the preservation of the internal microstructure of the biogenic elements, as well as the accessibility of the phosphatic elements using non-invasive, chemical preparation techniques.

Paleoecology

Vertebrate Faunal Distribution in the Western Interior Seaway

A notable aspect of the paleofauna at the Van der Voort locality lies in its relatively diverse taxonomic composition. From 5.4 kg of inoceramite, 260.1 g of insoluble sediments (mostly bioclasts) was extracted. Those 260.1 g of sediments, combined with some pre-prepared material from the Manitoba Museum, yielded a minimum of nineteen identifiable vertebrate taxa, consisting of at least twelve chondrichthyans; at least thirteen osteichthyans; and at least one marine reptile (with another marine reptile, *Brachauchenius* sp., recognized from an impression of a tooth in an unprepared block collected from the Van der Voort locality in the collections of the Manitoba Museum). Considering, however, the enormous number of fragmented, unidentifiable specimens, it should also be noted that the true number of taxa is in all likelihood much greater (for example, of the 4044 bone, tooth and scale fragments retained by the 0.843 mm mesh size from sample VdV005, only approximately 350 could be assigned reasonable

taxonomic identifications). The Little Woody samples, meanwhile, were only examined superficially and were found to contain specimens of *Protosphyraena* sp., *Enchodus* sp., *Squalicorax falcatus*, *Squalicorax volgensis*, *Carcharias* cf. *C. saskatchewanensis*, and *Cretoxyrhina mantelli* (all of which are recognized on the basis of preserved teeth); constituting an ichthyofauna consistent with that of the Van der Voort inoceramites.

Assuming that the inoceramites recovered from the Van der Voort and Little Woody River localities are early Middle Cenomanian in age, numerous taxa listed and discussed above potentially represent the earliest known occurrences. *Protosphyraena* sp., *Squalicorax falcatus*, a salmoniform and *Xiphactinus audax* are all examples of taxa whose occurrence here may represent their oldest North American records. Other potential examples of such taxa include *Enchodus* cf. *E. gladiolus*, *Enchodus* cf. *E. petrosus*, *Enchodus* cf. *E. shumardi*, and the Order Anguilliformes. This latter occurrence is remarkable for being roughly contemporaneous with the earliest eels known worldwide (from Lebanon) and thus indicates that by Early to Middle Cenomanian time early eels were already on both sides of the opening Atlantic Ocean.

Although no new taxa are being erected in this study, it is possible, if not likely, that some of the specimens described herein represent undescribed species. Examples include those taxa referred to here as *Archaeolamna* sp., “Cretoxyrhinid A”, “Cretoxyrhinid B”, “Cretoxyrhinid C”, *Carcharias* sp. A, *Carcharias* sp. B, “Teleost A”, and “Teleost B”, as well as the unidentified caturid, the unidentified anguilliform, and the unidentified basal euteleost. The rationale for not describing new taxa is based primarily on the relatively small sample sizes of the elements in question, and due to their highly disarticulated nature. The high degree of disarticulation was particularly problematic with regards to the

identification of actinopterygian fishes that lacked distinctive dental morphologies, whose identification was hampered by a paucity of published comparative data.

The vast majority of the taxa recognized in this study are relatively “typical” components of Late Cretaceous and/or more specifically Cenomanian-aged marine vertebrate paleofaunas from the Western Interior Seaway (e.g. Russell, 1988; Welton and Farish, 1993; Cappetta and Case, 1999; Cicimurri, 2001a, b; Friedman, 2004; Cumbaa et al., 2006; Shimada et al., 2006; Cook, 2007). We can see in fact that all the taxa which occur in the Van der Voort/Little Woody paleofauna also occur in the Pasquia Hills paleofauna (though there are notable differences in abundance, which will be discussed later). Indeed, when comparing the Van der Voort/Little Woody paleofauna against the Pasquia Hills and other Cenomanian-aged paleofaunas from North America, it is the absences of some taxa that are significant. These include *Squalicorax curvatus*, *Carcharias* (a.k.a. *Cenocarcharias* sensu Cappetta and Case, 1999) *tenuiplicatus*, and *Cretodus semiplicatus*. Ptychodontid sharks are absent from the Van der Voort /Little Woody paleofauna, whereas *Ptychodus anonymus*, *P. decurrens*, and/or *P. occidentalis* are not uncommon in other Cenomanian localities from the Western Interior of the United States (e.g. Welton and Farish, 1993; Shimada et al., 2006) or Canada (e.g. Cumbaa et al., 2006; Cook, 2007). In fact, the Van der Voort/Little Woody paleofauna lacks durophagus vertebrates almost entirely, containing only trace remains tentatively identified as being of pycnodontid origin. Conversely, a variety of durophagus fishes including ptychodontids, pycnodonts, plethodonts, and batoids may be variably present in Cenomanian-aged deposits elsewhere (Texas, Welton and Farish, 1993; Cappetta and

Case, 1999; Colorado, Shimada et al., 2006; Saskatchewan, Cumbaa et al. 2006; and Alberta, Cook, 2007); though rays are far rarer and less diverse in the Canadian localities.

Tetrapods are also uncommon in the Van der Voort/Little Woody deposits. Dolichosaurs, mosasauroids (i.e. *mosasauroida incertae sedis*), pliosaurs and polycotylids are known from the Tobe locality in Colorado (Shimada et al., 2006), while the Pasquia Hills bonebeds have been reported to contain lizards, turtles, elasmosaurs, pliosaurs, polycotylids, and even some dinosaur remains (Cumbaa and Tokaryk, 1999). A notable component of other bonebeds studied from the Manitoba Escarpment is also an abundance of fossils derived from a diverse assemblage of birds: a minimum of five species of early avians are known from the Pasquia Hills bonebeds, representing the oldest diverse avifauna known in North America (Tokaryk et al., 1997). However, no avian remains have yet been discovered amongst the samples collected from the Van der Voort or Little Woody River localities.

While comparisons against the Tobe, Pasquia Hills and Watino localities are valuable, those deposits are believed to be of a slightly younger Cenomanian age than the Van der Voort and Little Woody River deposits. As the bonebeds from these localities lie within the fish scale marker beds as recognized in the Manitoba Escarpment by McNeil and Caldwell (1981), comparison with the paleofauna of the correlative Fish Scales Formation of central Saskatchewan and the proposed Fish Scales Member of the Shaftesbury Formation in the northwestern plains of Alberta (sensu Bloch et al., 1993) is essential and informative. In the description of fauna from horizons correlative with the Fish Scales Formation found within the Shaftesbury Formation in the northwestern plains of Alberta by Leckie et al. (1992), the most abundant vertebrate recognized is the small

teleost *Osmeroides transversus*. Also identified from their samples are remains assignable to the Ichthyodectidae, Enchodontiformes, and ichthyosaurs. Also known from the Fish Scales is a new species of acanthomorph teleost, *Xenyllion zonensis*, which is the oldest known acanthomorph (spiny-rayed) teleost from North America (Wilson and Murray, 1996).

As mentioned briefly in the “Systematic Paleontology” section, some of the unidentified teleost remains described and figured by Leckie et al. (1992) appear similar to the basal euteleost described in this study, and the evidence for the presence of enchodontoids and ichthyodectids among the inoceramites studied here is well founded. However, evidence of neither *Osmeroides transversus* nor *Xenyllion zonensis* was detected among the Van der Voort vertebrate remains. Another very notable difference between the western paleofauna of Leckie et al. (1992) and the eastern one described herein is the complete absence of chondrichthyans from the former, compared to their relative abundance and diversity in the latter. The differences then, between the paleofauna of the fish scale marker beds of the Manitoba Escarpment (as observed at the Van der Voort farm and Little Woody River localities) and the proposed Fish Scales Member of the Shaftesbury Formation of the northwestern plains of Alberta are far greater than those between the former and the later Cenomanian paleofauna of the Manitoba Escarpment known from the Pasquia Hills.

Indeed, the paleofauna of the “fish scales member” of the Shaftesbury Formation (described by Leckie et al., 1992) is, if anything, far more akin to that described from the Mowry Shale in Utah (e.g. Stewart et al., 1994; Anderson and Kowallis, 2004) and Wyoming (e.g. Vuke, 1984; Stewart and Hakel, 2006). Stewart and Hakel (2006) list

primitive ichthyodectiforms, ichthyodectoid ichthyodectiforms, *Enchodus*, and *Xenyllion* sp. among the vertebrates collected from pelagically-deposited, fine-grained sediments of the Mowry Shale near Casper, Wyoming. Furthermore, two species of the teleost fish *Holcolepis* named from the Mowry Shale on the basis of scales (Cockerell, 1919) are argued by some (Cumbaa and Murray, in press) to belong in fact to the genus *Osmeroides*. *Osmeroides* sp. is also described among taxa from the Mowry Shale in Wyoming in the earlier work of Vuke (1984), along with the ichthyodectid *Gillicus* sp. and the ichthyosaur *Platypteryginus americanus*. All Cretaceous ichthyosaur material from North America has been assigned to this latter taxon, which has been listed among marine reptiles from the Mowry Shale based on fragmentary evidence by others as well (e.g. Massare and Dain, 1989). Evidence now exists that a second species lived in North America as well, at least in the northern-most reaches of the seaway in what is now the Northwest Territories (Maxwell and Caldwell, 2006). In Utah, Stewart et al. (1994) mention the presence of a possible plesiosaur, a possible crocodylian, ichthyodectiform and alepisauroid teleosts including *Enchodus*, and an early sphenoccephalid paracanthopterygian (hypothesized by the authors to be of the genus *Xenyllion*). Anderson and Kowallis (2004) describe lensoid “pods” of concentrated fish teeth, bones, scales and microcoprolites from outcrops of the Mowry Shale near Vernal, Utah, and note that *Enchodus* is particularly abundant, while teeth of the lamniform shark *Carcharias amonensis* were also among those recovered. Chondrichthyans are, in fact, quite rarely mentioned among marine vertebrates from the Mowry Shale, and the most diverse assemblage, described from South Dakota, includes only four taxa: *Hybodus* sp., *Cretodus semiplicatus*, *Carcharias amonensis*, and a sawfish, *Onchopristis dunklei*

(Cicimurri, 2004). These vertebrate assemblages demonstrate a clear resemblance to the “fish scale marker bed” of the Shaftesbury Formation.

In Wyoming and Montana, the Mowry Shale is conformably bounded by the Arrow Creek Bentonite (which has yielded an $^{40}\text{Ar}/^{39}\text{Ar}$ date of 98.52 ± 0.41 Ma) below and the Clay Spur Bentonite (which has yielded an $^{40}\text{Ar}/^{39}\text{Ar}$ date of 97.17 ± 0.69 Ma) above (dates from Obradovich, 1993; stratigraphy from Porter, 1998). The position of the Albian-Cenomanian boundary is controversial, and as such the Mowry Shale is placed by some workers entirely within the Late Albian (Warren and Stelk, 1969; Obradovich and Cobban, 1975; Stelk, 1975; Davis and Byers, 1993; Oboh-Ikuenobe et al., 2007), and others place it either partially or entirely within the Early Cenomanian (Hancock et al., 1993, Obradovich, 1993; Cobban and Kennedy, 1998). Obradovich’s (1993) definition of the Cenomanian Age was from 98.5 ± 0.5 to 93.3 ± 0.2 Ma based on $^{40}\text{Ar}/^{39}\text{Ar}$ chronostratigraphic and molluscan biostratigraphic methods. Considering that a bentonite associated with the base of the Fish Scales Formation has yielded an $^{40}\text{Ar}/^{39}\text{Ar}$ date of 97.59 Ma (Ridgley et al., 2001), it seems likely that the Mowry Shale is temporally correlative, at least in part, with the base of the Shaftesbury Formation in the northwestern plains of Alberta, the Fish Scales Formation in central Saskatchewan, and the Belle Fourche Member of the Ashville Formation in the Manitoba Escarpment. The latter correlation is contrary to McNeil and Caldwell’s (1981) interpretation that the Westgate Member of the Ashville Formation, which underlies the Belle Fourche Member, is homotaxic with the Mowry Shale.

Regardless of the exact chronostratigraphic position of the Albian-Cenomanian boundary, however, the ichthyofauna from the fish scales bed near the base of the

Shaftesbury Formation undeniably compares more favorably with the Mowry Shale ichthyofauna than it does with that described herein from McNeil and Caldwell's (1981) "fish scale marker beds" in the Manitoba Escarpment. There are two potential explanations for these faunal differences. The first is a biogeographic explanation, proposing two separate faunas. The majority of the localities from which the Mowry Shale is described above, as well as the locality from which the fauna of the basal Shaftesbury Formation was described, are all located closer to the western margin of the WIS, contrasting the position of the Manitoba Escarpment near the eastern margin. Any number of factors potentially differentiating the paleoecological conditions of the eastern and western margins could be hypothesized, including, but not limited to, differing sedimentation rates (e.g. McNeil and Caldwell, 1981; Stott, 1984; Leckie and Rosenthal, 1986) or the differences generated by circulation patterns within the seaway (e.g. Wright, 1984). The second explanation is of biostratigraphic nature. The diversity and composition of the chondrichthyan fauna, for example, known from the siliciclastically starved Pasquia Hills bonebeds is quite readily comparable to that of the clastic wedge that is the stratigraphically higher (middle Cenomanian) Dunvegan Formation in northwestern Alberta (Cook, 2007), as well as to similarly-aged chondrichthyan faunas in Colorado (Shimada et al., 2006) and Texas (Welton and Farish, 1993; Friedman, 2004). At this stratigraphic level the widespread similarities of the vertebrate faunas places the Van der Voort inoceramite fauna in the middle Cenomanian. Faunal differences between these two bioclastic accumulations might be explained by the changing paleogeography of the WIS. The bioclastic conglomerate of the basal Shaftesbury Formation, representing fishes that lived in the Mowry Sea, closed to Tethyan influence. In contrast, the fauna of

the Van der Voort bioclastic accumulations resembles a Greenhorn Sea assemblage, influenced by sea-level rise and Tethyan-influence (Schröder-Adams et al., 1996).

Paleoecological Interpretations

There is no doubt that the taphonomic and diagenetic features of the Van der Voort inoceramites indicate that a certain degree of time-averaging took place during their deposition, and that the taxa listed above cannot simply be seen as a “snapshot” of a once living ecosystem. However, the evidence supporting the interpretation that these deposits experienced only moderate to minimal amounts of transport and reworking permits the paleofauna to be assessed as a “within-habitat time-averaged assemblage” (Kidwell and Bosence, 1991). This type of fossil assemblage consists of a mixture of many generations originating from a “single, temporally persistent community over a period of relative environmental stability” which can represent accumulation over years to thousands of years (Kidwell and Flessa, 1996). In comparing the lower overall concentration of vertebrate fossils, the smaller clast sizes, the lower degree of abrasion, and the signs of early cementation observed in the Van der Voort inoceramites with the bone-biophospharenites from the Bainbridge River (both BR-3 and BR-1), the Carrot River, and the Thunder Hill localities, it appears likely that the Van der Voort inoceramites may contain the least time-averaged Cenomanian vertebrate assemblage yet collected and described from the Manitoba Escarpment.

In agreement with Cumbaa et al. (2006), this study confirms that both bony fishes and sharks are more diverse and abundant in northern waters during the Early to Middle Cenomanian than previously recognized. During the Middle through Late Cretaceous, the North American climate was warmer than at present and was at least seasonally humid

(e.g. Glancy et al., 1993). A “north equals cooler” generalization being usually quite safe in relation to global climatic patterns, it may be something of an oversimplification regarding the temperatures in the Western Interior Seaway during the Cenomanian. Preliminary oxygen isotope data from fossil fish teeth indicate warmer paleotemperatures in the Western Interior Seaway during the Cenomanian in Saskatchewan than in the Santonian and Campanian in Kansas and Alabama, respectively (Munro, 2000). More recently, a large oxygen isotope study of fossil fish teeth by Pucéat et al. (2003) indicated a thermal optimum in Cenomanian oceans, with lower latitudinal thermal gradients than today. Therefore, the high diversity of fishes at the Van der Voort locality is likely due, at least in part, to this warmer climate; elasmobranchs in particular would benefit from these warmer conditions (see Compagno, 1984 for modern shark distributions). Results from Cenomanian bonebeds in Canada are in contrast to previously described vertebrate faunas of the northern part of the Western Interior Seaway interpreted to have lived in mild- to cool-temperate conditions during Coniacian through Maastrichtian time. These assemblages are described as being of low diversity in all groups; dominated by plesiosaurs, hesperornithiforms, and the mosasaur genus *Platecarpus*, with rare turtles and sharks (Nicholls and Russell, 1990).

All of the specimens examined from the Van der Voort locality consist of completely disarticulated and fragmented teeth, bones and scales, and as such direct evidence of paleoecological dynamics is virtually non-existent. The only exception is the relatively common microcoprolites that contain vertebrate inclusions (e.g. Plate XI, Fig. 7), however, these are of relatively uncertain origin. Nevertheless, the diversity of

vertebrates recognized at the Van der Voort locality implies that the paleofauna possessed diverse life habits, and were connected via complex trophic relationships.

The most conspicuous vertebrates, in terms of size, at the Van der Voort locality are primarily “large” macrophagous carnivores. Examples include cretoxyrinid sharks, “crow sharks” of the genus *Squalicorax*, the bizarre pachycormiform *Protosphyraena*, the giant teleost *Xiphactinus*, and the plesiosaur *Brachauchenius* (all have estimated total body lengths of 1.5 m or greater). All have been putatively described as predators (or in the case of *Squalicorax*, as a scavenger; Druckenmiller et al., 1993) of other vertebrates. These taxa are believed to consume prey such as chondrichthyans, osteichthyans, marine turtles, mosasaurs, plesiosaurs, marine birds, and occasional “bloat-and-float” carcasses of terrestrial vertebrates washed out to sea (e.g. Bardack, 1965; Schwimmer et al., 1997a; Shimada, 1997; Cicimurri and Everhart, 2001; Everhart et al., 2004; Shimada and Everhart, 2004; Everhart and Hamm, 2005). While no direct evidence of such trophic relationships between large predators and/or scavengers and their prey were observed in this study, it is likely that predator-prey relationships similar to those inferred from other faunas from the Western Interior Seaway would exist at the Van der Voort locality.

The majority of vertebrates from the Van der Voort locality, meanwhile, are “small” macrophagous carnivores (with estimated body lengths of less than 1.5 m). These include small sharks of the genus *Carcharias* and bony fishes such as *Elopopsis*, and *Enchodus*, which are considered to have been piscivorous (e.g. see Campagno, 1984; Shimada and Everhart, 2003). The abundance of fossil specimens collected for each taxon may not necessarily reflect each taxon’s original abundance in the paleoenvironment due to numerous variables, including inter- and intraspecific tooth

count variations (Shimada et al., 2006) and the differing preservation potential of different skeletal structures among and between taxa (Kidwell and Flessa, 1996). This being considered, it would still be difficult to conclude that *Enchodus* was not a common component of the paleofauna considering the abundance of *Enchodus* teeth among those fossils recovered from the Van der Voort locality. *Enchodus* is interpreted to have likely been a pelagic predator (Goody, 1969), as well as an important food base for other marine vertebrates, having been found in the preserved stomach contents of pachyrhizodontid fishes (e.g. Shimada and Everhart, 2003), anacoracid sharks (Shimada et al., 2006) and plesiosaurs (Cicimurri and Everhart, 2001). Considering the abundance of *Enchodus* teeth among vertebrate bioclastic concentrations in the Western Interior Seaway (e.g. Anderson and Kowallis, 2004; Friedman, 2004; Cumbaa et al., 2006; Shimada, 2006; Shimada et al., 2006), it seems clear that *Enchodus* was an important link in the complex food web of these Cretaceous waters.

A group of vertebrates that are conspicuously absent are those vertebrates that are inferred to have been durophagous. As previously mentioned, ptychodontids, batoids, pycnodonts and possibly plethodonts are all forms with crushing, pavement-like dentitions known from the Western Interior Seaway of both Canada and the United States (e.g. Welton and Farish, 1993; Cappetta and Case, 1999; Shimada et al., 2006; Cumbaa et al. 2006; Cook, 2007). Ptychodontids are commonly viewed as benthic elasmobranchs, and are interpreted to have been predators of ostreid and inoceramid bivalves, and possibly cirripeds (Kauffman, 1972; Stewart, 1988a; Hattin, 1996). Pycnodonts, meanwhile, were deep-bodied osteichthyans that apparently fed on shelled invertebrates such as bivalves and echinoderms (Nursall, 1996). While batoids are believed to have been less diverse in

the northern parts of the Western Interior Seaway (Cook, 2007), the dearth of ptychodontids and pycnodonts is somewhat enigmatic considering the apparent abundance of inoceramids and ostreids (i.e. *Ostrea dunveganensis*) at the Van der Voort locality. Pycnodonts are in fact only tentatively included in the list of taxa from the Van der Voort locality on the basis of very fragmentary material. This lack of durophagous fishes at the Van der Voort locality may simply be due to insufficient sampling, though it is also possible to speculate that it may be due to prevalent dysoxic bottom waters excluding them from preying on the benthic inoceramids and ostreids. Many inoceramids are believed to have been adapted to live in dysoxic bottom water conditions (e.g. Kauffman, 1990; MacLeod and Hoppe, 1992; Sageman and Binna, 1997; Kauffman et al., 2007). Poorly developed benthic foraminiferal assemblages in these Cenomanian mudstones and shales have been linked to anoxic and dysoxic bottom water conditions (Schröder-Adams et al., 1996; Schröder-Adams et al., 2001).

Another “group” of osteichthyan taxa preserved in relative abundance at the Van der Voort locality are particularly “small” fishes such as the unidentified basal euteleost, the unidentified anguilliform, and the unidentified caturid. Most North American Cretaceous marine teleosts consist of relatively large-sized taxa, such as the ichthyodectids, the pachyrhizodontoids, and large enchodontids (Russell, 1988). Unlike in Tethyan ichthyofaunas (e.g. in the Cenomanian of Lebanon; Forey et al., 2003), there are relatively few small-sized fossil fishes represented in North America (Stewart, 1996). This study represents one of a growing number from the Western Interior of North America (e.g. Waldman, 1969; Wiley and Stewart, 1981; Stewart, 1984; Leckie et al., 1992; Stewart et al., 1994; Fielitz, 1996; Cumbaa and Tokaryk, 1999; Fielitz, 2002;

Friedman, 2004; Cumbaa et al., 2006; Shimada et al., 2006; Stewart and Hakel, 2006; Cumbaa and Murray, in press) which sheds more light on those fishes which likely occupied lower positions in the ancient food web than the megafauna for which the Western Interior Seaway is more popularly known (e.g. see the cretoxyrhinid, anacoracid, ichthyodectid, mosasaur and plesiosaur stars of the 2007 film “Sea Monsters: A Prehistoric Adventure”). These smaller fishes, including the unidentified basal euteleost, the unidentified anguilliform, and the unidentified caturid, though present at localities such as the Bainbridge River (BR-3) locality, are likely under-represented there due to preservational (i.e. taphonomic) biases against fossils of that size and fragility. The taphonomic and diagenetic processes leading to the preservation of the Van der Voort inoceramites, meanwhile, worked to better preserve these smaller, more delicate skeletal elements. Interestingly, one possible paleoecological link between these species may be their preservation along-side abundant inoceramid-derived calcite prisms.

Bivalves of the extinct family Inoceramidae are preserved in a wide variety of facies beginning in the Permian (Kauffman and Runnegar, 1975; Crampton 1988) and ending in the mid-Maastrichtian (Dhondt, 1983; MacLeod and Orr, 1993). Many species were capable of growing to large sizes (e.g. specimens of *Platyceramus platinus* would commonly grow to over a metre in length along the growth axis, and could rarely exceed two and three metres in length; summarized in Kauffman et al., 2007) and, when the characteristic outer layer of their valves disaggregated, could produce in excess of 10^8 foraminiferal-sized (~ 0.1 mm diameter) polygonal prisms of calcite (MacLeod and Orr, 1993). Additionally, inoceramids are often the dominant to exclusive macrofossils in strata that are interpreted to have been deposited in inhospitable dysoxic bottom waters

and found in bathyal to abyssal sedimentary rocks sampled by the Deep Sea Drilling Project (MacLeod and Hoppe, 1992). Stewart (1984) described assemblages of fossil fishes from the Upper Cretaceous Chalks of Kansas (specifically the Fairport Member of the Carlile Formation and the Smoky Hill Chalk of the Niobrara Formation) where groups comprised of up to 100 fishes and/or three separate species would be preserved within the mantle cavity of a single inoceramid. Based on the distribution of these and other fossil fish species, within and without of inoceramid valves preserved in the chalks, Stewart (1984) argued that these associations were not taphonomic artifacts but rather evidence that these small fishes were commensal symbionts with the inoceramids that would take shelter between their living valves, possibly by night. While the assemblages of fishes described by Stewart (1984) are comprised largely of halecostome fishes, they also include the halecomorph *Paraliodesmus* (similar to the unidentified caturid) and the only formally named species of North American Cretaceous eel, *Urenchelys abditus*. The basal euteleost, the anguilliform, and the caturid are all fishes which would likely not have surpassed 15 cm in total length (based on comparisons with related taxa, listed in "Systematic Paleontology" above) and considering the abundance of large predators in the Western Interior Seaway, the benefit of such behavior is obvious. Nilsson and Östland-Nilsson (2004) reported on 31 species of modern coral reef fishes from the Australian Great Barrier Reef that could maintain their rate of oxygen consumption in relatively severely oxygen-depleted waters and speculated that this may be of benefit to these small species in permitting them to hide from predators at night, deep within the reef, in microenvironments that would become hypoxic due to coral respiration. While it is pure speculation, it is interesting to note that such symbiotic relationships have been

proposed for small fishes and inoceramids elsewhere in the Western Interior Seaway, and that low bottom water oxygenation may not only have limited or inhibited durophagous predation of the inoceramids themselves, but it may also have created dysoxic refugia for small fishes sheltering between their valves.

As the last of the ichthyosaurs vanished (Russell 1988, 1993) and the earliest mosasauroids began to appear (Bell and Vonloh, 1998; Vonloh and Bell, 1998; Shimada et al., 2006), the Cenomanian Age was the backdrop for a significant increase in the abundance and diversity of non-hybodontid euselachians as they spread out over much of the globe (Russell, 1993; Williamson et al., 1993; Pervushov et al., 1997). This study contributes, among other things, to a trend recognized by Shimada et al. (2006) in the literature towards a growing number of recent studies pertaining to pre-Turonian Cretaceous elasmobranch assemblages (e.g. Cicimurri, 2001a, 2001b; Cumbaa et al., 2006; Shimada et al., 2006; Cook, 2007) indicating that elasmobranchs were achieving high diversity by the Middle Cenomanian in the Western Interior Seaway. Results of this study and others (e.g. Cumbaa et al. 2006) demonstrate that bony fish abundance and diversity, particularly teleosts, has also been underestimated. This study also further contributes to a growing number of studies (e.g. Cumbaa and Tokaryk, 1999; Cumbaa et al., 2006; Cook, 2007) challenging the theory that the Cretaceous marine vertebrate paleofauna of the Western Interior Seaway in Canada can be characterized by, among other factors, a rarity of sharks (as per the Northern Interior Faunal Subprovince proposed by Nicholls and Russell, 1990).

Paleoenvironmental Interpretations

The Van der Voort inoceramites are comprised primarily of sand-sized calcite prisms derived from the disaggregated outer layer of the shells of inoceramid bivalves, in addition to abundant phosphatic vertebrate fossils (bones, teeth, and scales) and ichnofossils (microcoprolites). Disarticulated valves of the oyster *Ostrea dunveganensis* are also common. In the Van der Voort inoceramites, the preservation of numerous, seemingly undeformed microcoprolites indicates a continuous rain of biogenic sediment to the sea floor in relatively quiet water and without the disturbance of detritivores or bioturbators. The concentration of vertebrate fossils and ichnofossils, along with the rarity of siliciclastic components, suggests a relatively long period of deposition in an environment deprived of terrigenous input. Large vertebrate clasts are relatively few, while smaller, more delicate elements (e.g. cranial and mandibular elements of small teleosts, anguilliform vertebral elements) are preserved in greater relative abundance than in the phosphatic bonebeds found elsewhere along the Manitoba Escarpment.

The concentration of bioclasts, coupled with evidence of physical abrasion, hydraulic sorting, and the minimal time spent in the sulfate reduction zone, is consistent with a dominantly parautochthonous ("an assemblage composed of autochthonous specimens that have been reworked to some degree but not transported out of the original life habitat"; Kidwell et al., 1986), or within-habitat time-averaged (Kidwell and Bosence, 1991) assemblage. Though amalgamated and perhaps reworked, the Van der Voort inoceramites are comparatively less so (and are thus less time-averaged) than other vertebrate-rich bioclastic accumulations examined from the Manitoba Escarpment.

The biogenic constituents of the Van der Voort and Little Woody River inoceramites appear to have been derived from the slowly accumulating rain of nektonic vertebrate bones, teeth, scales and fecal pellets into a benthos dominated by a severely limited bivalve community comprised predominantly of inoceramids and the oyster *Ostrea dunveganensis*. The limited diversity of benthic bivalves is suggestive of stressed ecological conditions. The affinity of inoceramid bivalves for dysoxic facies (e.g. Kauffman, 1990; MacLeod and Hoppe, 1992; Sageman and Binna, 1997; Kauffman et al., 2007), together with authigenic pyrite precipitation within preserved inoceramid prisms, suggests that this stress was largely due to low oxygen conditions at or near the sediment water interface. This would be consistent with the Belle Fourche Member of the Ashville Formation in the Manitoba Escarpment at large: finely laminated shales and bentonitic clays deposited under relatively low energy conditions with negligible siliciclastic input and low to negligible oxygen concentrations in bottom waters (e.g. McNeil and Caldwell, 1981; Schröder-Adams et al., 1996; Schröder-Adams et al., 2001).

While some taxa, such as the lamniform shark *Carcharias amonensis*, have been interpreted as preferentially inhabiting shallow, inshore marine waters (Welton and Farish, 1993), the apparent absence of hesperornithiforms common to northern Western Interior Seaway waters (e.g. Nicholls and Russell, 1990; Tokaryk et al., 1997; Cumbaa et al., 2006), combined with the above mentioned taphonomic and diagenetic evidence, argues against the interpretation of these sediments originating in a nearshore, possibly lagoonal paleoenvironment as with the Bainbridge River (BR-3) and Carrot River bonebeds (Schröder-Adams et al., 2001; Cumbaa et al., 2006). Indeed, it seems more

likely that these biogenic sediments originated somewhat further from shore, in a more middle shelf-like environment, beneath storm wave base.

Before final burial, however, the biogenic clasts comprising the Van der Voort inoceramites underwent a certain amount of transport. Numerous authors have described calcarenites interbedded with mudstone beds of variable thickness, comprised principally of fine silt to medium sand-sized calcitic inoceramid prisms and Ca-phosphatic fish debris (bone fragments, scales and teeth) with secondary amounts of silt to fine-sand sized quartz grains, pyrite framboids, and phosphatized coprolites from the Late Cretaceous (Middle/Upper Cenomanian to Lower Turonian) Greenhorn Limestone in the Western Interior of the U.S. (e.g. Cobban and Scott, 1972; Kauffman, 1977; Hattin, 1975, 1986; Sageman, 1996).

Sedimentological, paleoecological, and stratigraphic features of these skeletal limestones have led to the interpretation that these deposits represent tempestites that formed in response to impingement by storm wave base during relative sea-level fall in the basin (Sageman, 1996). The depositional model proposed by Sageman (1996) involves a two-step process: (1) during sea-level fall bottom muds are eroded and winnowed, and skeletal material accumulates; a process which would have been most effective on the cratonic, eastern side of the basin, away from the diluting influence of siliciclastic sources, and was hypothesized to have been mainly driven by storms. (2) With subsequent sea-level rise, storm processes would continue to rework and transport skeletal material deeper into the basin, while relatively few, large storms would influence the deeper parts of the basin. Applying sequence stratigraphic terminology, Sageman

(1996) interpreted these skeletal limestone packages to correspond to lowstand and early transgressive systems tracts.

Biogenic clasts (both calcitic and phosphatic) are randomly oriented to slightly cross-stratified within the lensoid inoceramites at both the Van der Voort and Little Woody River localities, and the abrasion and hydraulic sorting profiles indicate significant physical transport and/or reworking (though comparatively less than the other bone-biophospharenites examined from the Manitoba Escarpment. At the Little Woody locality, contacts between the inoceramite horizons and the enveloping shales were observed to be sharp, and some vertebrate-derived clasts within the Van der Voort (e.g. Fig. 16b) show signs of having possibly been ripped-up from clay-rich facies. Though the exact relationship between the inoceramites at the Van der Voort locality and the enveloping shales of the Belle Fource Member of the Ashville Formation are not known, a depositional model akin to that described by Sageman (1996) for the tempestite deposition of skeletal limestones seems the most plausible explanation for these bioclastic concentrations. This would not be altogether different from the depositional model proposed for the bone-biophospharenite deposits at the Bainbridge and Carrot River localities (Schröder-Adams et al., 2001; Cumbaa et al., 2006), where the bonebeds are attributed to amalgamation of bioclasts on the sea floor during early transgression following a drop in sea level and/or as the result of marine erosion events.

The inoceramite horizon at the Little Woody River locality, though not the primary focus of this study, provides a proxy due to preserved column of sediments, by which the depositional history of the Van der Voort inoceramites may be illustrated. The dark shales above and below the Little Woody inoceramites represent what could be

considered the “normal” background sedimentary regime of the Belle Fourche Member of the Ashville Formation: slow deposition of fine mud and clay particles (McNeil and Caldwell, 1981) amidst oxygen-depleted bottom waters (Schröder-Adams, 1996; Schröder-Adams, 2001). The shales are barren of benthic foraminifera, but do contain abundant algal cysts, inoceramid-derived calcite prisms, and fish bone, scale, and tooth fragments disseminated throughout (Schröder-Adams, pers. comm., 2007).

These low energy, oxygen-depleted bottom waters supported only a limited epifaunal community (inoceramids and *Ostrea dunveganensis*), and vertebrate bones, scales and teeth, as well as microcoprolites, slowly accumulated on the sea-floor over a relatively long time period. An eventual lowering of sea-level, however, would bring these quiet bottom waters within the range of infrequent, storm-generated wave activity, disrupting water stratification. These waves would have transported the bioclasts basinward, concentrating them as the finer clay and mud particles drifted away. The resulting deposit, which may have settled into pre-existing depressions on the sea-floor (locally expressed as lenses), was a randomly oriented mix of disarticulated bioclastic debris, identical in composition to the assemblage disseminated throughout the enveloping shales, only more concentrated. The newly deposited bioclastic concentrate may have been reworked by subsequent storm waves; however, it is unlikely that these were frequent, as evidenced by the well-preserved microcoprolites. This episodic disruption of water mass stratification was also short-lived, indicated by lack of bioturbation or epifaunal colonization of the bioclastic concentrate. Finally, the shales above the inoceramite horizon represent a return to “normal” fine-grained background sedimentation in oxygen-depleted bottom waters.

Sea level changes are known to have been frequent in the Middle to Upper Cenomanian and into the Turonian (e.g. Laurin and Sageman, 2007; Plint and Kreitner, 2007). For the early-Late Cenomanian strata of the Doe Creek unit at the base of the Kaskapau Formation in northwestern Alberta and northeastern British Columbia, Plint and Kreitner (2007) estimated vertical relative sea level excursions of approximately 10 metres for thirteen sequences, each representing cycles spanning a maximum time range of 9 to 74 thousand years. Sea level changes of up to ten metres would have had a pronounced effect on the depth of the Western Interior Seaway over great tracts of the eastern margin, where the average depositional gradient towards the basin centre would have been negligible ($\ll 1^\circ$; Sageman and Arthur, 1994). Sea level changes of similar magnitude in the early Middle Cenomanian, however frequent, may be responsible for the deposition of the Van der Voort inoceramites. Sageman (1996) further illustrated that these lowstand tempestites can be correlated westward from condensed, comparatively unconformity-riddled eastern strata to coarse, basinward-prograding clastic wedges in several regions. With further research and detailed subsurface correlations, the inoceramites of the "fish scale marker beds" of the Belle Fourche Member of the Ashville Formation in the Manitoba Escarpment have the potential to become useful sequence stratigraphic tools in recognizing the timing and magnitude of sea-level changes in the fine-grained, mud-dominated and unconformity-riddled strata of the northeastern Western Interior Seaway.

CONCLUSIONS

The Manitoba Escarpment preserves the erosional margin of the Western Interior Seaway in Canada, and outcropped along its length are numerous Cenomanian-aged horizons remarkable for their concentration of vertebrate skeletal material. The calcarenites ("inoceramites") collected from the newly described Van der Voort and Little Woody River localities are interpreted as early Middle Cenomanian in age on the basis of comparisons against published descriptions of the strata of the Manitoba Escarpment, as well as molluscan and vertebrate biostratigraphy. These bioclast-rich samples contain, in addition to abundantly preserved inoceramid bivalve-derived calcite prisms, a minimum of twelve chondrichthyan taxa, thirteen osteichthyan taxa, and two reptilian taxa, which collectively represent the earliest truly diverse fauna known from Cenomanian-aged strata in Canada. For several taxa their presence represents the oldest known occurrence in North America; the most notable being what is likely the oldest evidence of eels from this continent. The fauna represents a diverse community of vertebrates which would have interacted with one another through complex trophic relationships.

The synthesis of taphonomic data collected from the Van der Voort samples indicates that the bioclasts were concentrated by physical processes such as winnowing by storms in the siliciclastically-starved setting of the eastern margin of the Western Interior Seaway. The Van der Voort bioclasts were transported, winnowed, and reworked to a lesser degree than the bone-biophospharenites known from the Pasquia Hills, and are therefore interpreted to have been initially deposited relatively further offshore than these latter bonebeds, beneath storm wave base. The greater distance to paleoshorelines is

supported by the lack of typical marginal marine faunal elements. Comparison against other bioclastic concentrations from along the Manitoba Escarpment reveals that variability in the amount of inoceramid-derived prismatic calcite buried along with the concentrated vertebrate bioclasts may have affected the timing of cementation, and thus effected the amount of reworking, pyritization and compaction that the deposits would ultimately undergo. This, in turn, affects the quality of preservation of the vertebrate remains.

The Van der Voort inoceramites are believed to have been deposited as the result of storms (i.e. as tempestites) impinging on the extremely shallowly sloping sea floor of the eastern margin of the Western Interior Seaway during one of the frequent Cenomanian sea-level oscillations. Similar deposits were found in the Greenhorn Limestone of the United States, where skeletal limestones were interpreted as tempestites deposited during sea-level lowstands or early transgressive phases. With further research, deposits such as the Van der Voort and Little Woody River inoceramites may become useful tools in interpreting the sea-level history of the unconformity-riddled strata of the Manitoba Escarpment, and in better understanding its relationship with the history of the basin as a whole.

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PLATES

PLATE I

Figure 1: *Hybodus butleri* tooth (MM V-2923), labial (left) and lingual (right) views.

Figure 2: *Ptychodus* cf. *P. decurrens* tooth (P 3015.1), occlusal (left), labial (centre, top), lingual (centre, bottom) and basal (right) views. Specimen collected as float from along the Bainbridge River between localities BR-3 and BR-2 locality.

Scale bars equal 2 mm

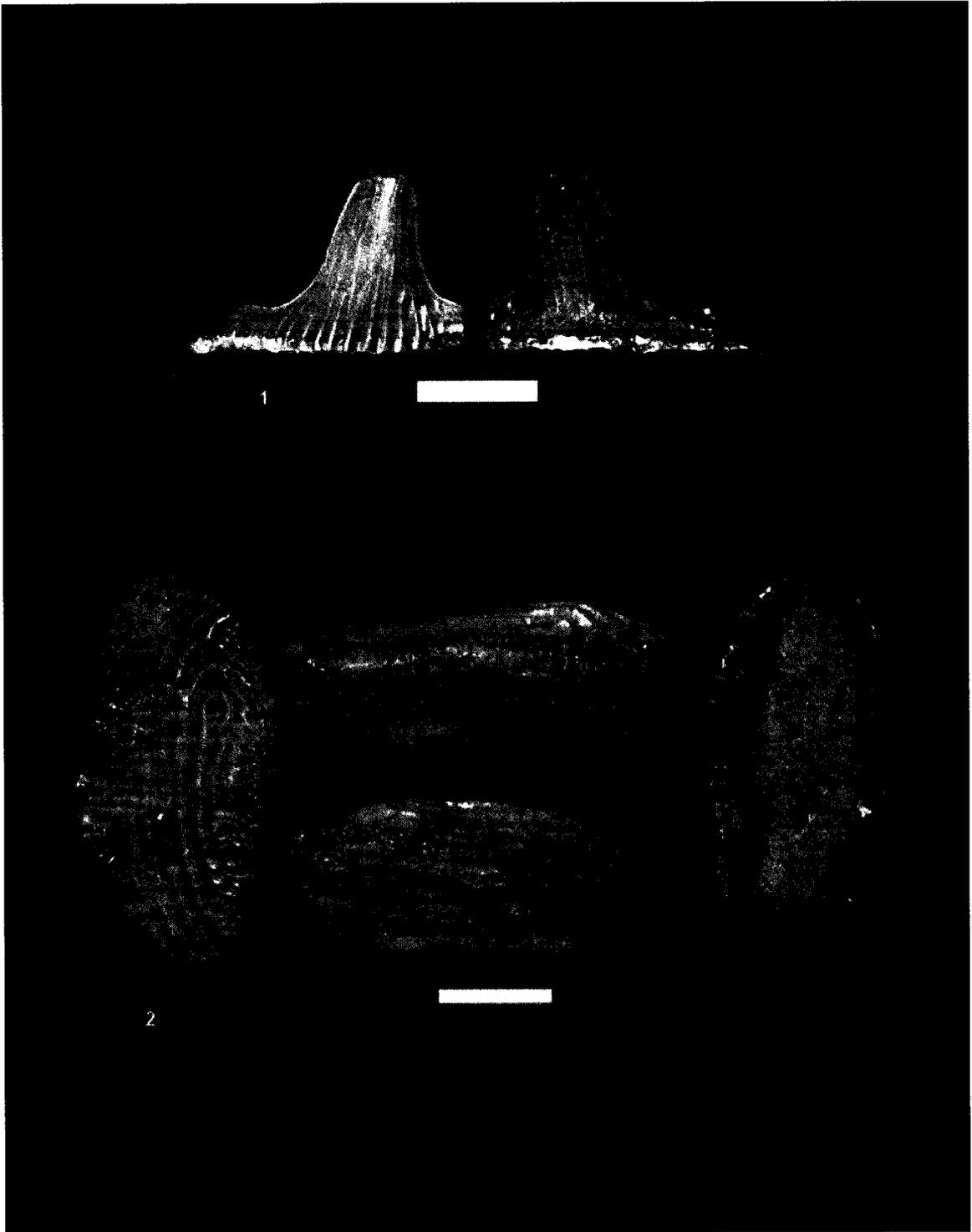


PLATE II

Figure 1: *Squalicorax volgensis* right(?) anterior tooth (MM V-2924), lingual (left) and labial (right) views

Figure 2: *Squalicorax volgensis* left parasymphyseal(?) tooth (MM V-2925), lingual (left) and labial (right) views

Figure 3: *Squalicorax volgensis* right anterolateral tooth (MM V-2926), lingual (left) and labial (right) views

Figure 4a: *Squalicorax volgensis* left anterolateral tooth (MM V-2927), lingual (top) and labial (bottom) views.

Figure 4b (inset): *Squalicorax volgensis* left anterolateral tooth (MM V-2927) - magnification of irregular serrations

Figure 5: *Squalicorax volgensis* right lateral tooth (MM V-2928), lingual (left) and labial (right) views

Figure 6: *Squalicorax volgensis* left lateral tooth (MM V-2929), lingual (left) and labial (right) views

Figure 7: *Squalicorax falcatus* left anterolateral tooth (MM V-2930), lingual (left) and labial (right) views

Figure 8a: *Squalicorax falcatus* broken anterolateral tooth (MM V-2931), lingual (left) and labial (right) views

Figure 8b (inset): *Squalicorax falcatus* broken anterolateral tooth (MM V-2931) - magnification of serrations

Scale bars equal 2 mm

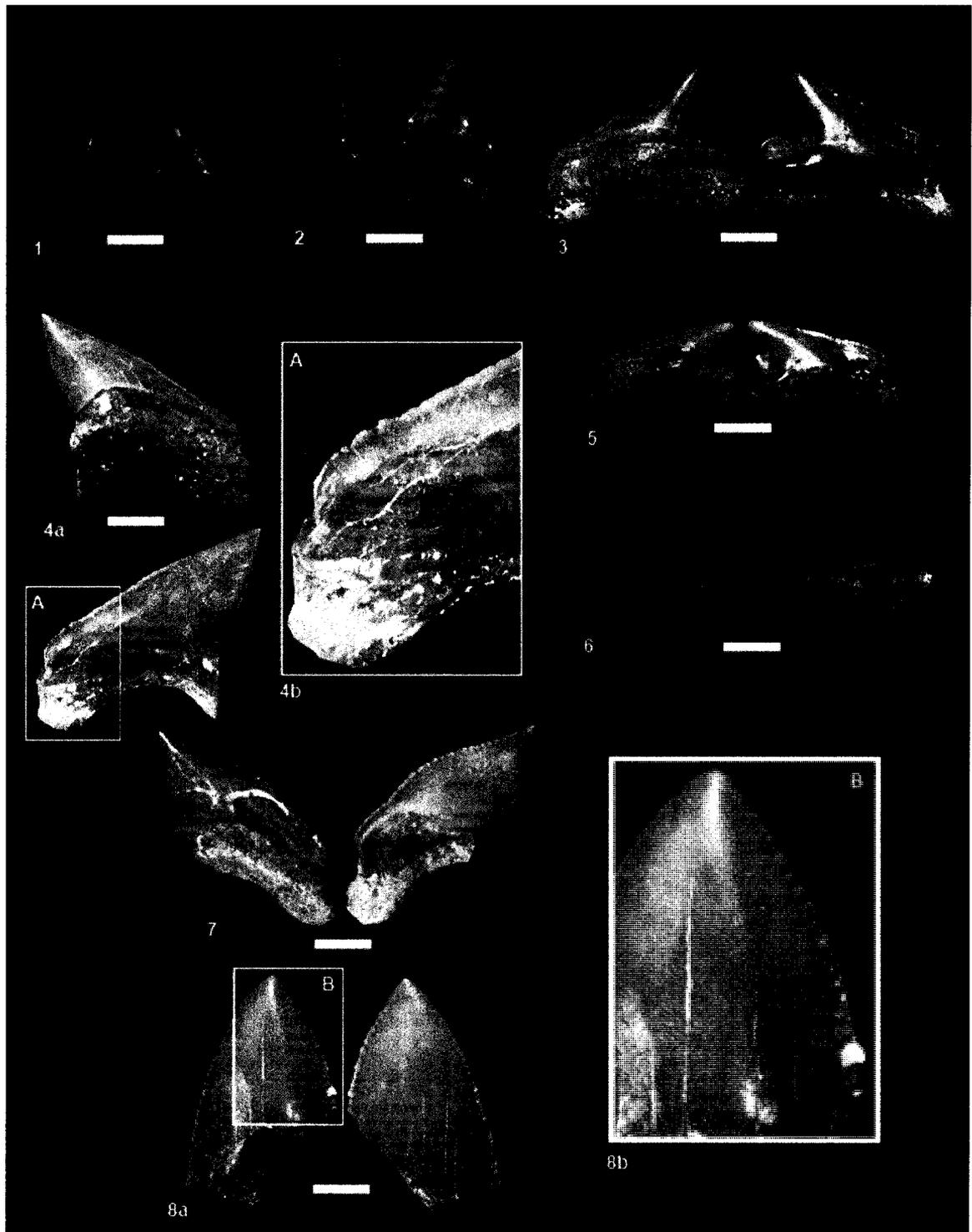


PLATE III

Figure 1: *Archaeolamna* sp. left parasymphyseal tooth (MM V-2932), lingual (left) and labial (right) views

Figure 2: *Archaeolamna* sp. right intermediate tooth (MM V-2933), lingual (left) and labial (right) views

Figure 3: *Archaeolamna* sp. anterior tooth (MM V-2934), lingual (left) and labial (right) views

Figure 4: *Archaeolamna* sp. anterior tooth (MM V-2935), lingual (left) and labial (right) views

Figure 5a: *Archaeolamna* sp. left lateral tooth (MM V-2936), lingual (left) and labial (right) views

Figure 5b (inset): *Archaeolamna* sp. left lateral tooth (MM V-2936), magnification of longitudinal folds of enamel on labial basal crown surface

Figure 6a: *Archaeolamna* sp. left distal-lateral tooth (MM V-2937), lingual (left) and labial (right) views

Figure 6b (inset): *Archaeolamna* sp. left distal-lateral tooth (MM V-2937), magnification of longitudinal folds of enamel on labial basal crown surface

Figure 7: *Cretalamna appendiculata* left(?) anterior tooth (MM V-2938), lingual (left) and labial (right) views

Figure 8: *Cretalamna appendiculata* anterior tooth (MM V-2939), lingual (left) and labial (right) views

Figure 9: *Cretoxyrhina mantelli* anterior tooth (MM V-3018), lingual (left) and labial (right) views. Specimen collected from the Little Woody River locality.

Scale bars equal 2 mm (for Figs 1-8); 1 cm for Fig. 9

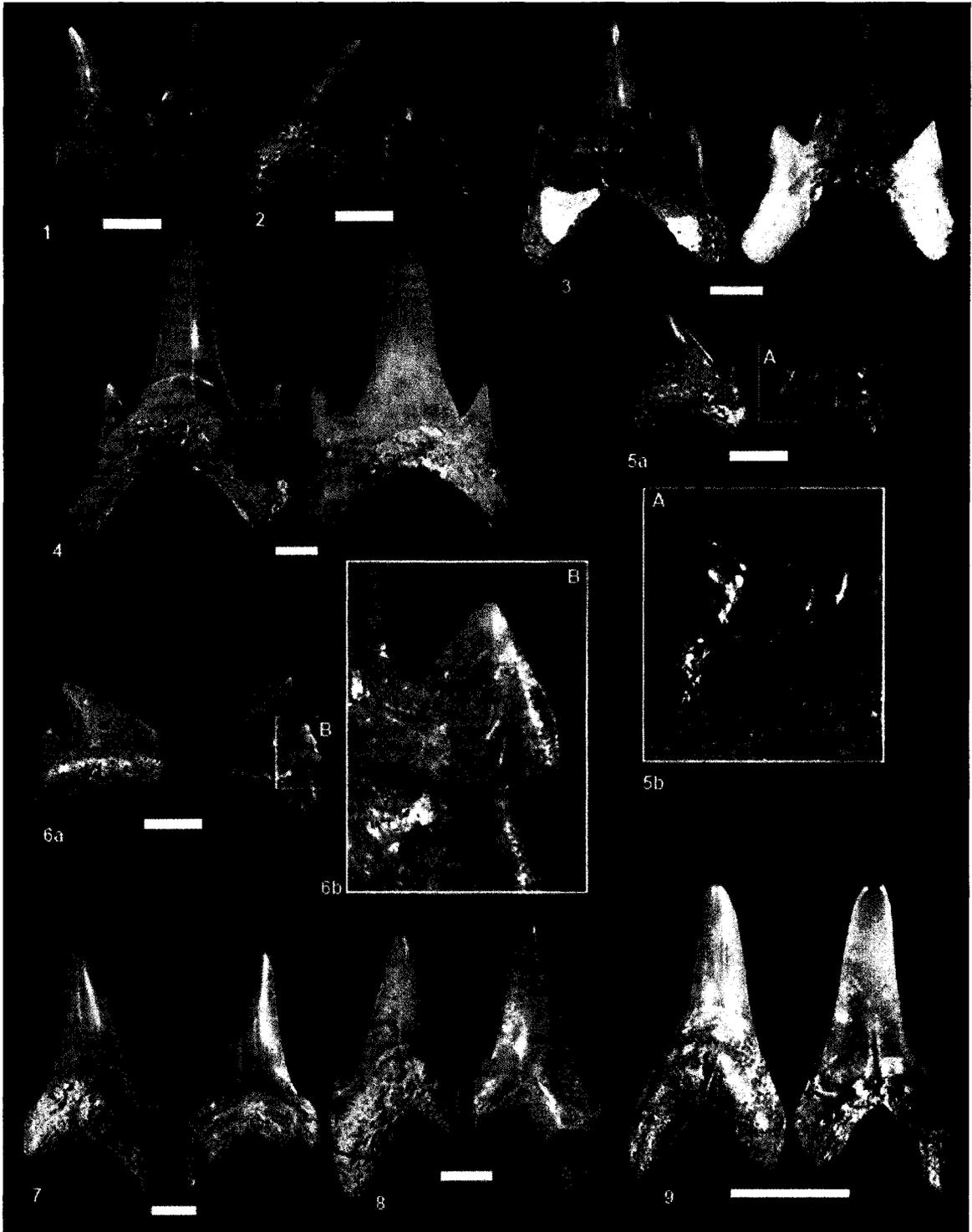


PLATE IV

Figure 1: "Cretoxyrhinid A" left anterolateral tooth (MM V-2940), labial (left) and lingual (right) views

Figure 2: "Cretoxyrhinid A" left anterolateral tooth (MM V-2941), labial (left) and lingual (right) views

Figure 3: "Cretoxyrhinid B" right(?) anterolateral tooth (MM V-2942), labial (left) and lingual (right) views

Figure 4: "Cretoxyrhinid B" right(?) anterolateral tooth (MM V-2943), labial (left) and lingual (right) views

Figure 5: "Cretoxyrhinid C" right anterolateral tooth (MM V-2944), labial (left) and lingual (right) views

Figure 6: *Carcharias amonensis* right(?) anterior tooth (MM V-2945), labial (left) and lingual (right) views

Figure 7: *Carcharias amonensis* left anterior tooth (MM V-2946), labial (left) and lingual (right) views

Figure 8: *Carcharias amonensis* left anterior tooth (MM V-2947), labial (left) and lingual (right) views

Figure 9: *Carcharias amonensis* left anterolateral tooth (MM V-2948), labial (left) and lingual (right) views

Figure 10: *Carcharias amonensis* left distal-lateral tooth (MM V-2949), labial (left) and lingual (right) views

Figure 11: *Carcharias amonensis* right distal-lateral tooth (MM V-2950), labial (left) and lingual (right) views

Scale bars equal 2 mm



PLATE V

Figure 1: *Carcharias* cf. *C. saskatchewanensis* left anterolateral tooth (MM V-2951), labial (left) and lingual (right) views

Figure 2a: *Carcharias* cf. *C. saskatchewanensis* left anterolateral tooth (MM V-2952), labial (left) and lingual (right) views

Figure 2b (inset): *Carcharias* cf. *C. saskatchewanensis* left anterolateral tooth (MM V-2952), magnification of short longitudinal ridges of enamel on labial basal crown surface (mesial cusplet)

Figure 2c (inset): *Carcharias* cf. *C. saskatchewanensis* left anterolateral tooth (MM V-2952), magnification of short longitudinal ridges of enamel on labial basal crown surface (distal cusplet)

Figure 3: *Carcharias* cf. *C. saskatchewanensis* right anterolateral tooth (MM V-2953), labial (left) and lingual (right) views

Figure 4: *Carcharias* cf. *C. saskatchewanensis* right anterolateral tooth with pathologically split cusp (MM V-2954), labial (left) and lingual (right) views

Figure 5: *Carcharias* sp. A right anterolateral(?) tooth (MM V-2955), labial (left) and lingual (right) views

Figure 6: *Carcharias* sp. B anterior tooth (MM V-2956), labial (left) and lingual (right) views

Scale bars equal 2 mm

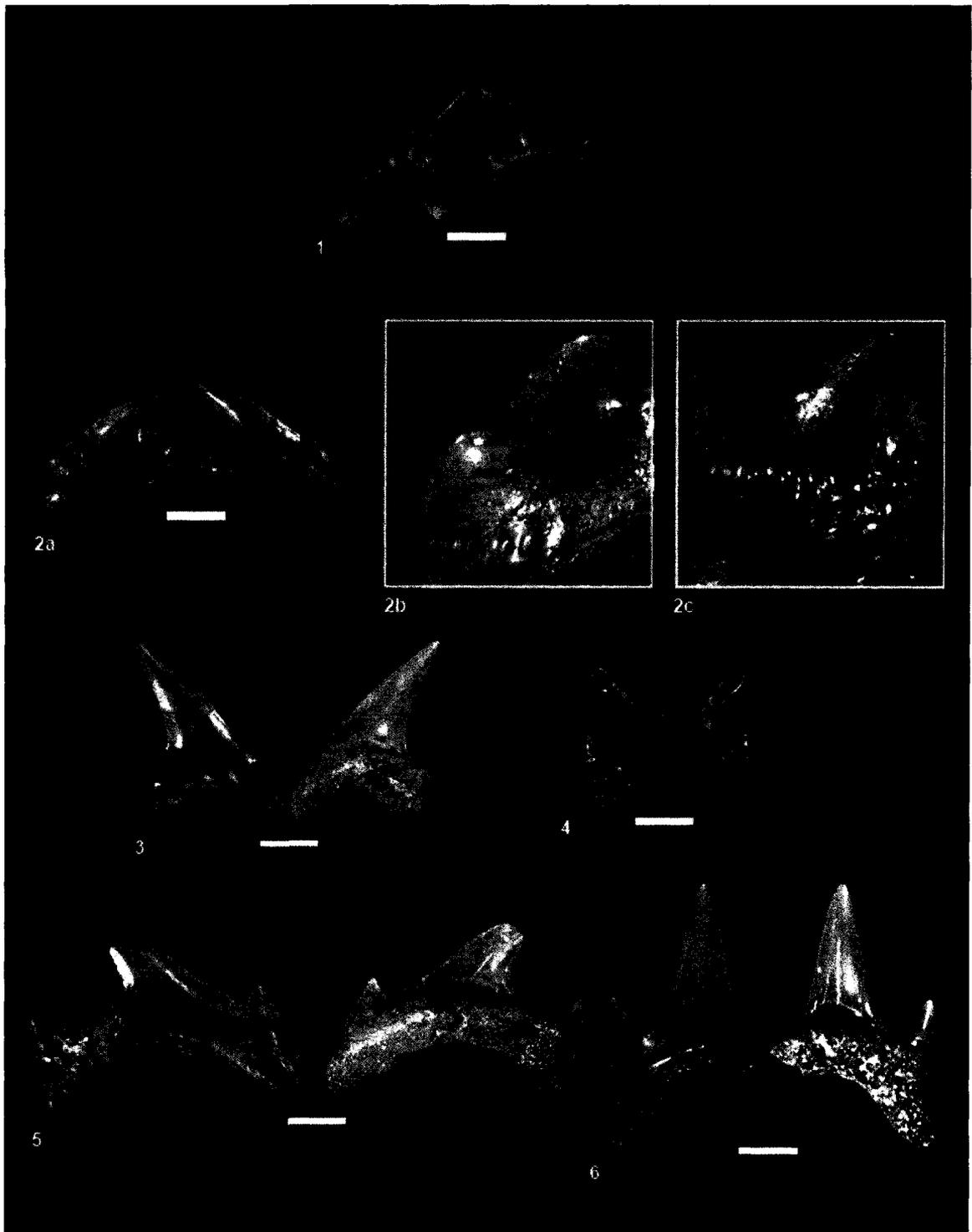


PLATE VI

Figure 1: unidentified caturid – halved centra (clockwise from upper left - MM V-2957, MM V-2958, MM V-2959, MM V-2960), lateral views

Figure 2: unidentified caturid – whole centrum (MM V-2961), anterior (left), left lateral (centre) and posterior (right) views

Figure 3: unidentified caturid - generalized scale (MM V-2962), lateral (left) and medial (right) views

Figure 4: unidentified caturid – lateral line scale scale (MM V-2963), lateral (left) and medial (right) views

Figure 5: Pycnodontidae incertae sedis – bone fragment with ornamented, enameloid surface (MM V-2964), lateral view

Figure 6: *Protosphyraena* sp. teeth (clockwise from centre - MM V-2965, MM V-2966, MM V-2967)

Figure 7: *Xiphactinus audax* tooth (MM V-2968)

Figure 8: *Xiphactinus audax* tooth (MM V-2969)

Figure 9: Unidentified ichthyodectid vertebra (MM V-2970), left lateral view

Figure 10: *Elopopsis* sp. right tooth (MM V-2971), mesial (left) and lingual (right) views

Scale bars equal 2 mm

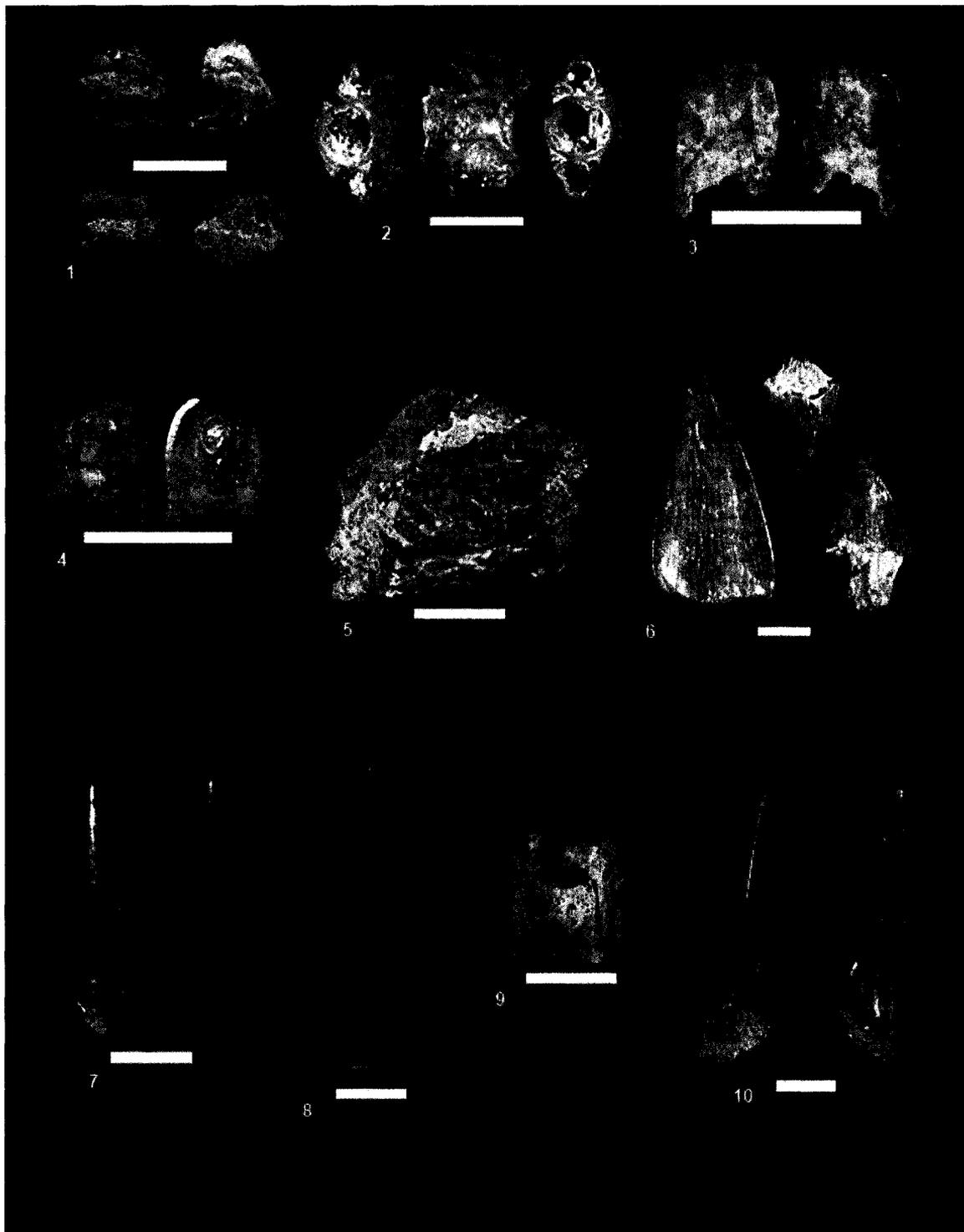


PLATE VII

Figure 1: unidentified salmoniform vertebrae (MM V-2972, left; MM V-2973, right)

Figure 2: unidentified salmoniform basioccipital (MM V-2974), left lateral (left) and dorsal (right) views

Figure 3: *Enchodus* cf. *E. gladiolus* tooth (MM V-2975)

Figure 4: *Enchodus* cf. *E. gladiolus* tooth (MM V-2976), lateral (left) and mesial (right) views

Figure 5: *Enchodus* cf. *E. gladiolus* left palatine (MM V-2977), medial (top) and lateral (bottom) views

Figure 6: *Enchodus* cf. *E. petrosus*(?) teeth (MM V-2978, left; MM V-2979, right)

Figure 7: *Enchodus* cf. *E. petrosus*(?) left palatine (MM V-2980), medial (left) and lateral (right) views

Figure 8: *Enchodus* cf. *E. shumardi* teeth (MM V-2981, left; MM V-2982, right)

Figure 9: *Enchodus* cf. *E. shumardi* left palatine (MM V-2983), lateral view

Scale bars equal 2 mm (Fig. 1-4, 6-9); 4 mm (Fig. 5)

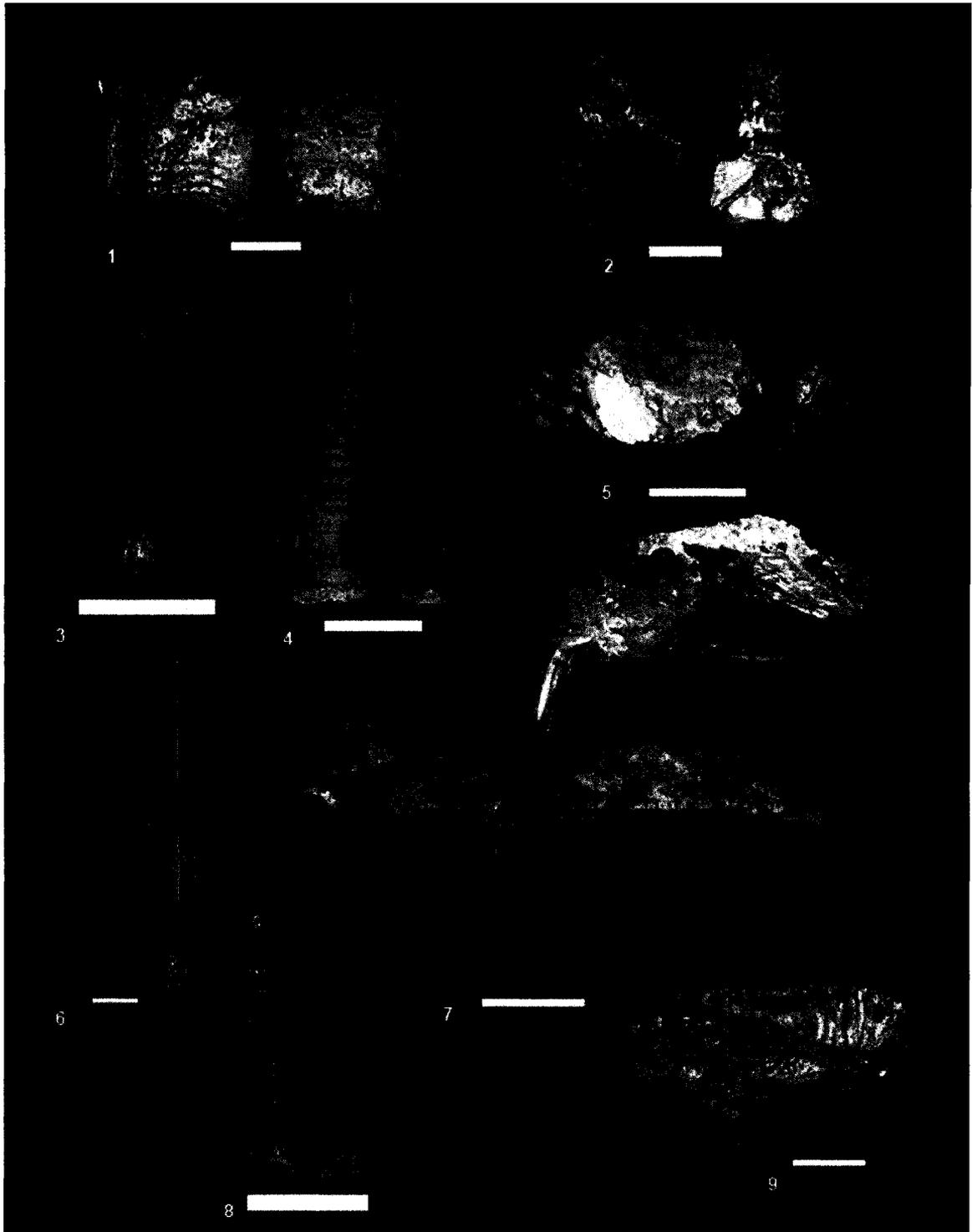


PLATE VIII

Figure 1: *Enchodus* sp. left ectopterygoid (MM V-2984), medial (left) and lateral (right) views

Figure 2: *Enchodus* sp. dentary fragments (MM V-2985, top; MM V-2986, bottom)

Figure 3: *Enchodus* sp. jaw fragments (MM V-2987), lateral (top) and medial (bottom) views

Figure 4: *Enchodus* sp. scale (MM V-2988), dorsal (left), oblique lateral (centre) and ventral (right) views

Figure 5: Anguilliform cf. unidentified anguilliform single right unfused neural arch (MM V-2989), medial (left) and lateral (right) views

Figure 6: Anguilliform cf. unidentified anguilliform single right unfused neural arch (MM V-2990), medial (left) and lateral (right) views

Figure 7: Anguilliform cf. unidentified anguilliform single left unfused neural arch (MM V-2991), medial (left) and lateral (right) views

Figure 8: Anguilliform cf. unidentified anguilliform single left unfused neural arch (MM V-2992), medial (left) and lateral (right) views

Scale bars equal 2 mm

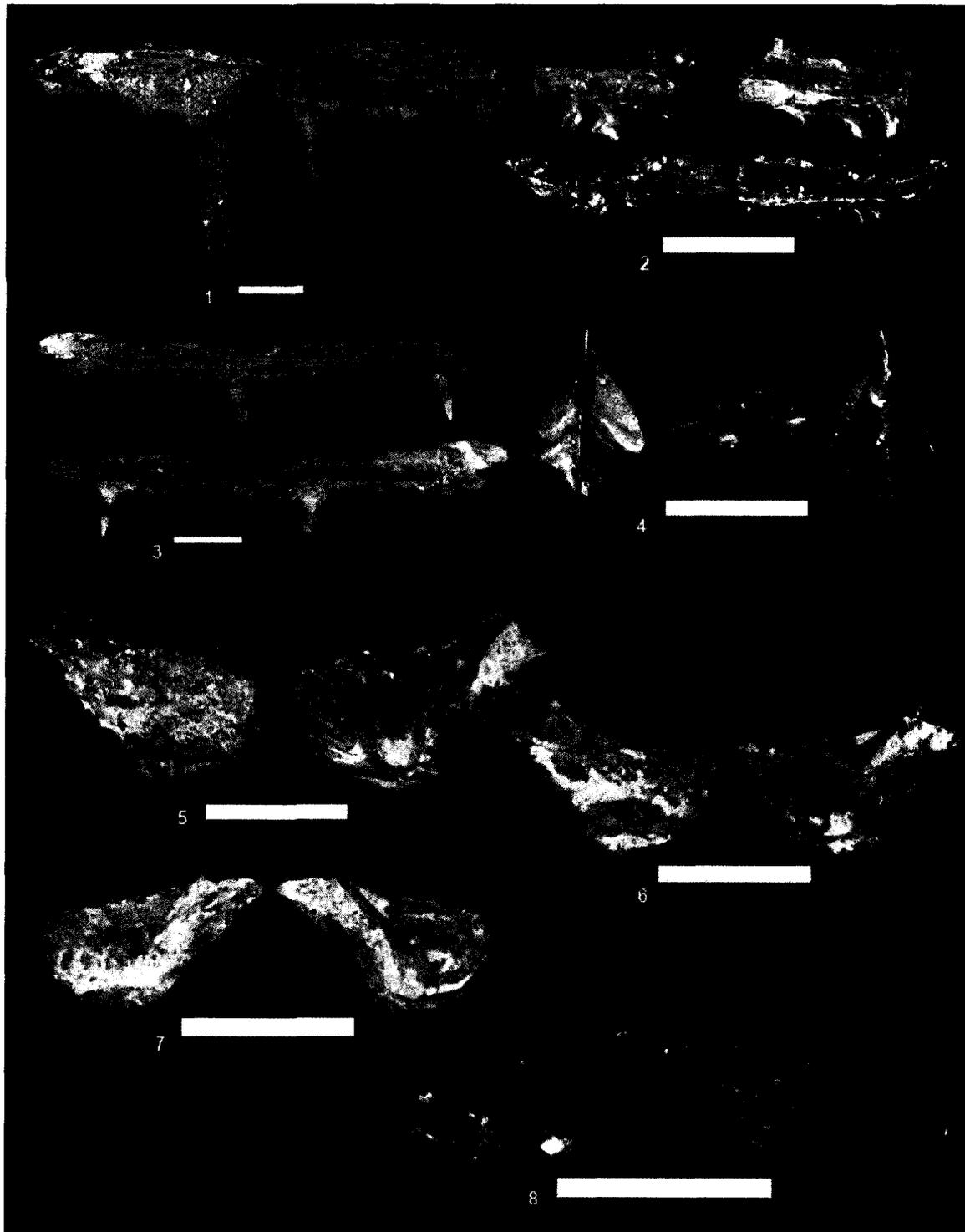


PLATE IX

Figure 1: unidentified basal euteleost left dentary (MM V-2993), medial (top) and lateral (bottom) views

Figure 2a: unidentified basal euteleost right dentary (MM V-2994), medial (top) and lateral (bottom) views

Figure 2b: unidentified basal euteleost right dentary (MM V-2994), magnified view of the medial side of the anterior end of the dentary, showing broken bases of teeth and symphysis

Figure 3: unidentified basal euteleost left hyomandibular (MM V-2995), lateral (left) and medial (right) views

Figure 4: unidentified basal euteleost left hyomandibular (MM V-2996), lateral (left) and medial (right) views

Figure 5: unidentified basal euteleost right hyomandibular (MM V-2997), lateral (left) and medial (right) views

Figure 6a: unidentified basal euteleost maxillary fragments (clockwise from upper left - MM V-2998, MM V-2999, MM V-3000), medial view

Figure 6b: unidentified basal euteleost maxillary fragment (MM V-3000), magnified view of the bottommost fragment from the previous fragment, showing broken bases of teeth

Figure 7: unidentified basal euteleost preopercular (MM V-3001)

Scale bars equal 2 mm

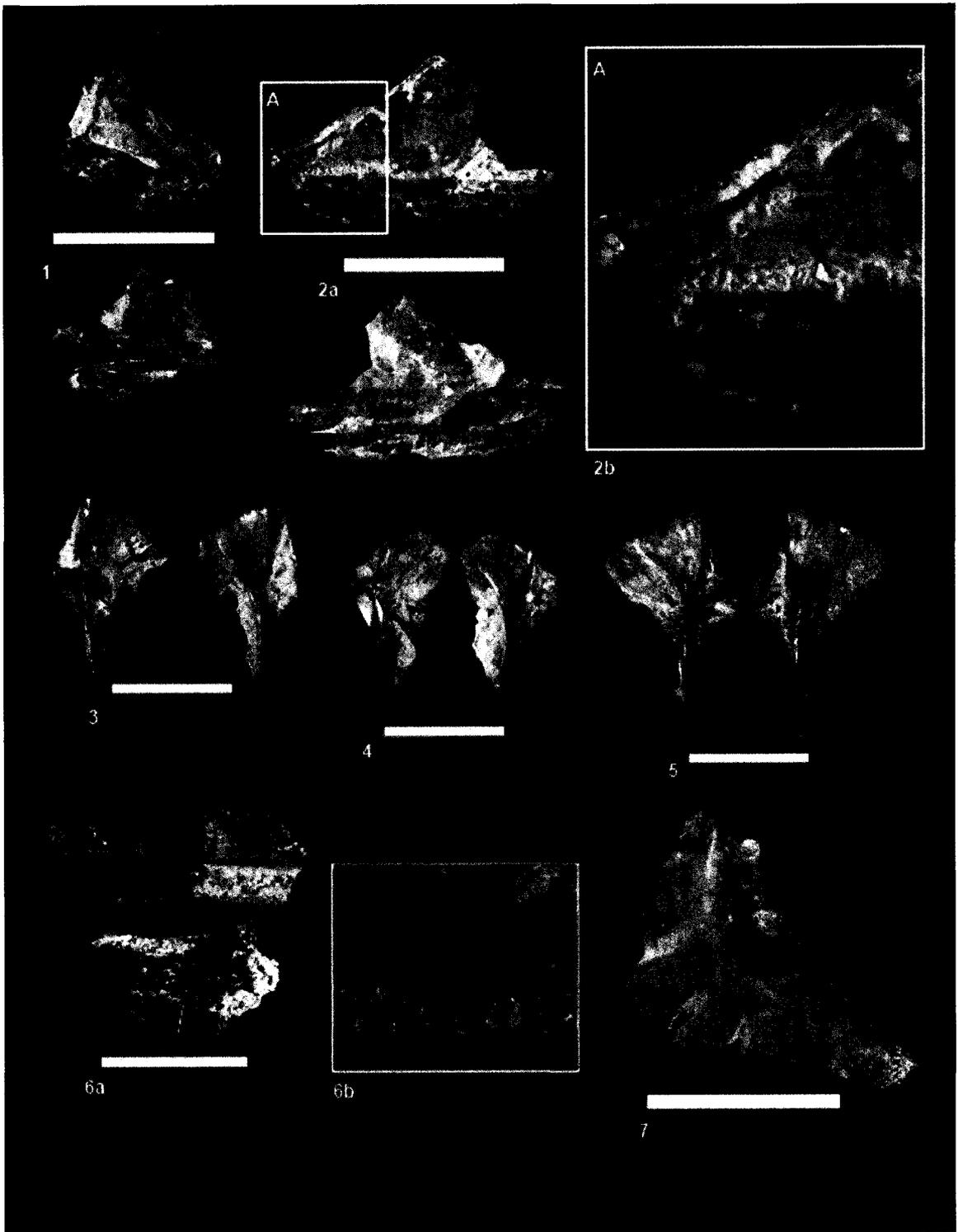


PLATE X

Figure 1: unidentified basal euteleost right angulo-articular (MM V-3002), medial (left) and lateral (right) views

Figure 2: unidentified basal euteleost left angulo-articular (MM V-3003), medial (left) and lateral (right) views

Figure 3: unidentified basal euteleost right quadrate (MM V-3004), medial (left) and lateral (right) views

Figure 4: unidentified basal euteleost right quadrate (MM V-3005), medial (left) and lateral (right) views

Figure 5: unidentified basal euteleost supraoccipital (MM V-3006), dorsal view

Figure 6: "Teleost A" teeth (from left - MM V-3007, MM V-3008, MM V-3009)

Figure 7: "Teleost A" jaw fragment (MM V-3010), lateral(?) (top) and occlusal (bottom) views

Figure 8: "Teleost A" jaw fragment, partially preserved within a coprolitic mass (MM V-3011), oblique occlusal view

Figure 9: "Teleost B" tooth (MM V-3012), mesial(?) (left) and lateral (right) views

Scale bars equal 2 mm

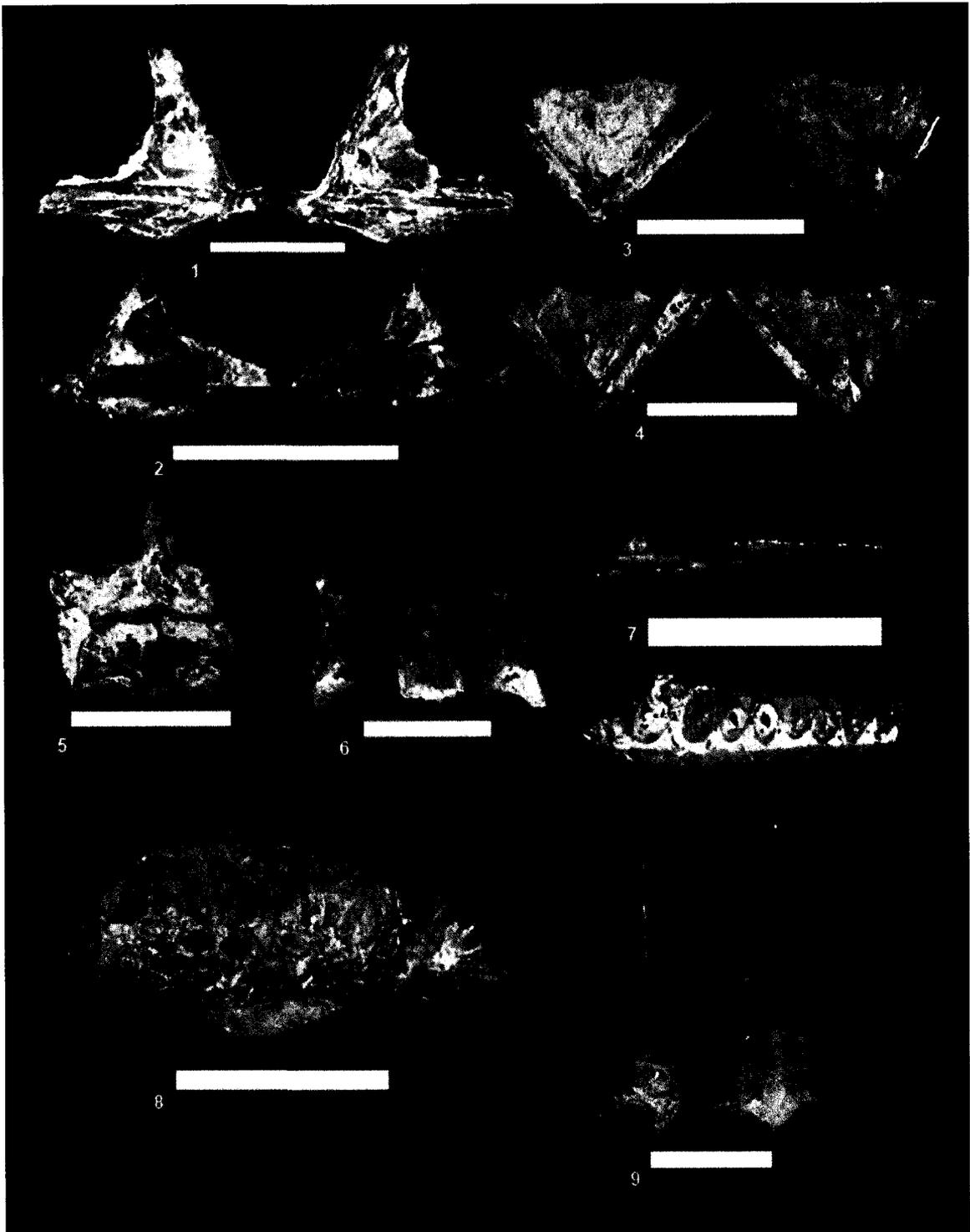


PLATE XI

Figure 1: unidentified hesperornithiform tooth (P 3015.2), medial (left) and lateral (right) views. Specimen collected as float from along the Bainbridge River between localities BR-3 and BR-2 locality.

Figure 2: unidentified hesperornithiform bone fragment (P 3015.3). Specimen collected as float from along the Bainbridge River between localities BR-3 and BR-2 locality.

Figure 3: unidentified turtle marginal scute (MM V-3013), dorsal, proximal, distal and ventral views (from left to right). Notice smooth groove running across the distal end

Figure 4: *Brachauchenius* sp. tooth impression (MM V-3020)

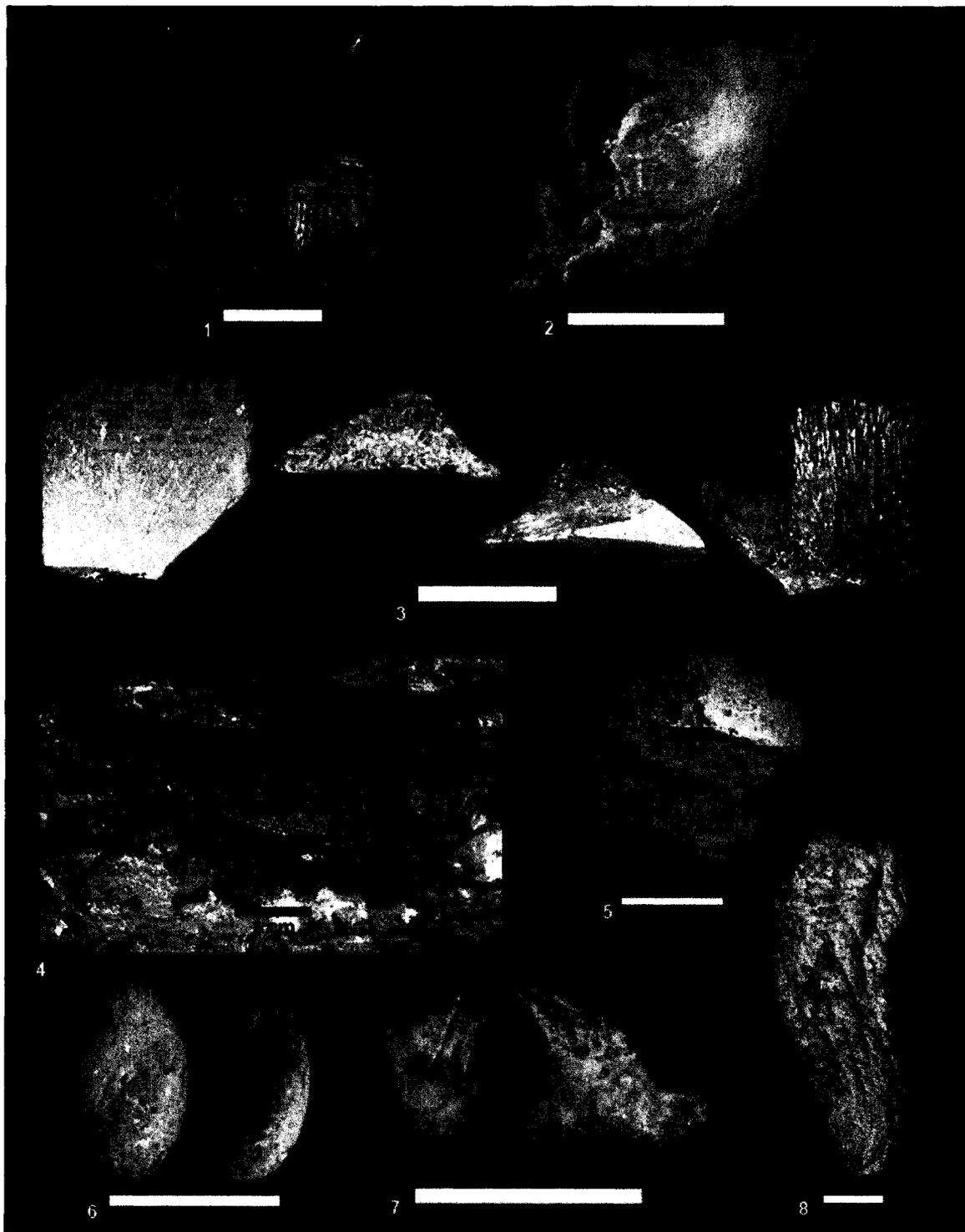
Figure 5: unidentified plesiosaur phalangeal element (P 3015.4). Specimen collected as float from along the Bainbridge River between localities BR-3 and BR-2 locality.

Figure 6: vertebrate microcoprolite (MM V-3014), under direct light (left) and low angle lighting highlighting a slightly spiraled shaped (right)

Figure 7: vertebrate microcoprolites containing distinct vertebrate bone inclusions (MM V-3015, left; MM V-3016, right), including an osteichthyan vertebra (left) and the caudal end of an osteichthyan basioccipital (right)

Figure 8: vertebrate enterospira (MM V-3017)

Scale bars equal 2 mm (Fig. 1, 6-8); 6 mm (Fig. 2, 5); 1 cm (Fig. 3-4)



APPENDICES

**APPENDIX I:
VAN DER VOORT LOCALITY CALCARENITE SAMPLE
MEASUREMENTS**

Van Der Voort Locality Calcarenite Sample Measurements				
Specimen #	Pre-acid treatment			Post-acid treatment
	Weight (g)	Volume (displacement; in mL)	Notes	Dry weight of recovered, insoluble clasts (g)
VdV001	1580	635		106.6
VdV002	1652	635		51.5
VdV003	412*	~250* ²	*Initial weight includes box. Box weighed 17g. 412-17 = 395g as total specimen weight. * ² this specimen was very crumbly; volume is <i>very</i> approximate.	49.2
VdV004	1220	480		34.7
VdV005	591	250		18.1

**APPENDIX II:
SPECIMEN INVENTORY**

Specimen Inventory			
Sample #: BR-3 float – Pt. 1 of 2		Sieve Size: No. 10	
Specimen #	Element	Count	Notes
*all elements referred to by anatomical name only are of unidentified actinopterygian taxa unless otherwise specified			
	<i>Carcharias amonensis</i> teeth	2	
	<i>Carcharias</i> sp. B teeth	1	
	<i>Carcharias</i> sp. C teeth	2	
	Coprolite fragments	32	
	Coprolites	34	
	<i>Elopopsis</i> sp. tooth base	1	
	<i>Enchodus</i> sp. teeth & palatine	3	2 teeth, 1 palatine
	<i>Hybodus butleri</i> teeth	1	
P 3015.4	Plesiosaur phalange fragment	1	Plate XI – Fig. 5
P 3015.1	<i>Ptychodus</i> sp. teeth	1	Plate I – Fig. 2
	<i>Squalicorax falcatus/curvatus</i> teeth	1	
	<i>Squalicorax volgensis</i> teeth	2	
	“Teleost A” fish teeth	1	
	Unidentified compact-shaped bones & fragments	17	Mostly tetrapod-like in appearance (vs. piscine)
	Unidentified elongate-shaped bones & fragments	5	Mostly tetrapod-like in appearance (vs. piscine)
P 3015.3	Unidentified plate-shaped bird bone fragments	2	Plate XI – Fig. 2
	Unidentified plate-shaped bones & fragments	18	Mostly tetrapod-like in appearance (vs. piscine)
	Unidentified shark tooth fragments	2	
	Vertebrae – Morphotype #12	3	This morphotype is BR-3 specific: appears osteichthyian; anterior face of centrum almost flat (vs. concave)
	Vertebrae – Morphotype #4	6	
	Vertebrae – unidentified shark	1	
	Vertebral fragments – Morphotype #8	1	
	Vertebral fragments – shark(?)	6	
	Vertebral fragments – unidentified – compact-shaped	19	

Specimen Inventory			
Sample #: BR-3 float – Pt. 2 of 2		Sieve Size: No. 10	
Specimen #	Element	Count	Notes
*all elements referred to by anatomical name only are of unidentified actinopterygian taxa unless otherwise specified			
	Vertebral fragments – unidentified – plate- shaped	14	
Total Count:		176	*This sample was used in the comparative taphonomic census

Specimen Inventory			
Sample #: BR-3 float – Pt 1 of 3		Sieve Size: No. 20	
Specimen #	Element	Count	Notes
*all elements referred to by anatomical name only are of unidentified actinopterygian taxa unless otherwise specified			
	<i>Archaeolamna</i> sp. teeth	5	
	Unidentified cretoxyrhinid tooth	1	<i>Cretoxyrhina mantelli</i> symphyseal or juvenile?
	Basioccipitals – Morphotype #1	3	
P 3015.1	Bird tooth	1	Hesperorinthiform? Plate XI – Fig. 1
	<i>Carcharias</i> sp. C	2	
	Caturidae – vertebral arch elements, centra & scales	4	2 arches, 1 centrum, 1 scale
	Coprolite fragments	65	
	Coprolites	50	
	<i>Elopopsis</i> sp. teeth & tooth fragments	11	
	<i>Protosphyraena</i> sp. tooth fragments	1	
	Ichthyodectiform teeth	1	
	<i>Enchodus</i> sp. teeth, tooth frag.s, palatines, & jaw frag.s	86	10 palatines & jaw fragments; 76 teeth & tooth fragments
	<i>Hybodus butleri</i> tooth fragments	2	
	Pyrite blobs – compact-shaped	8	Clusters of diagenetically-derived pyrite
	Quartz grains	10	All subrounded to rounded
	Pyrite blobs – plate-shaped	6	Clusters of diagenetically-derived pyrite
	<i>Squalicorax falcatus/curvatus</i> tooth fragment	1	
	<i>Squalicorax volgensis</i> teeth	3	
	Unidentified “holish” element fragments	2	Not the same as “holy jaws”; hole covered patches of fish bone of unknown anatomical affinity
	Unidentified “elongo-plate” element fragments	1	
	Unidentified opercular fragment	1	
	Unidentified “jerry-curl” element fragment	1	
	Unidentified “squished tooth” jaw fragment	1	

Specimen Inventory			
Sample #: BR-3 float – Pt 2 of 3		Sieve Size: No. 20	
Specimen #	Element	Count	Notes
*all elements referred to by anatomical name only are of unidentified actinopterygian taxa unless otherwise specified			
	Unidentified cerato- /epihyal fragments	10	
	anguilliform vertebral fragments	4	
	“basal euteleost” hyomandibular fragments	1	
	Unidentified “jerry-curl” bone fragments	3	
	Unidentified uroneural “basal euteleost”	1	
	supraoccipital(?) fragments	2	
	Unidentified “elongo- plate” element fragments	1	
	Pycnodont(?) facial bone w/ texturing	2	
	Unidentified compact- shaped bones & fragments	248	
	Unidentified elongate- shaped bones & fragments	142	1 2-3mm; 1 4-5mm & 1 5-6mm appear to be bird bones
	Unidentified “spines” & fragments	23	
	“basal euteleost” articular fragments	1	
	Unidentified ceratohyal fragments	2	
	Unidentified “jerry-curl” bone fragment	1	
	Unidentified epibranchial fragments	2	
	Unidentified “elongo- plate” element fragments	3	
	Unidentified fish scale fragments	35	
	Unidentified fish teeth & tooth fragments	12	2 double carinate, lingually curved teeth (“Teleost B”); 10 “hollow-type” teeth (“Teleost A”)
	Unidentified fish tooth fragments	8	

Specimen Inventory			
Sample #: BR-3 float – Pt 3 of 3		Sieve Size: No. 20	
Specimen #	Element	Count	Notes
*all elements referred to by anatomical name only are of unidentified actinopterygian taxa unless otherwise specified			
	Unidentified opercular fragments	3	
	“basal euteleost” quadrate fragments	3	
	“basal euteleost” dentary fragments	1	
	Unidentified plate-shaped bones & fragments	494	3 3-4mm appear to be bird bones
	Unidentified shark tooth fragments	13	
	Vertebrae - fish	21	2 MT#1/#2; 1 MT#3; 4 MT#4; 4 MT#6; 6 MT#8; 4 MT#12
	Vertebral fragments – unidentified – compact-shaped	116	
	Vertebral fragments – unidentified – elongate-shaped	13	
	Vertebral fragments – unidentified – plate-shaped	198	
Total Count:		1629	*This sample was used in the comparative taphonomic census

Specimen Inventory			
Sample # MB Museum – Pt 1 of 3		Sieve size: n/a	
Specimen #	Element	Count	Notes
*all elements referred to by anatomical name only are of unidentified actinopterygian taxa unless otherwise specified			
	<i>Archaeolamna</i> sp. teeth	19	
MM V-2932	<i>Archaeolamna</i> sp. tooth	1	Plate III – Fig. 1
MM V-2936	<i>Archaeolamna</i> sp. tooth	1	Plate III – Fig. 5
MM V-2937	<i>Archaeolamna</i> sp. tooth	1	Plate III – Fig. 6
	Basioccipital – Morphotype #1	1	
	Vertebrae – Morphotype #5	1	
	Vertebrae – Morphotype #8	1	
	Vertebral fragment - unidentified	1	
	Vertebrae – unrecognized morphotype	1	
	<i>Carcharias amonensis</i> teeth	24	
MM V-2946	<i>Carcharias amonensis</i> tooth	1	Plate IV – Fig. 7
MM V-2947	<i>Carcharias amonensis</i> tooth	1	Plate IV – Fig. 8
MM V-2950	<i>Carcharias amonensis</i> tooth	1	Plate IV – Fig. 11
	<i>Carcharias</i> sp. A teeth	4	Wide set cusplets, very vertical (vs. divergent)
	<i>Carcharias</i> sp. B teeth	2	Root lobes have distinct “corners” beneath lateral cusplets.
MM V-2956	<i>Carcharias</i> sp. B tooth	1	Plate V – Fig. 6
	<i>Carcharias</i> sp. C teeth (cf. <i>C.</i> <i>saskatchewanensis</i>)	2	Small enameloid ridges on one side or other of crown base.
MM V-2952	<i>Carcharias</i> sp. C tooth (cf. <i>C.</i> <i>saskatchewanensis</i>)	1	Plate V – Fig 2
MM V-2953	<i>Carcharias</i> sp. C tooth (cf. <i>C.</i> <i>saskatchewanensis</i>)	1	Plate V – Fig. 3
MM V-2938	<i>Cretalamna</i> <i>appendiculata</i> tooth	1	Plate III – Fig. 7
MM V-2939	<i>Cretalamna</i> <i>appendiculata</i> tooth	1	Plate III – Fig. 8
	<i>Cretalamna</i> <i>appendiculata</i> tooth	1	
	<i>Elopopsis</i> sp. teeth	14	
	<i>Enchodus</i> palatine & palatine fragments	7	6 unidentifiable to species; 1 similar to <i>E.</i> <i>shumardi</i>
MM V-2977	<i>Enchodus</i> palatine	1	Cf. <i>E. gladiolus</i> ; Plate VII – Fig. 5

Specimen Inventory			
Sample # MB Museum – Pt 2 of 3		Sieve size: n/a	
Specimen #	Element	Count	Notes
*all elements referred to by anatomical name only are of unidentified actinopterygian taxa unless otherwise specified			
	<i>Enchodus</i> teeth & tooth fragments	131	
MM V-2975	<i>Enchodus</i> tooth	1	Plate VII – Fig. 3
MM V-2976	<i>Enchodus</i> tooth	1	Plate VII – Fig. 4
MM V-2981	<i>Enchodus</i> tooth	1	Plate VII – Fig. 8, left
MM V-2982	<i>Enchodus</i> tooth	1	Plate VII – Fig. 8, right
	Extremely rounded bone fragments	2	
MM V-2923	<i>Hybodus butleri</i> tooth	1	Plate I – Fig. 1
	Possible ichthyodectiform teeth	5	Have relatively small central pulp cavity; most possess a translucent, amber-colored apex; quite conical (minimal lateral compression); lack carinae
MM V-2968	ichthyodectiform teeth	1	Plate VI – Fig. 7
MM V-2969	ichthyodectiform teeth	1	Plate VI – Fig. 8
	<i>Protosphyraena</i> sp. teeth	2	
MM V-2965	<i>Protosphyraena</i> sp. tooth	1	Plate VI – Fig. 6, centre
MM V-2966	<i>Protosphyraena</i> sp. tooth	1	Plate VI – Fig. 6, right
MM V-2967	<i>Protosphyraena</i> sp. tooth	1	Plate VI – Fig. 6, left
	Pycnodont(?) skull bone fragment	1	Has small, knobbily texture akin to texturing found on pycnodont facial bones
	Ornamented scale(?) fragment	1	
			<i>Enchodus</i> sp.?
	Small vial unexamined fine material	n/a	
MM V-2930	<i>Squalicorax falcatus</i> tooth	1	Plate II – Fig. 7
MM V-2931	<i>Squalicorax falcatus</i> tooth fragment	1	Plate II – Fig. 8
	<i>Squalicorax falcatus</i> tooth fragment	1	
	<i>Squalicorax volgensis</i> teeth & tooth fragments	13	
MM V-2927	<i>Squalicorax volgensis</i> tooth	1	Plate II – Fig. 4
	“Teleost A” fish teeth	6	
MM V-2940	“Cretoxyrhinid A “ tooth	1	Similar to both <i>Archaeolamna</i> & <i>Cretoalamna</i> , but possesses higher, narrower & much more erect cusplets. Plate IV – Fig. 1
MM V-2941	“Cretoxyrhinid A “ tooth	1	Plate IV – Fig. 2

Specimen Inventory			
Sample # MB Museum – Pt 3 of 3		Sieve size: n/a	
Specimen #	Element	Count	Notes
*all elements referred to by anatomical name only are of unidentified actinopterygian taxa unless otherwise specified			
MM V-2942	“Cretoxyrhinid B”	1	No nutrient groove, broad crown base & wide set cusplets; cusplets low & triangular. Cusp weakly sigmoidal at tip, slightly convex labial face. Plate IV – Fig. 3
MM V-2943	“Cretoxyrhinid B”	1	Plate IV – Fig. 4
MM V-2944	“Cretoxyrhinid C”	1	Broad, flat & <u>enormous</u> root; mesial cusplet poorly developed; distal cusplet very broad, low, & triangular. Labial face of cusp flat; cutting edge continuous across crown. Plate IV – Fig. 5
	Unidentified gill raker fragments	2	Broken tooth bases showing teeth were compressed perpendicular to jaw length
	Unidentified Elongate spine fragments	3	
	Unidentified compact-shaped bone fragments	1	
	Unidentified fish jaw fragments	2	
	“Teleost B” teeth	4	
	Unidentified shark tooth	1	Cusp morphology like <i>S. volgensis</i> , but possesses a holaulachorhizus root (like an odontaspidid)
	Unidentified shark tooth fragments	33	
Total Count:		316	
MM – Manitoba Museum			

Specimen Inventory			
Sample #: VdV001 – Pt. 1 of 3		Sieve Size: No. 10	
Specimen #	Element	Count	Notes
*all elements referred to by anatomical name only are of unidentified actinopterygian taxa unless otherwise specified			
	<i>Archaeolamna</i> sp. teeth	4	
MM V-2934	<i>Archaeolamna</i> sp. tooth	1	Plate III – Fig. 3
MM V-2935	<i>Archaeolamna</i> sp. tooth	1	Plate III – Fig. 4
	“oreo” bone fragments	13	Plate-shaped frags of layered-looking bone, w/ dark grey outer layers & off-white inner layer
	“basal euteleost” dentaries	1	
	“basal euteleost” articular	1	
	Basioccipital fragments – Morphotype #1	4	
	Basioccipital fragments – Morphotype #3 (salmoniform)	1	
	<i>Carcharias amonensis</i> teeth	2	
MM V-2955	<i>Carcharias</i> sp. A teeth	1	Plate V – Fig. 5
	Caturid scales	1	
	Caturid vertebral centrum	1	No arches preserved
	Cerato-/epihyal fragments	16	
	Coprolite fragments	8	
	Coprolites	28	
	Dentary fragment w/ tiny teeth	1	<i>Elopopsis?</i>
	Digested-looking bone fragments	8	
	<i>Elopopsis</i> sp. teeth	4	
MM V-2984	<i>Enchodus</i> ectopterygoid	1	Broken during examination. Plate VIII – Fig. 1
MM V-2980	<i>Enchodus</i> palatine	1	Cf. <i>E. petrosus</i> Plate VII – Fig. 7
	<i>Enchodus</i> palatine	1	Unidentified species, tooth vertical
	<i>Enchodus</i> teeth	9	
MM V-2978	<i>Enchodus</i> tooth	1	Cf. <i>E. petrosus</i> , Plate VII – Fig. 6, left
MM V-2979	<i>Enchodus</i> tooth	1	Cf. <i>E. petrosus</i> , Plate VII – Fig. 6, right
	Gill raker(?) fragments	1	
	“Basal euteleost” hyomandibulars	1	
	Mineral residues	n/a	
	Opercular fragments	3	
	Other fish scales & fragments	33	
MM V-3011	Partially coprolite-packed jaw fragment (“Teleost A”)	1	Plate X – Fig. 8
MM V-2954	Pathological shark tooth (cf. <i>C saskatchewanensis</i>)	1	Alternatively could be a distal <i>Archaeolamna</i> tooth. Plate V – Fig. 4

Specimen Inventory			
Sample #: VdV001 – Pt. 2 of 3		Sieve Size: No. 10	
Specimen #	Element	Count	Notes
*all elements referred to by anatomical name only are of unidentified actinopterygian taxa unless otherwise specified			
	Phosphatic pebble fragments	6	1 whole; 5 fragments, all likely from same pebble
	Possible ichthyodectiform tooth	1	Elongate, non-striated, non-carinate
MM V-3017	Possible internal gut cast (aka enterospira)	1	Compositionally akin to a coprolite, but w/ an unparalleled degree of surface texturing (“ropey” in appearance) Plate XI – Fig. 8
	“basal euteleost” Preopercular fragments	1	
	pterygiophore basipterygium	1 1	
MM V-2964	Pycnodont(?) skull bone fragment	1	Has a small-scale, knobily texture reminiscent of the texturing of pycnodont facial bones. Plate VI – Fig. 5
	Quadrates	3	
	Scale-like fish bone fragments	21	
MM V-2925	<i>Squalicorax volgensis</i> tooth	1	Plate II – Fig. 2
MM V-2926	<i>Squalicorax volgensis</i> tooth	1	Plate II – Fig. 3
MM V-2928	<i>Squalicorax volgensis</i> tooth	1	Plate II – Fig. 5
	<i>Squalicorax volgensis</i> tooth	1	
	“basal euteleost” supraoccipitals	2	
	Turtle bone fragments	5	Mostly anatomically indistinct
MM V-3013	Turtle bone fragments	1	Large marginal carapace element with small piece broken from corner Plate XI – Fig. 3
	Unidentified compact-shaped fish bones & fragments	47	
	Unidentified elongate-shaped fish bones & fragments	41	
	Unidentified plate-shaped fish bones & fragments	98	Could be fragments of any number of bones of the skull or opercular series
	Urohyal fragments	1	
	Vertebrae – Morphotype #1/#2	16	
	Vertebrae – Morphotype #3	16	
	Vertebrae – Morphotype #4	14	Two w/i this count are fused to one another

Specimen Inventory			
Sample #: VdV001 – Pt. 3 of 3		Sieve Size: No. 10	
Specimen #	Element	Count	Notes
*all elements referred to by anatomical name only are of unidentified actinopterygian taxa unless otherwise specified			
	Vertebrae – Morphotype #7	8	
	Vertebrae – Morphotype #9	3	
	Vertebrae – unrecognized morphotypes	2	
	Vertebral fragments	37	
Total Count:		481	
MM – Manitoba Museum			

Specimen Inventory			
Sample #: VdV002 – Pt. 1 of 2		Sieve Size: No. 10	
Specimen #	Element	Count	Notes
*all elements referred to by anatomical name only are of unidentified actinopterygian taxa unless otherwise specified			
MM V-2974	Basioccipital fragments – Morphotype #3 (salmoniform)	1*	*broke into 3 pieces during photography Plate VII – Fig. 2
	<i>Carcharias amonensis</i> tooth	1	
	Caturid scales	4	
MM V-2961	Caturid vertebrae	1	Plate VI – Fig. 2
	Coprolites	11	
	Coprolite fragments	4	
	<i>Elopopsis</i> tooth	1	Pyritized
	<i>Enchodus</i> teeth	6	Tiny teeth embedded in undissolved matrix
	Pyritic film fragments	n/a	
	<i>Squalicorax volgensis</i> tooth	1	
	Unidentified articular fragments	1	
	Unidentified cerato- /epihyal fragments	2	
	Unidentified compact- shaped fish bones & fragments	8	
	Unidentified elongate- shaped fish bones & fragments	4	
	Unidentified fish scales & fragments	17	
	Unidentified opercular fragments	2	
	Unidentified plate- shaped fish bones & fragments	31	
	Unidentified preopercle fragments	1	
	“basal euteleost” supraoccipital fragments	1	
	Vertebrae – Morphotype #1/#2	3	
	Vertebral fragments – Morphotype #1/#2	2	
	Vertebrae – Morphotype #3	7	
	Vertebrae – Morphotype #4 (salmoniform)	4	One of which is fractured into 3 large pieces, another (the largest) also has a smaller piece included.
	Vertebral Fragments (Morphotype #4)	1	

Specimen Inventory			
Sample #: VdV002 – Pt. 2 of 2		Sieve Size: No. 10	
Specimen #	Element	Count	Notes
<i>*all elements referred to by anatomical name only are of unidentified actinopterygian taxa unless otherwise specified</i>			
MM V-2973	Vertebrae – Morphotype #4 (salmoniform)	1	Plate VII – Fig. 1, right
	Vertebrae – Morphotype #8	1	
	Vertebrae – Morphotype #9	1	
	Vertebrae – unrecognized morphotype	1	6-7mm in length, possibly ichthyodectiform
	Vertebrae – unrecognized morphotypes	7	
	Vertebral fragments – unidentified	7	
Total Count:		132	
MM – Manitoba Museum			

Specimen Inventory			
Sample #: VdV003 – Pt. 1 of 1		Sieve Size: No. 10	
Specimen #	Element	Count	Notes
*all elements referred to by anatomical name only are of unidentified actinopterygian taxa unless otherwise specified			
	"elongo-plate" element	1	Elongate element with articular surface at "base", attached to a large (mostly missing) platey surface (see photo for clarification)
MM V-2951	<i>Carcharias</i> sp. C tooth (cf. <i>C. saskatchewanensis</i>)	1	Shows small enameloid ridges on labial crown base. Plate V – Fig. 1
	Corprolites & coprolite fragments	3	
	<i>Enchodus</i> tooth	1	
	Quartz grains & other residues	3	One quartz grain, the other two strange fragments are likely artifacts of acid preparation
	Unidentified compact-shaped fish bone fragments	3	
	Unidentified elongate-shaped fish bone fragments	2	
	Unidentified fish scale fragments	3	
	Unidentified plate-shaped fish bone fragments	9	
	Vertebrae – Morphotype #1/#2	3	
	Vertebrae – Morphotype #9	1	
	Vertebrae – Morphotype #3	2	
	Vertebrae – Morphotype #4	1	
	Vertebrae – Morphotype #7	3	
	Vertebral fragments - unidentified	24	
Total Count:		60	(total count includes 1 quartz grain, but not the other 2 strange grains)
MM – Manitoba Museum			

Specimen Inventory			
Sample #: VdV004 – Pt. 1 of 2		Sieve Size: No. 10	
Specimen #	Element	Count	Notes
*all elements referred to by anatomical name only are of unidentified actinopterygian taxa unless otherwise specified			
	“Holy” fish jaw element	1	<i>Belonostomous</i> (?)...though it lacks external enameloid
MM V-2948	<i>Carcharias amonensis</i> tooth	1	Plate IV – Fig. 9
	Coprolites	8	1 possesses some “ropey” texturing on some of its surface
	Coprolite fragments	8	
	Digested-looking bone fragments	3	
MM V-2971	<i>Elopopsis</i> sp. tooth	1	Plate VI – Fig. 10
	<i>Elopopsis</i> sp. tooth	1	
MM V-2987	<i>Enchodus</i> sp. jaw(?) fragments w/ teeth	1	Broken in two pieces. Plate VIII – Fig. 3
	<i>Enchodus</i> sp. tooth fragments	5	Appears to be <i>E. petrosus</i> .
	<i>Enchodus</i> sp. palatine fragment	1	
MM V-2983	<i>Enchodus</i> sp. palatine	1	Consistent w/ <i>E. shumardi</i> ; though quite large & robust - Plate VII – Fig. 9
	Fragments of “articulated” <i>Inoceramus</i> prisms	4	Prismatic calcareous material that survived acid treatment
	<i>Protosphyraena</i> sp. tooth	1	
	Pyrite film fragments	n/a	Pyritic films that appear to have coated grains; sloughed off during preparation
	<i>Squalicorax volgensis</i> teeth	2	
MM V-2924	<i>Squalicorax volgensis</i> tooth	1	Plate II – Fig. 1
MM V-2929	<i>Squalicorax volgensis</i> tooth	1	Plate II – Fig. 6
	Unidentified “elongo-plate” bones	2	
	Unidentified “jerry-curl” bone fragment	1	
	Unidentified compact-shaped bone fragments	4	2 of these are particularly dense; may be reptilian
	Unidentified fish scale fragments	10	

Specimen Inventory			
Sample #: VdV004 – Pt. 2 of 2		Sieve Size: No. 10	
Specimen #	Element	Count	Notes
*all elements referred to by anatomical name only are of unidentified actinopterygian taxa unless otherwise specified			
	“basal euteleost” hyomandibular bones	1	
	Unidentified plate-shaped fish bones & fragments	31	Includes 1 cerato-/epihyal fragment
	Unidentified, plate-shaped bone fragment w/ highly sculptured surface	3	Turtle?
	Vertebrae – Morphotype #1/#2	2	
	Vertebrae – Morphotype #4	1	Fractured into 4 pieces
	Vertebrae – Morphotype #5	1	
	Vertebrae – Morphotype #8	1	
	Vertebral fragments – unidentified	15	
Total Count:		112	
MM – Manitoba Museum			

Specimen Inventory			
Sample #: VdV004 – Pt. 1 of 2		Sieve Size: No. 20	
Specimen #	Element	Count	Notes
*all elements referred to by anatomical name only are of unidentified actinopterygian taxa unless otherwise specified			
	Basioccipital fragments – Morphotype #1	5	
	Caturid scales and scale fragments	60	
MM V-2963	Caturid scale	1	Plate VI – Fig. 4
	Caturid vertebral arch element	6	
	coprolites	56	4 w/ visible “ropey” texturing on at least part of their surface
	Coprolite fragments	23	
	Heavily abraded, almost spherical, compact-shaped bone fragments	14	Look as though they may have been digested
	<i>Enchodus</i> scale	1	
MM V-2988	<i>Enchodus</i> scale	1	Plate VIII – Fig. 4
	<i>Enchodus</i> sp. jaw fragments	4	
MM V-2985	<i>Enchodus</i> sp. dentary frag.	1	Plate VIII – Fig. 2, top
MM V-2986	<i>Enchodus</i> sp. dentary frag.	1	Plate VIII – Fig. 2, bottom
	<i>Enchodus</i> sp. teeth	10	Up to 13 of these may all be pieces of one large tooth
	<i>Enchodus</i> sp. tooth fragments	20	
	“Teleost A” teeth & fragments	5	
	Unidentified shark tooth fragment	1	
	Unidentified “holy” bone jaw fragments	2	
	“basal euteleost” dentaries	11	
	articular fragments	5	Includes “basal euteleost”
	Unidentified cerato-epihyal fragments	21	
	Unidentified compact-shaped fish bones & fragments	122	
	anguilliform vertebral fragments	6	
MM V-2992	anguilliform vertebral fragment	1	Plate VIII – Fig. 8
	Unidentified elongate-shaped fish bones & fragments	155	
	Unidentified epibranchial fragments	3	
	Unidentified fish scale fragments	277	
	Unidentified “gill raker” fragments	3	

Specimen Inventory			
Sample #: VdV004 – Pt. 2 of 2		Sieve Size: No. 20	
Specimen #	Element	Count	Notes
<small>*all elements referred to by anatomical name only are of unidentified actinopterygian taxa unless otherwise specified</small>			
MM V-2998	“basal euteleost” maxilla frag.	1	Plate IX – Fig. 6, upper left
MM V-2999	“basal euteleost” maxilla frag.	1	Plate IX – Fig. 6, upper right
MM V-3000	“basal euteleost” maxilla frag.	1	Plate IX – Fig. 6, bottom
	“basal euteleost” hyomandibular fragments	7	
	Unidentified opercular fragments	6	
	Unidentified plate-shaped fish bone fragments	681	
	Unidentified prevomer fragments	2	1 Morphotype #1 (the more common) & 1 Morphotype #2 (“the beak”)
	Unidentified basipterygium	1	
	Unidentified spine bases	3	
	<i>Elopopsis</i> jaw fragments	5	
	Unidentified quadrate fragments	6	Includes “basal euteleost”
	“basal euteleost” supraoccipitals	5	
	Unidentified urohyal fragments	6	
	Vertebrae – Morphotype #1/#2	19	
	Vertebrae – Morphotype #3	14	
	Vertebrae – Morphotype #4	2	
	Vertebrae – Morphotype #5	14	
	Vertebrae – Morphotype #7	6	
	Vertebrae – Morphotype #8	6	
	Vertebrae – unrecognized morphotypes	5	
	Vertebral fragments - unidentified	227	Most fragments that are of much larger vertebrae appear very much like Morphotype #4
Total Count:		1833	
MM – Manitoba Museum			

Specimen Inventory			
Sample #: VdV005 – Pt. 1 of 1		Sieve Size: No. 10	
Specimen #	Element	Count	Notes
*all elements referred to by anatomical name only are of unidentified actinopterygian taxa unless otherwise specified			
	<i>Archaeolamna</i> sp. teeth	5	
MM V-2933	<i>Archaeolamna</i> sp. tooth	1	Plate III – Fig. 2
	Basioccipital – Morphotype #1	1	
	Unidentified prevomer – Morphotype #1	1	
	<i>Carcharias amonensis</i> teeth	2	
MM V-2945	<i>Carcharias amonensis</i> tooth	1	Plate IV – Fig. 6
MM V-2949	<i>Carcharias amonensis</i> tooth	1	Plate IV – Fig. 10
	<i>Carcharias</i> sp. A	1	
	Coprolites	19	
	<i>Elopopsis</i> sp. teeth	1	
	Unidentified fish tooth	1	
	“Teleost A” tooth	1	
	<i>Enchodus</i> sp. teeth	5	
	<i>Enchodus</i> sp. palatines	2	
	Mineral grains	n/a	
	<i>Squalicorax volgensis</i> teeth	2	
	Unidentified ceratohyals	3	
	Unidentified compact-shaped bones & fragments	9	
	Unidentified elongate spines & fragments	2	
	Unidentified elongate-shaped bones & fragments	11	
	“basal euteleost” hyomandibular	1	
	Unidentified plate-shaped bones & fragments	32	2 vials
	Unidentified scale fragments	4	
	Unidentified shark tooth(?) fragment	1	
	“basal euteleost” supraoccipital	1	
	Unidentified uroneural fragment	1	
	Vertebrae – Morphotype #1	9	
MM V-2970	Vertebrae – Morphotype #11	1	Ichthyodectiform? Plate VI – Fig. 9
	Vertebrae – Morphotype #2	6	
	Vertebrae – Morphotype #3	11	
	Vertebrae – Morphotype #4	5	
	Vertebral fragments - Morphotype #4	1	
MM V-2972	Vertebra – Morphotype #4	1	Plate VII – Fig. 1 (left)
	Vertebrae – Morphotype #5	8	
	Vertebrae – Morphotype #7	3	
	Vertebrae – Morphotype #8	1	
	Vertebrae – Morphotype #9	1	
	Vertebrae – unrecognized morphotype	1	
	Vertebral fragments - unidentified	6	
Total Count:		163	*This sample was used in the comparative taphonomic census
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Specimen Inventory			
Sample #: VdV005-A – Pt. 1 of 4		Sieve Size: No. 20	
Specimen #	Element	Count	Notes
<small>*all elements referred to by anatomical name only are of unidentified actinopterygian taxa unless otherwise specified</small>			
	Basioccipitals	12	11 Morphotype #1; 1 Morphotype #2
	Caturid scales & scale fragments – 1-2mm	25	
	Caturid scales & scale fragments – 2-3mm	11	
MM V-2962	Caturid scale	1	Plate VI – Fig. 3
	Caturid scales & scale fragments – 3-4mm	4	
MM V-2957	Caturid vertebral arch element	1	Plate VI – Fig. 1, upper left
MM V-2958	Caturid vertebral arch element	1	Plate VI – Fig. 1, upper right
MM V-2959	Caturid vertebral arch element	1	Plate VI – Fig. 1, lower right
MM V-2960	Caturid vertebral arch element	1	Plate VI – Fig. 1, lower left
	Caturid vertebral arch element	1	
	Coprolites – compact-shaped	25	
	Coprolites – plate-shaped	19	
	Dubious caturid scales & scale fragments	32	
	<i>Enchodus</i> sp. teeth & jaw fragments	5	1 tooth, 4 jaw fragments w/ some small teeth
	<i>Enchodus</i> sp.(?) scale fragments	2	
	Fin spine base fragment	1	Acanthomorph?
	Prevomer – Morphotype #1	1	
MM V-3007	“Teleost A” tooth	1	Plate X – Fig. 6, left
MM V-3008	“Teleost A” tooth	1	Plate X – Fig. 6, centre
MM V-3009	“Teleost A” tooth	1	Plate X – Fig. 6, right
MM V-3010	“Teleost A” jaw fragment	1	Plate X – Fig. 7
	Unidentified “jerry-curl” bone fragment	1	
	“basal euteleost” dentaries & fragments – 1-2mm	10	
MM V-2993	“basal euteleost” dentary – 1-2mm	1	Plate IX – Fig. 1
	“basal euteleost” dentaries & fragments – 2-3mm	10	
MM V-2994	“basal euteleost” dentary – 2-3mm	1	Plate IX – Fig. 2
	“basal euteleost” dentaries & fragments – 3-4mm	8	

Specimen Inventory			
Sample #: VdV005-A – Pt. 2 of 4		Sieve Size: No. 20	
Specimen #	Element	Count	Notes
<small>*all elements referred to by anatomical name only are of unidentified actinopterygian taxa unless otherwise specified</small>			
	Unidentified "spine" fragments	58	6 size classes in 4 separate vials
	"basal euteleost" articulars & fragments	7	
MM V-3002	"basal euteleost" articular	1	Plate X – Fig. 1
MM V-3003	"basal euteleost" articular	1	Plate X – Fig. 2
	Unidentified compact-shaped fish bones & fragments – 1-2mm	64	
	Unidentified compact-shaped fish bones & fragments – 2-3 & 3-4mm	30	28 2-3mm; 2 3-4mm
	Unidentified dubious preopercular fragments	9	
	anguilliform vertebral fragments	15	
MM V-2989	anguilliform vertebral fragment	1	Plate VIII – Fig. 5
MM V-2990	anguilliform vertebral fragment	1	Plate VIII – Fig. 6
MM V-2991	anguilliform vertebral fragment	1	Plate VIII – Fig. 7
	Unidentified elongate-shaped bones & fragments	123	6 size classes in 4 separate vials
	Unidentified elongate-shaped fish bones & fragments (additional)	7	
	Unidentified elongate-shaped fish scale fragments	7	
	Unidentified epi-/ceratohyals & fragments	18	
	Unidentified epibranchial bones	7	
	"basal euteleost" hyomandibulars & fragments	23	
MM V-2995	"basal euteleost" hyomandibular	1	Plate IX – Fig. 3
MM V-2996	"basal euteleost" hyomandibular	1	Plate IX – Fig. 4
	Unidentified hypurals	7	
	Unidentified opercular fragments	10	

Specimen Inventory			
Sample #: VdV005-A – Pt. 3 of 4		Sieve Size: No. 20	
Specimen #	Element	Count	Notes
*all elements referred to by anatomical name only are of unidentified actinopterygian taxa unless otherwise specified			
	Unidentified plate-shaped fish bones & fragments – 1-2mm	235	
	Unidentified plate-shaped fish bones & fragments – 2-3mm	196	
	Unidentified plate-shaped fish bones & fragments – 3-4 & 4-5mm	45	44 3-4mm; 1 4-5mm
	Unidentified plate-shaped fish bones & fragments (additional)	11	
	Unidentified plate-shaped fish scales & scale fragments – 1-2mm	82	
	Unidentified plate-shaped fish scales & scale fragments – 2-3mm	38	
	Unidentified plate-shaped fish scales & scale fragments – 3-4mm	5	
MM V-3001	“basal euteleost” preopercular fragment	1	Plate IX – Fig. 7
	“basal euteleost” preopercular fragment	1	
	quadrates & fragments	23	3 size classes in 2 separate vials; includes “basal euteleost”
MM V-3006	“basal euteleost” supraoccipital	1	Plate X – Fig. 5
	“basal euteleost” supraoccipital	1	
	Unidentified urostyle	1	
	Vertebrae – Morphotype #1	37	3 size classes; each in separate vial
	Vertebrae – Morphotype #2	25	2 size classes; each in separate vial
	Vertebrae – Morphotype #3	43	3 size classes; each in separate vial
	Vertebrae – Morphotype #4	3	1 size class; in own vial
	Vertebrae – Morphotype #5	45	4 size classes; each in separate vial
	Vertebrae – Morphotype #6	18	2 size classes; each in separate vial
	Vertebrae – Morphotype #7	17	2 size classes; each in separate vial

Specimen Inventory			
Sample #: VdV005-A – Pt. 4 of 4		Sieve Size: No. 20	
Specimen #	Element	Count	Notes
<small>*all elements referred to by anatomical name only are of unidentified actinopterygian taxa unless otherwise specified</small>			
	Vertebrae – Morphotype #8	21	3 size classes; each in separate vial
	Vertebrae – Morphotype #9	1	
	Vertebrae – unrecognized morphotypes – 1-2mm	3	
	Vertebrae – unrecognized morphotypes – 0-1mm	7	
	Vertebral fragments – unidentified – 0-1mm – compact-shaped	13	
	Vertebral fragments – unidentified – 0-1mm – plate-shaped	11	
	Vertebral fragments – unidentified – 1-2mm – compact-shaped	54	The most heavily abraded tend to be small pieces of much larger vertebrae
	Vertebral fragments – unidentified – 1-2mm – plate-shaped	84	
	Vertebral fragments – unidentified – 2-3mm	13	Includes one piece of a Morphotype #4 vertebrae that would have once been quite large
	Vertebral fragments – unidentified – 3-4mm	3	
Total Count:		1608	*This sample was used in the comparative taphonomic census
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Specimen Inventory			
Sample #: VdV005-B – Pt. 1 of 2		Sieve Size: No. 20	
Specimen #	Element	Count	Notes
*all elements referred to by anatomical name only are of unidentified actinopterygian taxa unless otherwise specified			
	Basioccipital - fragments	25	14 Morphotype #1; 7 Morphotype #2; 4 unidentified
	Unidentified prevomer fragments	4	All morphotype #1
	Fin spine base fragments	2	1 of 2 destroyed during examination. (Acanthomorph?)
	Caturid centra	1	
	Caturid scales	41	
	Caturid vertebral arch elements	10	
	Coprolites & coprolite fragments	102	
MM V-3014	Coprolite	1	Plate XI – Fig. 6
MM V-3015	Coprolite	1	Plate XI – Fig. 7, left
MM V-3016	Coprolite	1	Plate XI – Fig. 7, right
	<i>Enchodus</i> sp. teeth & tooth fragments	9	
	"Teleost B" tooth	1	
MM V-3012	"Teleost B" tooth	1	Plate X – Fig. 9
	Quartz grain	1	~1.5mm ³ , subrounded
	Unidentified "jerry-curl" bone fragments	3	
	Unidentified epibranchials	2	
	"basal euteleost" hyomandibulars & fragments	35	
	anguilliform vertebral fragments	25	
MM V-2997	"basal euteleost" hyomandibular	1	Plate IX – Fig. 5
	articulars & fragments	19	Includes "basal euteleost" specimens
	"basal euteleost" dentaries & fragments	27	
	quadrates & fragments	17	Includes "basal euteleost" specimens
MM V-3004	"basal euteleost" quadrates	1	Plate X – Fig. 3
MM V-3005	"basal euteleost" quadrates	1	Plate X – Fig. 4
	Unidentified compact-shaped fish bones & fragments	146	

Specimen Inventory			
Sample #: VdV005-B – Pt. 2 of 2		Sieve Size: No. 20	
Specimen #	Element	Count	Notes
*all elements referred to by anatomical name only are of unidentified actinopterygian taxa unless otherwise specified			
	Unidentified elongate "spines" & fragments	72	
	Unidentified elongate-shaped fish bones & fragments	188	
	Unidentified fish scales & fragments	210	
	Unidentified gill raker fragments	13	Includes "basal euteleost" maxillae frag.s Not the same as "holly jaws"; hole covered patches of fish bone of unknown anatomical affinity
	"holish" fragments	2	
	Unidentified opercular fragments	33	
	Unidentified interoperculae	3	
	Unidentified preoperculae & fragments	7	
	Unidentified dubious preopercular fragments	9	
	Unidentified plate-shaped fish bones & fragments	488	
	Unidentified urohials & fragments	7	
	Unidentified epi/ceratohyal fragments	36	
	Unidentified ceratohyals	19	
	Vertebrae – unrecognized morphotypes	11	
	Vertebral fragments - unidentified	327	
	Vertebral Morphotype #1/#2	88	
	Vertebral Morphotype #3	106	
	Vertebral Morphotype #5	103	
	Vertebral Morphotype #6	13	
	Vertebral Morphotype #7	54	
	Vertebral Morphotype #8	7	
Total Count:		2273	
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Additional Specimens

- Block of unprepared Van Der Voort Farm locality calcarenite w/ impression of plesiosaur tooth (MM V-3020) - **Plate XI – Fig. 4**
- Sample of unprepared Little Woody River locality calcarenite examined for lithological, sedimentological, and paleontological comparison with Van Der Voort material (MM V-3018) – **Plate III – Fig. 9**

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**APPENDIX III:
CEMENT ANALYSIS DATA**

