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TYPE SECTION OF THE UPPER CARBONIFEROUS BURSUM FORMATION, SOUTH-CENTRAL NEW MEXICO, AND THE BURSUMIAN STAGE

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ABSTRACT.—The term Bursum has been used to refer to a lithostratigraphic unit, a biostratigraphic zone or to a stage (Bursumian) of the earliest Permian or latest Carboniferous in North America. The type section of the lithostratigraphic unit Bursum Formation in Socorro County, New Mexico, is 85 m thick, conformably overlies the Moya Member of the Atrasado Formation and is disconformably overlain by red-bed siliciclastics of the Abo Formation. The Bursum section is mostly shale (55% of the measured section), red-bed mudstone (23%) and marine limestone (19%), with minor conglomerate and sandstone (< 3%). We pick the base of a mappable Bursum Formation at a point of maximum lithologic contrast between a 10-m-thick interval of red-bed mudstone of the lower Bursum above light brownish gray bioclastic limestones of the Madera Group. Limestone microfacies of the type Bursum section indicate deposition in shallow, low energy shelf environments in the photic zone in waters of normal salinity. Most type Bursum shale units also were deposited in a shallow marine environment, but some pedogenically modified mudstones and arksoic sandstones indicate subaerial deposition on a coastal plain.

Invertebrate macrofossils from four limestone intervals in the type Bursum section are mostly brachiopods, but include bryozoans, bivalves, scaphopods, gastropods, nautiloids, trilobites and crinoids. These taxa generally have both Virgilian and Wolfcampian records elsewhere, and they indicate deposition in low energy, shallow marine environments.

The fusulinacean fauna of the type Bursum section, and of immediately underlying strata of the upper Atrasado Formation, is characteristic of the early Wolfcampian. Fusulinacean distribution at the type section also indicates that the base of the Bursum Formation (lithostratigraphic unit) does not correspond to the base of a fusulinacean zone. The Bursum type section is not an adequate stratotype for a Bursumian Stage. Indeed, the proposed Bursumian Stage is nothing more than a fusulinacean zone and should be abandoned.

INTRODUCTION

In New Mexico, Upper Pennsylvanian-Lower Permian strata record a major shift in environments from Late Pennsylvanian seas dominated by the deposition of platform carbonates to Early Permian alluvial plains and riverine floodplains that were the sites of deposition of red-bed siliclastics (e.g., Read and Wood, 1947; Kottlowski, 1960; Cook et al., 1998). Classically, the underlying Upper Pennsylvanian strata have been assigned to the Madera and Magdalena groups, for which an extensive and parochial stratigraphic nomenclature exists throughout the state (e.g., Armstrong et al., 1979; Kues, 2001). The overlying Lower Permian red beds are assigned to the Abo Formation and its homotaxial northern equivalents, the Cutler and Sangre de Cristo formations. However, in most sections, a set of "transitional beds," composed of a mixture of marine carbonates and nonmarine clastics, separates the Pennsylvanian marine strata from the Lower Permian nonmarine strata. In much of central New Mexico, these transitional beds are assigned to the Bursum Formation of Wilpolt et al. (1946).

Lucas et al. (2000a) described in detail the type section of the Bursum Formation (Fig. 1) in order to define it more precisely as a lithostratigraphic unit. They also presented a preliminary study of fusulinaceans from the Bursum type section in order to establish the biostratigraphic position of the Bursum Formation at its type section. This biostratigraphy suggested that the base of the Bursum Formation (lithostratigraphic unit) does not correspond to the base of the Bursumian Stage (chronostratigraphic unit) used by some workers. Here, we review the sedimentary petrology and invertebrate macrofossils of the type Bursum section and question the validity of a Bursumian Stage. In this article, NMMNH = New Mexico Museum of Natural History, Albuquerque.

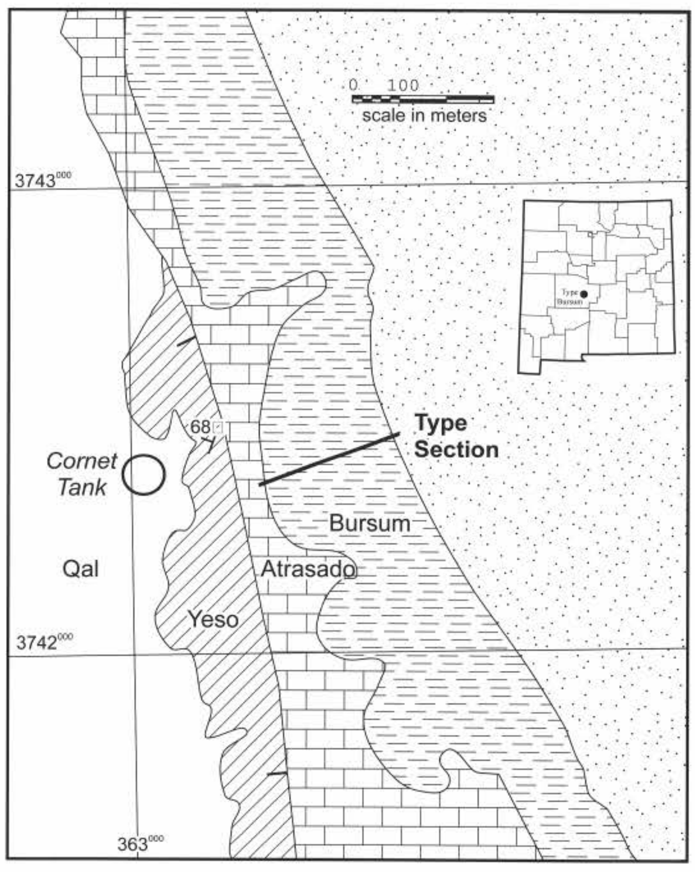


FIGURE 1. Geologic map of the type section of the Bursum Formation, Oscura Mountains, Socorro County, New Mexico (after Lucas et al., 2000a).

PREVIOUS STUDIES

Wilpolt et al. (1946) named the Bursum Formation as follows:

The Bursum formation is here named from exposures just west of Bursum triangulation point in the SE ¼ sec. 1, T. 6 S., R. 4 E., Socorro County. The type section is located about 30 miles south of the mapped area.

In the mapped area the Bursum formation consists of dark purplish-red and green shale in beds up to 40 feet thick, separated by thinner beds of arkose, arkosic conglomerate, and gray limestone. A thin, rubbly, nodular, purplish-gray limestone consisting of reworked limestone of the underlying arkosic member of the Madera formation occurs locally at the base. The limestone beds above, which are 1 to 6 feet thick, carry marine invertebrates. The fusulinacean *Schwagerina*, in association with very obese *Triticites venticosus*, has been collected from several localities. The Bursum formation ranges from 28 to 234 feet in thickness.

Because the type section of the Bursum Formation is outside of the area Wilpolt et al. (1946) mapped, they provided no detailed description. However, they did map the Bursum Formation throughout a large area in central New Mexico and presented several measured sections in columnar form. Furthermore, their observations on Bursum fusulinaceans, quoted above, provided a basis for recognition and correlation of the formation in central New Mexico (Fig. 2).

Subsequently, Wilpolt and Wanek (1951) mapped an area that included the type section of the Bursum Formation. Here, they mapped the Bursum overlying a tongue of the Abo Formation, which overlies strata they termed the upper arkosic member of the Madera Formation. They offered the following comments:

"The type section of the Bursum formation, named by Wilpolt and others (1946), is just west of the Bursum triangulation point in the SE ¼ sec. 1, T. 6 S., R. 4 E., Socorro County. The Bursum formation consists of thick beds of dark purplish-red and green shale separated by thinner beds of arkose, arkosic conglomerate, and gray limestone. A thin, rubbly, nodular, purplish-gray limestone conglomerate consisting of material derived from the underlying arkosic limestone member of the Madera limestone occurs locally at the base. The limestone beds above it contain marine invertebrates, including the fusulinacean *Schwagerina* in association with very obese *Triticites ventricosus*. A thick, massive, white-weathering limestone, occurring at the top of the formation in the Oscura Mountains, has been considered by Thompson (1942, pl. 2, opposite p. 20) to be of Wolfcamp age. Thompson assigned the strata below this massive bed and above the massive limestone of the arkosic limestone member of the Madera limestone to his Bruton formation. Thompson's Bruton formation is equivalent to all of the Bursum formation except the uppermost massive ledge and the thin beds of limestone interbedded with red and green shale that lie just above the top of the arkosic limestone member of the Madera in the Oscura Mountains and Hansonburg Hills. The Bursum formation ranges from 90 to 250 feet in thickness."

Thompson (1942) had named the Bruton Formation in the northern Oscura Mountains for a 35-m thick type section in the SE1/4 sec. 32, T5S, R6E that is a mixture of nonmarine and marine strata between Virgilian limestones and Wolfcampian limestone and overlying Abo Formation red beds (Fig. 3). Four years later, on a map legend, Wilpolt et al. (1946) renamed essentially the same unit the Bursum Formation, with a type section in the Hansonburg Hills only 15 km from Thompson's type section

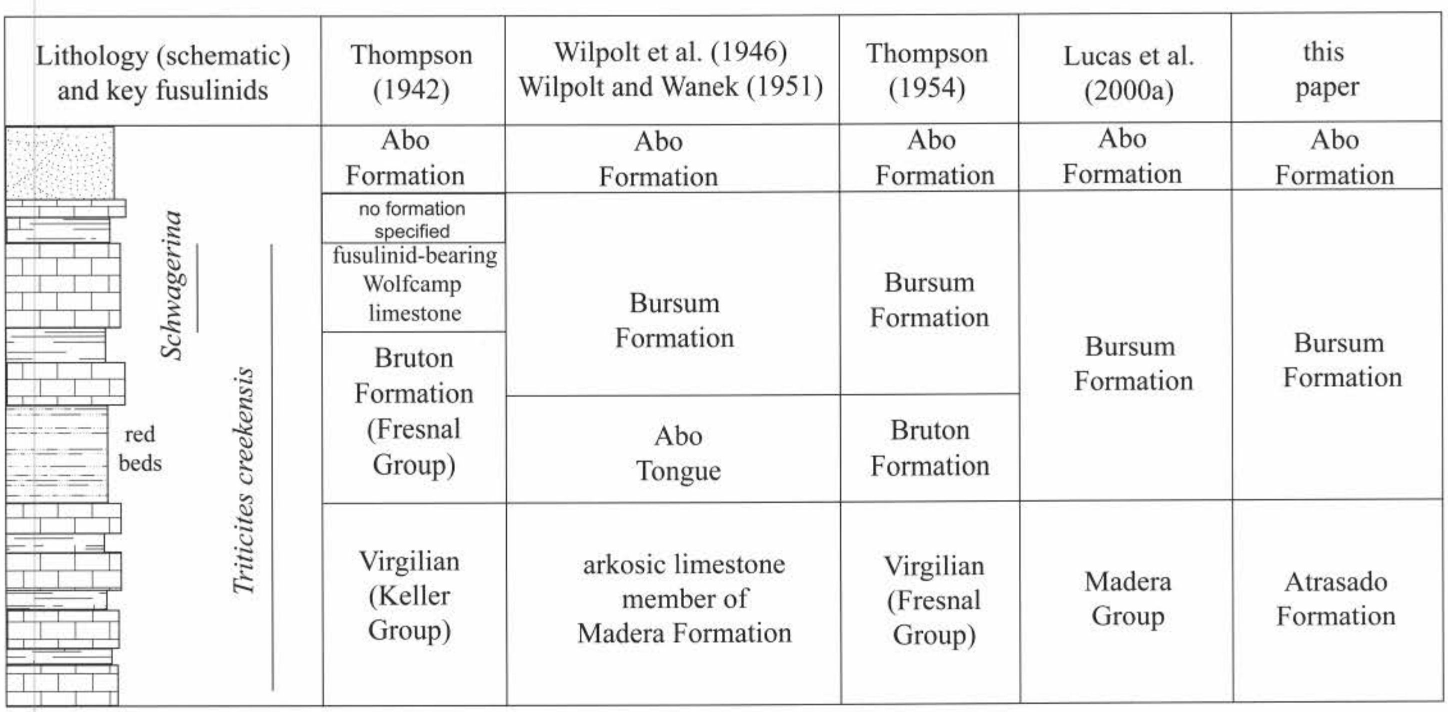


FIGURE 2.Changing concepts of the Bursum Formation stratotype (modified from Lucas et al., 2000a).

of the Bruton Formation (Lucas et al., 2000b). The only problem with Thompson's type Bruton section is that he placed the top of the Bruton Formation at the base of a marine limestone with *Schwagerina*. This limestone, and overlying intercalated marine and nonmarine strata (an interval about 20 m thick: Fig. 3), were assigned to no formation by Thompson (1942).

Thompson (1954, p. 18) subsequently made it clear that his concept of the Bursum was biostratigraphic/chronostratigraphic when he stated that "the term Bursum should be redefined so as to apply only to pre-Abo Wolfcampian rocks of New Mexico." Thompson therefore reassigned the upper 20 m of strata above his Bruton type section and below the Abo to the Bursum Formation (Fig. 2), but he also stated that "a lower part of the Bursum as defined by Wilpolt et al. here is retained in the Bruton formation." Thompson (1954) did not provide a description of the Bursum Formation type section, and his cross-section (Thompson, 1954, fig. 5) is so generalized that it is unclear exactly how he might have interpreted that section.

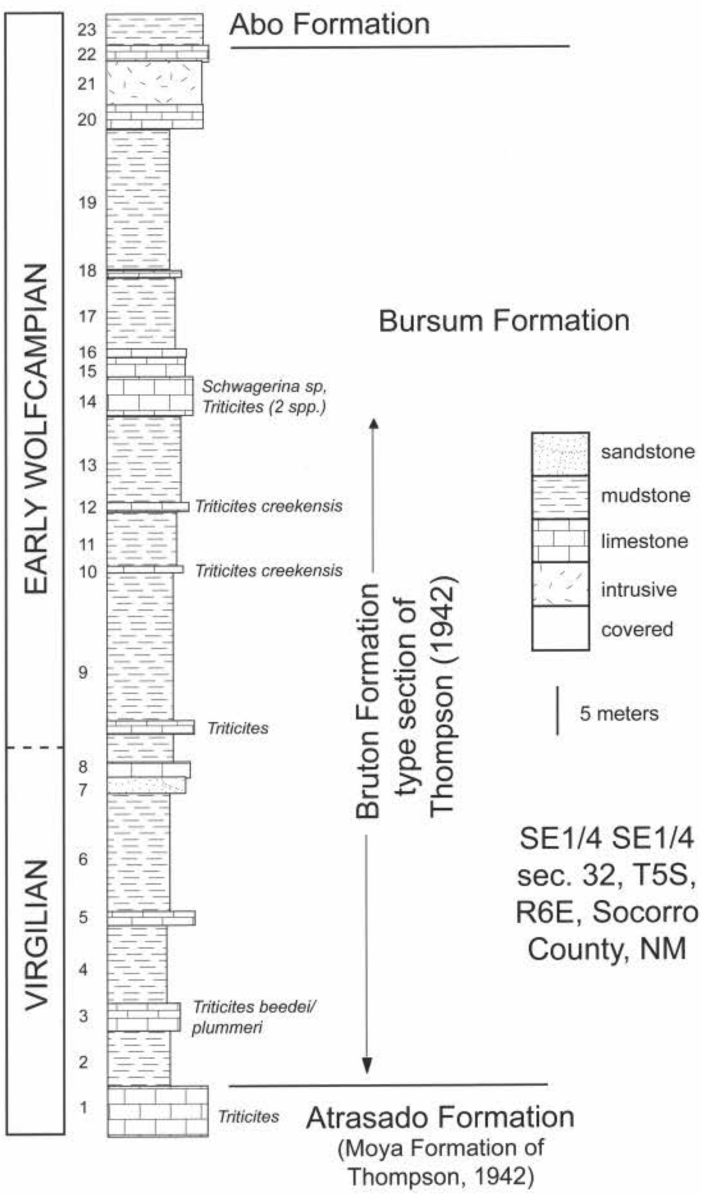


FIGURE 3. Type section of the Bruton Formation.

After Wilpolt et al. (1946), Bursum came to be widely used as a formation name in central New Mexico, but no new data were presented on its type section. Lucas et al. (2000a) described in detail the type section of the Bursum Formation and documented its fusulinacean assemblages (also see Lucas and Wilde, 2000). Here, we review the lithostratigraphy of the type section, interpret sedimentary environments based primarily on microfacies, and document the macroinvertebrate paleontology of the type Bursum.

LITHOSTRATIGRAPHY

The type section of the Bursum Formation (Fig. 4) designated by Wilpolt et al. (1946) is in the Hansonburg Hills of Socorro County in the NE ¼ SE ¼ sec. 1, T6S, R4E, between Cornet Tank and the Bursum Triangulation Point (Fig. 1). Here, the Bursum Formation crops out as a NW-SE-striking belt of strata that dip about 25° to the NE. Cornet Tank is built in valley floor alluvium, and outcrops immediately east of the tank are strata of the Permian (Leonardian) Yeso Formation that dip about 60° to the NNW. This is because a high angle normal fault has downdropped Yeso strata west of limestones and drab calcareous shales of the Atrasado Formation of the Madera Group (arkosic limestone member of Madera Formation as mapped by Wilpolt and Wanek, 1951: Kues, 2001) that dip eastward on the east side of the fault. Indeed, east of the fault, a single, eastward-dipping section of Atrasado, Bursum and Abo formations is present (Fig. 1).

At the type section (Fig. 4), we place the Bursum-Atrasado contact at a point of maximum lithologic contrast that facilitates mappability of the base of the Bursum Formation. Thus, the basal interval of the Bursum Formation is "red" (pale brown) mudstone with numerous calcrete nodules and lenticular beds of arkosic sandstone of fluvial origin (Fig. 4, bed 6), which disconformably? overlies gray limestones and brownish gray shale of the upper part of the Atrasado Formation (Fig. 4, beds 1-5). The red mudstone includes a single, thin lens of limestone with myalinid bivalves and other marine fossils (NMMNH locality 4978). The sandstone beds have trough axis orientations that indicate paleoflow was to the northwest. Probably, Wilpolt and Wanek (1951) mapped the lower red beds we assign to the Bursum Formation (Fig. 4, units 6-12) as a tongue of the Abo Formation. However, these beds do not merge laterally with the Abo and are thus assigned by us to the Bursum (for similar assignment, see Bachman, 1968).

The Bursum-Abo contact is also a readily mappable boundary characterized by distinctive lithologic contrast. Thus, the basal Abo is reddish brown and grayish red sandstone at the base of a nearly monochromatic succession of red beds of mudstone and fluvially-deposited sandstone and conglomerate (Fig. 4, unit 45). Underlying Bursum strata are grayish limestones and pale red and yellow shales (Fig. 4, units 38-44).

At the type section, the Bursum Formation is mostly shale (55% of the measured section) and lesser amounts of mudstone (23%) and lime mudstone and packstone (19%). Minor rock types are conglomerate (2%), sandstone (< 1%) and calcarenite (< 1%).

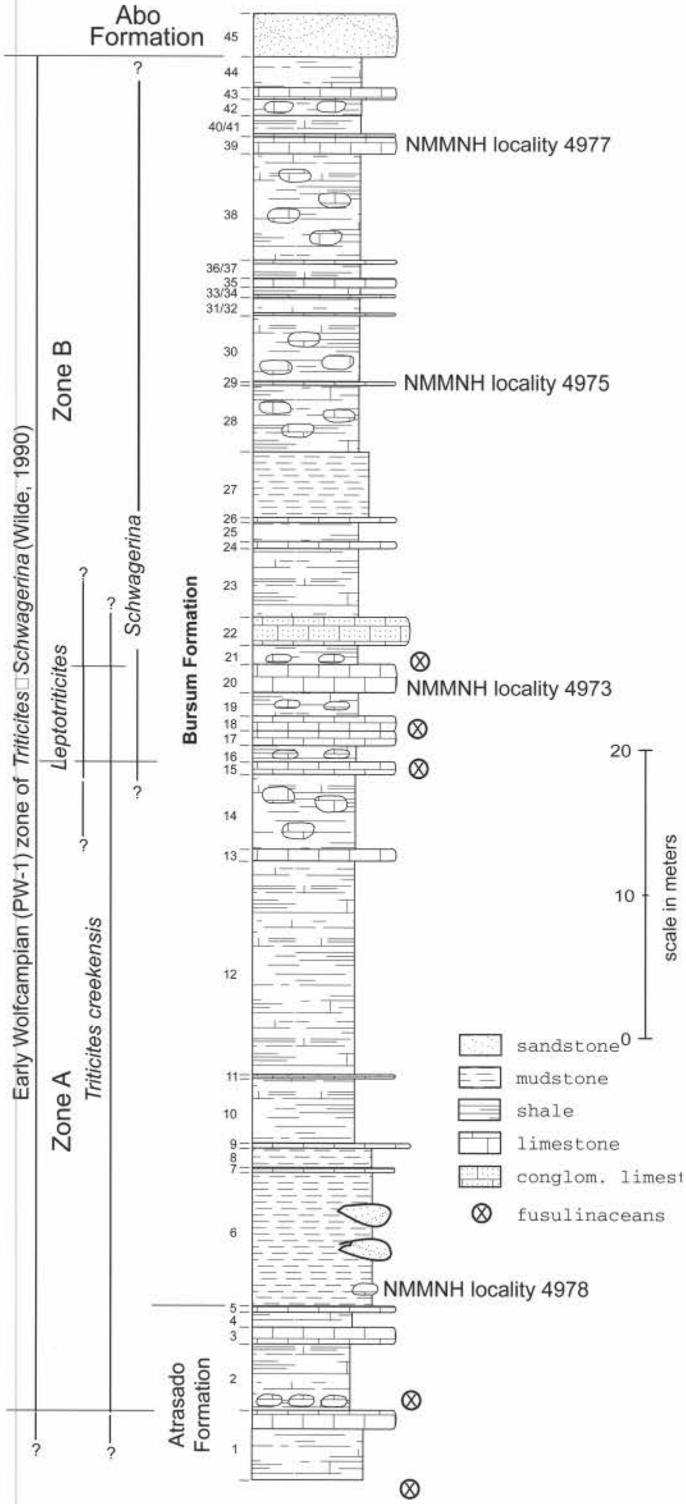


FIGURE 4. Type section of the Bursum Formation showing fossil distribution.

Bursum shales are dominantly "red" (pale reddish brown) and calcareous. Some shale intervals have abundant nodules of limestone. Bursum limestone beds are medium gray or dark gray, and are either unfossiliferous lime mudstones or fusulinacean-brachiopod-bryozoan packstones. The limestone beds form ledges or cuestas between shale slopes (Lucas et al., 2000a, fig. 4). Some shale beds, and the siliciclastic mudstone beds, particularly in the lower half of the type section (Fig. 4, units 6-16), are "red" (pale brown or grayish red). Conglomerate beds are clast supported and composed of limestone pebbles.

Thus, at its type section the Bursum Formation is a lithologically distinctive, readily mappable lithostratigraphic unit between the Atrasado and Abo formations. Unlike underlying Atrasado strata, the Bursum contains substantial intervals of red-bed shale and mudstone, and some beds of limestone-pebble conglomerate and trough-crossbedded sandstone. Unlike the overlying Abo Formation, the Bursum contains beds of marine limestone and calcareous shale. The unit is thus transitional between wholly marine (Atrasado) and wholly nonmarine (Abo) units, but retains an unique character.

Beginning at the type section, the Bursum Formation can be mapped southward in the Hansonburg Hills and other areas immediately west of the Oscura Mountains (Wilpolt and Wanek, 1951). Indeed, it has been recognized in nearly continuous outcrop as far south as Mockingbird Gap in the northern San Andres Mountains (Bachman, 1968; Lucas and Kues, 2001). Wilpolt et al. (1946) also mapped the Bursum Formation in the Joyita Hills and the Los Pinos and Manzano Mountains of Socorro, Torrance and Valencia Counties in central New Mexico (also see Kottlowski, 1963; Kottlowski and Stewart, 1970; Myers, 1973, and references they cite).

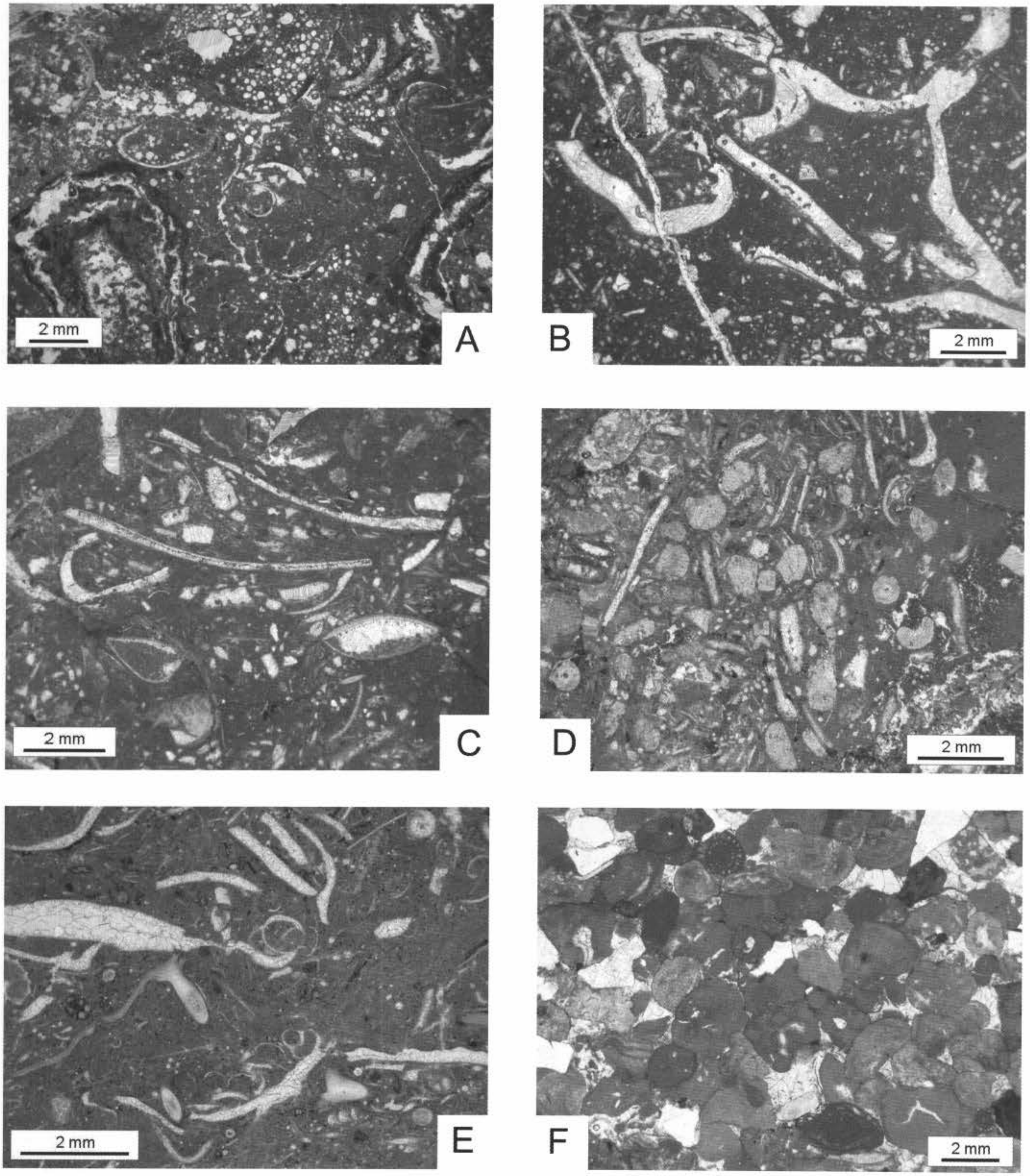
MICROFACIES AND SEDIMENTARY ENVIRONMENTS

We studied thin sections of all resistant units in the Bursum type section (Figs. 5-6).

Atrasado Formation

At the Bursum type section, limestones of the Atrasado Formation consist dominantly of bioclastic wackestone and subordinate phylloid algal wackestone and crinoidal wackestone/packstone. Bioclastic wackestones (units 1, 3 and 5: Figs. 5A-C) are poorly sorted, nonlaminated and bioturbated, and consist of gray micritic groundmass. Locally, some calcite cement is present. Larger bioclasts are recrystallized fragments of phylloid algae and shell fragments derived from bivalves and brachiopods. Small bioclasts include shell debris, echinoderms, bryozoans, ostracods, smaller foraminifers (*Calcitornella, Climacammina magna, Diplosphaerina, Globivalvulina, Syzrania, Tetrataxis, Tuberi-*

FIGURE 5. Thin section photographs of microfacies types of the upper part of the Atrasado Formation and type Bursum Formation (Fig. 4). A, Bioclastic wackestone composed of gray micrite, abundant small recrystallized sphaerical grains (?algal spores), recrystallized shell debris, echinoderms, bryozoans, ostracods, smaller foraminifers and recrystallized fragments of phylloid algae which are microbially encrusted (lower left) (unit 1). B, Algal wackestone composed of gray micritic groundmass containing large recrystallized fragments of phylloid algae (?*Eugonophyllum*), small algal (continued on next page)



fragments, subordinate echinoderms, ostracods, smaller foraminifers and bryozoans (unit 3). C, Bioclastic wackestone. Large bioclasts are mostly shell fragments (bivalves, brachiopods), subordinate recrystallized phylloid algae. Echinoderms, bryozoans, smaller foraminifers and ostracods are present. Groundmass is micrite. Interior of brachiopod (lower right) displays a well developed geopetal structure (unit 3C). D, Crinoidal wackestone/packstone, composed mostly of crinoid stem fragments, subordinate shell debris, bryozoans, phylloid algae, gastropods, ostracods and smaller foraminifers embedded in gray micrite (unit 5). E, Bioclastic wackestone containing abundant recrystallized shell debris and fragments of phylloid algae, subordinate gastropods, echinoderms, bryozoans, smaller foraminifers and brachiopod spines embedded in gray micrite (unit 9). F, Mixed siliciclastic-carbonate sandstone, moderately sorted and grain supported, composed mostly of recrystallized micritic carbonate grains, subordinate of detrital quartz and rare detrital feldspar grains. A few bioclasts (fusulinaceans, shell fragments, echinoderms) are present. The groundmass is blocky calcite cement (unit 6).

tina), gastropods, the calcareous alga *Epimastopora,* and locally abundant small spherical grains (?algal spores). Larger bioclasts are encrusted by cyanobacteria and rarely by *Palaeonubecularia*. The algal wackestone (unit 3: Fig. 5B) contains large, recrystallized phylloid algal fragments (?*Eugonophyllum*) and abundant small algal fragments, subordinate echinoderms, ostracods, brachiopod shell debris and bryozoans.

Crinoidal wackestone/packstone (Fig. 5D) is poorly sorted and consists of moderately to densely packed crinoid stem fragments, a few molluscan fragments, bryozoans, calcareous algae, ostracods and smaller foraminifers (*Calcitornella, Diplosphaerina, Syzrania, Tetrataxis*). A few micritic intraclasts are present too. The groundmass is gray micrite with minor amounts of calcite cement.

The limestones of the uppermost Atrasado Formation are characterized by a relatively high diversity biota. The presence of calcareous algae, abundance of micritic groundmass and the fossil assemblage is consistent with deposition in a low energy, shallow marine environment within the photic zone.

Bursum Formation

In the lowermost part of the Bursum Formation two types of sandstone are recognized petrographically: (1) coarse-grained arkosic arenite and (2) mixed siliciclastic-carbonate sandstone. The arkosic arenite is poorly sorted, and the grains are angular to subangular. The dominant grain type is detrital quartz, mostly monocrystalline, and subordinately polycrystalline. Detrital feldspars are quite abundant; they are mostly untwinned, occur as large and small grains and in most cases are slightly altered. Some rock fragments composed of quartz and feldspar as well as quartz and micas are present. Detrital micas (biotite and muscovite) are rare. Some detrital quartz grains display authigenic overgrowths. The groundmass consists of dark silty matrix.

Mixed siliciclastic-carbonate sandstone (Fig. 5F) is coarse-grained, moderately to well sorted and composed mainly of lithoclastic carbonate grains. Gray to brownish-gray micritic, unfossiliferous lithoclasts displaying small septarian fissures (reworked caliche) are the most abundant grain type. Detrital quartz grains are of minor abundance, and detrital feldspars are rare. Some bioclasts are present, mostly fusulinid tests, and rarely echinoderms, molluscan fragments and bryozoans. The groundmass consists mostly of blocky calcite cement, although some micrite is present. The presence of bioclasts indicates deposition in a shallow marine, high energy environment, probably tidal channels.

The thin limestone horizon of unit 9 (Fig. 5E) is a bioclastic wackestone composed of a few larger bioclasts (molluscan shell fragments and platy algae) and small bioclasts, including molluscan shell debris, ostracods, subordinate gastropods, echinoderms, bryozoans, smaller foraminifers (*Calcitornella, Diplosphaerina, Earlandia, Globivalvulina, Syzrania*), brachiopod spines and locally abundant spicules.

Unit 13 (Fig. 6A) is an approximately 1 m thick limestone composed of phylloid algal wackestone and fine grained bioclastic wackestone. The phylloid algal wackestone consists of gray micritic and pelmicritic groundmass and abundant recrystallized phylloid algal fragments. Minor constituents are fragments of bivalves, brachiopods, echinoderms, bryozoans, ostracods, gastropods and rare smaller foraminifers (*Calcitornella*). The fine-grained bioclastic wackestone contains abundant small bioclasts including sponge spicules, ostracods, shell debris, rarely echinoderms, bryozoans and smaller foraminifers (Fig. 6A). The nodular limestone is composed of gray limestone nodules up to several cm in diameter, which are imbedded in brownish-gray micrite containing a few small bioclasts. The microfacies of the limestone nodules is fine-grained bioclastic wackestone.

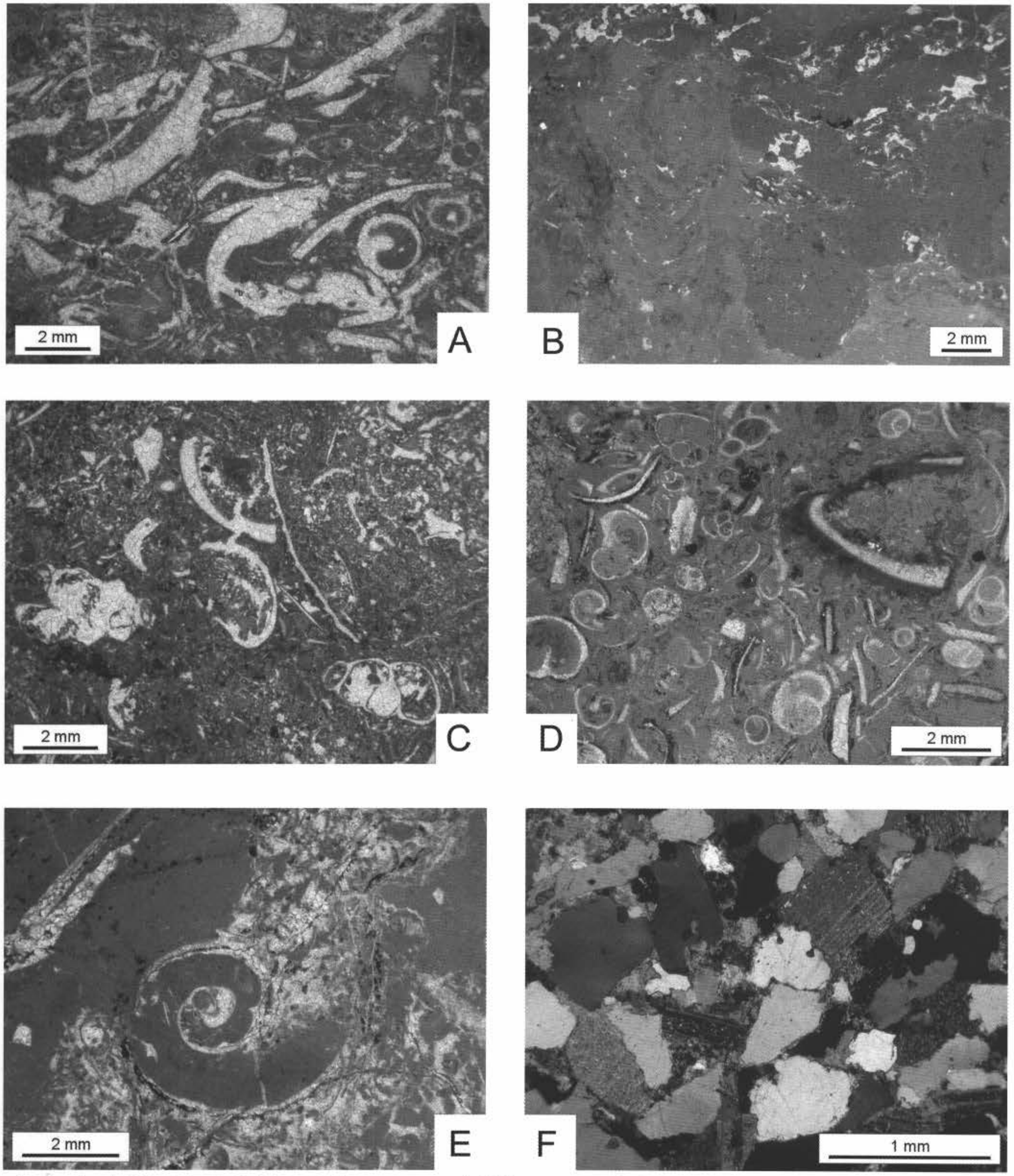
The thick limestone of unit 20 is formed of inhomogeneous, bioturbated mudstone (Fig. 6B) containing only a few fossil fragments (ostracods, small gastropods, echinoderm fragments and very rarely bryozoans). Unit 22 (Fig. 6C) consists of poorly sorted, bioturbated bioclastic wackestone/grainstone. The matrix is fine-grained bioclastic micrite containing abundant small bioclasts, particularly mollusc shell debris, ostracods and smaller foraminifers (*Syzrania*). Larger bioclasts consist of diverse molluscan fragments, bryozoans, recrystallized phylloid algae and echinoderms

Unit 24 (Fig. 4) is a nonlaminated, moderately sorted, mixed siliciclastic-carbonate siltstone composed of subangular detrital quartz grains, some detrital feldspars, rare detrital micas and abundant micritic carbonate grains. Some bioclasts are present, mostly ostracods, and rare smaller foraminifers (*Diplosphaerina, Globivalvulina*). The detrital grains are cemented by calcite.

The thin nodular limestone of unit 26 consists of small limestone nodules (up to several cm in diameter) of fine-grained bioclastic wackestone. The pelmicritic groundmass contains a diverse fossil assemblage of diverse molluscan fragments, echinoderms, bryozoans, brachiopod spines, ostracods, smaller foraminifers (*Calcitornella, Diplosphaerina, Globivlavulina, Syzrania, Tetrataxis*), and rare trilobite fragments. The limestone nodules are frequently bounded by microstylolites, indicating pressure solution. The groundmass between the limestone nodules is gray micrite and fine-grained siltstone.

The uppermost limestone beds (units 39 and 43) consist of bioclastic wackestone. The wackestone of unit 39 (Fig. 6D) contains diverse and abundant fragments of bivalves, brachiopods and gastropods, and subordinate crinoid fragments, ostracods and smaller foraminifers (*Globivalvulina, Tetrataxis*). Many shell fragments are encrusted by *Girvanella* and other micritic algae forming oncoid grains. The bioclastic wackestone of the uppermost limestone bed (unit 43) is fine-grained, slightly nodular, and bioturbated (Fig. 6E). The groundmass consists of micrite, which is locally pelmicrite. Also present sparse bioclasts of gastropods, echinoderms, ostracods and a few smaller foraminifers (mostly *Calcitornella*, rarely *Syzrania*). The top of unit 43 is a recrystallized dolomicrite, (it originally was a bioturbated micrite/pelmicrite), with a texture that indicates a probable unfos-

FIGURE 6. Thin section photographs of microfacies types of the Bursum Formation (continued). A, Bioclastic wackestone composed of recrystallized shell debris and phylloid algae, subordinate gastropods, brachiopods, echinoderms, bryozoans, ostracods and some smaller foraminifers are present. The groundmass is (Continued on next page)



gray micrite and peloidal micrite (unit 13). B, Mudstone, composed of inhomogenous micrite, locally pelmicrite, almost unfossiliferous (very rare ostracod shells), containing small irregular voids filled with calcite cement (unit 20). C, Bioclastic wackestone, composed of micritic and pelmicritic groundmass, some larger bioclasts (recrystallized shell debris, gastropods, phylloid algae) and abundant small bioclasts, mostly recrystallized (unit 22). D, Bioclastic wackestone composed of abundant recrystallized shell fragments (mostly bivalves) and small gastropods, subordinate echinoderm fragments, ostracods and smaller foraminifers, embedded in micritic groundmass. Some bioclasts are microbially encrusted (unit 39). E, Gray mudstone containing a few recrystallized gastropods and other unidentifiable bioclasts, and locally abundant small recrystallized bioclasts, peloids and some calcite cement (unit 43). F, Moderately sorted subangular arkosic sandstone composed of abundant monocrystalline and some polycrystalline quartz, abundant detrital feldspars (slightly altered), rare rock fragments, cemented by calcite (unit 45).

siliferous caliche horizon.

The sandstones, intercalated in shale in the lowermost part of the Bursum Formation, are probably incised channel fills. Bioclasts in the mixed siliciclastic-carbonate sandstone clearly point to deposition in a shallow marine, high energy environment, most probably in tidal channels. The arkosic sandstone is most likely a nonmarine fluvial channel deposit.

The thin intercalated limestones, which are dominantly composed of bioclastic wackestone, subordinately of phylloid algal wackestone and bioclastic mudstone, contain a relatively diverse biota, including calcareous algae, smaller foraminifers and fusulinaceans, brachiopods, bivalves, gastropods, bryozoans, echinoderms, ostracods and rarely trilobites, indicating deposition in a shallow, low-energy open shelf environment in the photic zone with normal salinity. Dominance of fine-grained carbonate sediments with frequent bioturbation points to deposition below the fair weather wave base, where the sea floor was affected by currents and waves only during storm events (forming grainstones: unit 22).

The uppermost limestone bed (unit 43), characterized by a wackestone with a low diversity fauna, was deposited in a restricted, low energy shallow marine environment. The top of this limestone bed probably represents a calichified horizon indicating subaerial exposure.

The thin limestone intercalations formed during rapid transgressions of relatively short duration. The fact that the limestones do not show any indications of karstification or pedogenic overprint (except the uppermost limestone of unit 43) indicates that the limestones have not been exposed subaerially, but were overlain by red shales/mudstones probably also deposited in a shallow marine coastal environment. Most of the red beds, particularly those containing caliche nodules, were deposited subaerially, most probably on a coastal plain environment. Arksoic sandstones represent fluvial deposition on this coastal plain.

FUSULINACEANS

Lucas et al. (2000a; also see Lucas and Wilde, 2000) documented fusulinaceans that indicate two local zones are represented in the type Bursum. Zone A extends from the base of the Bursum to the top of bed 15 (Fig. 4), or about 62 m, and includes *Triticites* sp. C, *T. creekensis,* and *Leptotriticites fivensis*. Zone B occurs within an interval of only about 10 m in the middle of the formation and includes *Triticites creekensis, Leptotriticites glenensis, Schwagerina grandensis,* and *S. campensis*.

Inasmuch as *T. creekensis* is in the lowest and highest collection, the entire section could be referred to that zone. Also, *Leptotriticites* occurs in beds 15 and 18 only, which could be representative of a thin subzone of that genus. *Schwagerina* does not occur in Zone A. We know from other areas of Kansas, Texas, and New Mexico that this zonation is not useful regionally, but may be locally. The entire Bursum fusulinacean fauna is typical of the early Wolfcampian (Wilde, 1990, zone PW-1), which is recognizable throughout North America.

INVERTEBRATE PALEONTOLOGY

Introduction

Although fusulinaceans from the Bursum Formation are well known (e.g., Lucas et al., 2000a), little information on the macroinvertebrate fossils of the Bursum has been reported since the formation was first recognized by Wilpolt et al. (1946). Our study of the Bursum type section has yielded marine invertebrate fossils from several horizons. These were briefly reported by Kues (in Lucas et al., 2000a) and Kues et al. (2000) and here are briefly summarized (see Kues, 2002a, for a complete description).

Girty (1909; also see Lee, 1909) first studied the Bursum invertebrate fauna, and he reported 37 taxa from strata he termed "lower Abo" at Abo Canyon, Mesa del Yeso, and in the northern part of the Sandia Mountains. Other than restudy or modernization of the names of a few of Girty's taxa, no subsequent studies of the Bursum fauna have been published. The fauna of the Bursum type section is from a locality Girty did not sample. It encompasses several different assemblages (Table 1) and paleoenvironments, and its composition and age relationships complement the fusulinacean record and add to information regarding the degree of faunal change across the Pennsylvanian-Permian boundary.

Faunal Assemblages

The 85-m-thick Bursum type section contains four limestone intervals yielding marine invertebrates, in addition to other units producing only fusulinaceans or which appear to be marine but lack identifiable fossils (Fig. 4). These four limestone intervals are at the base of unit 6 (NMMNH locality L-4978); units 19 and 21 (L-4973); unit 29 (L-4975), and unit 39 (L-4977), which are approximately 7 m, 49 m, 67 m, and 80 m, respectively, above the base of the Bursum (Fig. 4). A few additional fossils were collected as float from unit 14 (L-4976), but their exact stratigraphic provenance is not known.

The assemblage from the base of unit 6 is in a thin (5-cm-thick) limestone containing a dense coquina of hematized bivalve shells and bioclastic debris, locally with a few hematitic nodules and weathered limestone pebbles. Most of the bivalve shells are *Septimyalina burmai* Newell, and are often perforated by probable sponge borings. Occasional fragments of *Aviculopecten*, *Aviculopinna* and *Schizodus* were also observed within the coquina layer. Isolated specimens of the bivalves *Schizodus* and *Avuiculopinna*, the gastropod *Retispira*, the brachiopods *Derbyia* and *Meekella*, rhomboporoid bryozoans and isolated crinoid columnals also were collected from this unit. These fossils represent a wave-concentrated nearshore marine assemblage, with a minor contribution from offshore stenohaline taxa that were washed in.

Units 19 and 21 are thin, gray limestones separated by a thicker limestone bed that yielded no fossils. This interval is characterized especially by large productoid brachiopods (*Reticulatia americana* [Dunbar & Condra]), and the fauna consists almost entirely of a moderate diversity of brachiopods (Table 1) and a few bivalves, such as *Aviculopinna peracuta* (Shumard) and *Pseudomonotis hawni* (Meek & Hayden), together with fusulinaceans (*Schwagerina*). This assemblage suggests a shallow, marine, relatively offshore shelf environment. One of the brachiopods, *Neospirifer*, in particular has been interpreted as a

TABLE 1. Algal and invertebrate taxa from units in the Bursum type section, and numbers of specimens observed (for units 6, 14, 21, and 29) or subjective estimate of abundance for unit 39 (A = abundant; C = common; MC = moderately common; UC = uncommon; R = rare).

SPECIES	**Unit 6**	**Unit 14**	**Unit 21**	**Unit 29**	**Unit 39**
ALGAE					
Ottonosia sp.				11	
BRYOZOA					
Fenestrate fragments				1	
Rhomboporoid fragments	1			6	
BRACHIOPODA					
Orbiculoidea sp.				4	
Derbyia aff. *strophomenoidea* Cooper & Grant			1	7	
Derbyia sp. indet.	3			22	
Meekella striatocostata (Cox)			1		
Meekella sp. indet.					
Neochonetes granulifer (Owen)				93	
Juresania nebrascensis (Owen)		2		42	
Reticulatia americana (Dunbar & Condra)			36		
Hystriculina wabashensis (Norwood & Praten)			1		
Kozlowskia? sp.			1		
Linoproductus sp.			3		
Composita subtilita (Hall)			3		
Neospirifer alatus Dunbar & Condra			3		
BIVALVIA					
Nuculopsis aff. *Girtyi* Schenk				2	
Nuculavus sp.					R
Polidevcia sp.					R
Parallelodon aff. *kansasensis* Sayre				18	
Aviculopinna peracuta (Shumard)	1		1	21	
Septimyalina burmai Newell	C			70	C
Aviculopecten sp.	3			15	MC
Pseudomonotis hawni (Meek & Hayden)			2	1	
Schizodus aff. *Ulrichi* Worthen	1				
Schizodus aff. *alpinus* Hall	1			5	
Schizodus sp. indet.	1				
Permophorus cf. *tropidophorus* (Meek)					C
Permophorus sp. indet.				10	C
Wilkingia terminale (Hall)			1	2	
SCAPHOPODA					
Prodentalium? sp. indet.				1	
GASTROPODA					
Retispira aff. *tenuilineata* (Gerley)	1				
Retispira sp.					MC
Amphiscapha aff. *subrugosa* (Meek & Worthen)				15	
Goniasma lasallensis (Worthen)				9	MC
Stegocoelia (Hypergonia)? sp. indet.					R
Apachella? sp. indet.					C
Naticopsis sp. indet.					UC
CEPHALOPODA					
Mooreoceras sp. indet.				7	R
Ammonoid, indet.				1	
ARTHROPODA					
Trilobites, indet.				5	
ECHINODERMATA					
Crinoid stem fragments	1		1	3	

constituent of offshore communities in the late Paleozoic (e.g., Stevens, 1971; Rollins et al., 1979; Yancey and Stevens, 1981), but large productoids and *Composita* (e.g., the dictyoclostid-*Composita* community of Yancey and Stevens [1981] in Lower Permian strata of Nevada) have been interpreted to range from nearshore to relatively offshore, deeper-water, open-shelf environments. The fusulinaceans in this horizon may indicate more offshore than nearshore stenohaline environments (e.g., Stevens, 197l; Yancey and Stevens, 1981). Many of the fossils of this assemblage, especially larger specimens, have been subjected to expansion of the sedimentary matrix in which they are preserved, producing numerous cracks in the shells and a separation of the resulting shell parts—the so-called "exploded" preservation.

Unit 29 is a dark gray, brown-weathering limestone, typically coarsely crystalline and locally very bioclastic. Concentrations of shells and shell fragments are locally present, and some samples of this limestone are composed chiefly of densely packed gastropod and bivalve steinkerns. This unit contains the most diverse marine assemblage observed in the Bursum type section. It is dominated by brachiopods and bivalves in approximately similar numerical and diversity abundances. *Neochonetes*, *Juresania* and *Derbyia* are the three most abundant brachiopods, and *Septimyalina burmai*, *Aviculopinna peracuta*, *Parallelodon*, *Permophorus* and *Aviculopecten* are characteristic bivalves (Table 1). *Amphiscapha* is a moderately common gastropod, and other groups, including scaphopods, cephalopods, bryozoans, crinoids, trilobites and the alga *Ottonosia* are less common constituents of this assemblage. A shallow marine, open-shelf environment is suggested by the relatively large number of taxa and good representation of stenohaline groups. In Lower Permian strata of Kansas and Oklahoma, the encrusting alga *Ottonosia* is also part of a diverse marine biota, including many of the genera observed in unit 29 of the Bursum type section (Toomey et al., 1988). These authors inferred a shallow marine, low-energy lagoonal environment, possibly colonized by "sea grasses," that supported a brachiopod and bivalve fauna sufficient to provide ample numbers of shells for the alga to colonize and encrust.

The uppermost fossiliferous marine unit of the Bursum type section (unit 39) is a dark brownish-gray, tan weathering, slabby limestone with dense concentrations of mollusc shells and much bioclastic debris. Locally, quartz sand grains and small wood fragments are mixed with the shells. Successive thin layers of shells accumulated in low-energy conditions, as indicated by the fact that bedding planes are typically covered with weathered, disarticulated but frequently unbroken bivalve valves and large numbers of small gastropods. Except for one fragment of a crinoid stem, typically stenohaline invertebrates, such as brachiopods, bryozoans and echinoderms, are absent from this assemblage. The most abundant bivalves are *Septimyalina burmai* and *Permophorus* cf. *P. tropidophorus* (Meek), with lesser numbers of *Aviculopecten* and nuculoid taxa. At least a half dozen gastropod taxa were observed, but most are preserved as unidentifiable steinkerns or as cross sections through shells visible on the bedding planes. Many of these are of moderate size (up to about 20 mm high), rather high spired, and have inflated whorls and deeply indented sutures. Some of these are probably *Apachella*. Poorly preserved *Goniasma*, *Naticopsis* and small-to-relatively-large specimens of the bellerophontid *Retispira* are also present on the surfaces of limestone slabs. The depositional environment appears to have been a quiet, nearshore marine environment, possibly within an enclosed lagoon that experienced minor changes in salinity sufficient to exclude the more stenohaline invertebrate groups. This assemblage marks the youngest marine environments from the area of the Bursum type section, before the nonmarine red clastics of the Abo Formation prograded across it.

In general, the macroinvertebrate faunas of the Bursum type section mainly include species that occur in underlying Virgilian strata of New Mexico or are closely related to such species (e.g., Kues, 1996). Many of these species also occur in the mid-continent region and, for example among the brachiopods, nearly all of the named Bursum species have upper Pennsylvanian to lower Wolfcampian (traditional North American boundary placement) ranges in the cyclothemic sequnces of the American mid-continent (e.g., Dunbar and Condra, 1932). The large brachiopod *Derbyia* aff. *D. strophomenoidea* is an exception, as it is apparently limited to lower Wolfcampian strata in West Texas (Cooper and Grant, 1975). Among the bivalves, *Pseudomonotis hawni* has not been reported below the traditional Virgilian-Wolfcampian boundary in the mid-continent region (e.g., Newell, 1937). Newell (1942) reported that *Septimyalina burmai* has an exclusively Wolfcampian record in the mid-continent, but it is present in Virgilian strata in New Mexico (Kues, 1996). In general, it appears that little change took place in the marine inverstebrate faunas from the Virgilian Atrasado Formation to the Bursum Formation in central New Mexico.

THE BURSUMIAN STAGE

In North America, the Carboniferous (Pennsylvanian)-Permian boundary long corresponded to the base of the Wolfcampian Stage (Virgilian-Wolfcampian boundary). The recent establishment in western Kazakstan of a GSSP (global stratotype section and point) for the Carboniferous-Permian boundary (Davydov et al., 1998) forced the position to change in the North American regional scale. Correlation of this new boundary to the North American fusulinacean zonation indicates that the base of the Permian would now be close to the LO (lowest occurrence) of *Pseudoschwagerina*, which is within the Wolfcampian Stage (e.g., Baars et al., 1994b; Wahlman, 1998). Thus, the newly defined Carboniferous-Permian boundary corresponds to the lower-middle Wolfcampian boundary of earlier usage (Fig. 7).

In the standard global chronostratigraphic scale, each system base corresponds to the base of a stage (e.g., Aubry et al., 1999). Therefore, the secondary standard (*sensu* Cope, 1996) provided by the North American regional stages should also have the Carboniferous (Pennsylvanian)-Permian System boundary correspond to the base of a stage, but this requires some modification or redefinition of the regional stages. Baars et al. (1992, 1994a, b), working in Kansas, proposed to solve this problem by redefining the Virgilian Stage to encompass strata previously included in the lower Wolfcampian (Fig. 7). A second solution, advocated by Ross and Ross (1994), is to recognize an uppermost Carbon-

<table>
<tr><th>PER</th><th>ST</th><th>RUSSIAN PLATFORM FUSULINACEANS</th><th>N. AMERICAN FUSULINACEANS</th><th colspan="4">N. AMER. STAGES</th><th>PER</th></tr>
<tr><td rowspan="2">PERMIAN</td><td rowspan="2">Asselian</td><td>Sphaeroschwagerina fusiformis</td><td rowspan="2">Pseudoschwagerina beedei and Paraschwagerina gigantea</td><td rowspan="3">Wolfcampian</td><td rowspan="2">middle</td><td rowspan="2">Wolfcampian</td><td rowspan="2">Wolfcampian</td><td rowspan="2">PERMIAN</td></tr>
<tr><td>Sphaeroschwagerina vulgaris (aktjubensis)</td></tr>
<tr><td rowspan="2">UPPER CARBONIFEROUS</td><td rowspan="2">Ghzelian</td><td rowspan="2">Ultradaixina spp.</td><td>Triticites creekensis, Schwagerina and Pseudofusulina</td><td>early</td><td rowspan="2">Virgilian</td><td>Bursumian</td><td rowspan="2">PENNSYLVANIAN</td></tr>
<tr><td>Triticites and Dunbarinella</td><td colspan="2">Virgilian</td><td>Virgilian</td></tr>
</table>

FIGURE 7. Position of Carboniferous-Permian boundary on the Russian platform (left, after Davydov et al., 1995, 1997) and the position with respect to the North American stages with three alternative stage usages: traditional (left), expanded Virgilian (middle) and use of Bursumian (right).

iferous Bursumian Stage equivalent to the lower Wolfcampian of earlier usage (Fig. 7).

Various workers have used the term Bursumian, but only Ross and Ross (1994) have presented a rationale for a Bursumian Stage between the Virgilian and Wolfcampian. Nevertheless, Ross and Ross provided no explicit definition of the Bursumian, but instead based it on Thompson's (1954) use of the term Bursum Formation in New Mexico and west Texas, USA. Thus, Ross and Ross (1994, p. 3) stated that Thompson "clearly recognized that this unit [Bursum Formation] had lithologic continuity from north to south in both the San Andres and Sacramento Mountains of south-central New Mexico and that it extended into the northern part of the Hueco Mountains of West Texas." Nevertheless, Thompson's use of Bursum over this broad region was not as a lithostratigraphic unit, but as a fusulinacean biostratigraphic unit (zone). Thus, Thompson (1954, p. 18) stated that "the term Bursum should be redefined so as to apply only to pre-Abo Wolfcampian rocks of New Mexico." This is why he broadly applied the name Bursum to strata now termed the upper part of the Panther Seep Formation (San Andres Mountains: Kottlowski et al., 1956), Laborcita Formation (Sacramento Mountains: Otté, 1959), "Bursum-equivalent limestone unit" (Robledo Mountains: Wahlman and King, 2002) and Hueco Group (Hueco Mountains: Williams, 1963). These strata are not part of a single lithostratigraphic unit (formation), but instead they are an interval of diverse lithotypes with a distinctive fusulinacean assemblage of early Wolfcampian age (also see Kues, 2001). Thus, Thompson used Bursum to refer to a fusulinacean zone, not to a lithostratigraphic unit.

Bursum fusulinaceans, though distinctive, have long been recognized as typical of the early Wolfcampian (e.g., Zone PW-1 of Wilde, 1990). Thus, **"Bursumian"** as currently used is equivalent to a single fusulinacean zone (Lucas et al., 2000a; Davydov, 2001). An alternative biostratigraphy in central New Mexico, suggested by Myers (1988) and implied in the data of Lucas et al. (2000a), could recognize two "Bursumian" fusulinacean zones, a lower one between the LO of *Triticites creekensis* and the LO of *Schwagerina*, and an overlying zone containing primitive *Schwagerina* together with *T. creekensis* and several species of *Leptotriticites*. However, the base of the fusulinacean defined Bursumian is below the base of the Bursum Formation at its type section, and indeed has not been located there (Lucas et. al., 2000a; Lucas and Wilde, 2000). Also, the upper third of the Bursum type section lacks biostratigraphically significant marine fossils, and the nonmarine Abo Formation overlies the Bursum. Clearly, the Bursum lithostratotype is not a suitable type section for a Bursumian Stage (Lucas et al., 2000a).

Indeed, we have studied Bursum Formation sections throughout central New Mexico, and at all sections the upper Bursum lacks biostratigraphically significant fossils and is overlain by nonmarine red beds of the Abo Formation. Therefore, no Bursum Formation section can serve as an ideal stratotype of a Bursumian stage. Even identifying a boundary stratotype point for the base of the Bursumian remains problematic in sections of the Bursum Formation. Furthermore, basinal sections of the Bursum interval are those where Bursum strata are equivalent to part of the upper Panther Seep Formation and lowermost Hueco Group (Kottlowski et al., 1956; Lucas and Kues, 2001). These sections also have a sparse record of fusulinaceans (most notably *Schwagerina* at the Hueco base) and macroinvertebrates (Thompson, 1954; Kottlowski et al., 1956; Soreghan and Giles, 1999; Kues, 2002b; Lucas et al., 2002), and thus do not provide good potential stratotypes for the Bursumian.

Two potential "Bursumian" stratotypes outside of the Bursum outcrop belt are present in New Mexico. One is at Robledo Mountain, where strata of a "Bursum-equivalent limestone unit" immediately underlying the base of the Hueco Group contain a well-studied "Bursumian" fusulinacean assemblage and are overlain by Nealian fusulinaceans at the base of the Hueco Group (Wahlman and King, 2002). The other is in the Pedregosa basin of southwestern New Mexico at New Well Peak in the Big Hatchet Mountains. Here, strata of the Horquilla Limestone contain a remarkable record of fusulinaceans from Virgilian through middle Wolfcampian time (Zeller, 1965; Skinner and Wilde, 1975; Wilde, 1975). However, the "Bursum-equivalent limestone unit" and overlying basal Hueco Group at Robledo Mountain contain a low diversity of fusulinaceans (Wahlman and King, 2002), and the fusulinaceans of the Horquilla Limestone and their stratigraphic ranges have not yet been completely published.

In New Mexico, macroinvertebrates (mostly brachiopods, bivalves and gastropods) from the type section of the Bursum Formation and correlative strata differ little from stratigraphically lower, Virgilian macroinvertebrates (Kues, 1996, 2002a). The significant change in the macroinvertebrate fauna occurs above the Bursum Formation, in the overlying Hueco Group (Kues, 1995, 2002a). Therefore, on the basis of macroinvertebrates alone, the Bursum interval has closest affinities to the traditional Virgilian, and a "Bursumian" stage would be difficult to justify.

Finally, although numerical ages for the "Bursumian" and underlying and overlying stages are uncertain, most evidence suggests that the time represented by "Bursumian" deposition is much less than that represented by any of the North American Pennsylvanian, or Eurasian Carboniferous, stages. Harland et al. (1990) indicated that the shortest of the Eurasian stages, the Gzhelian, was about 6 million years (my) long. The Virgilian in North America, which began before the Gzhelian and ended about 1 my before the end of the Gzhelian, can be estimated based on the information in Harland et al. (1990) at about 7.5 my; the underlying Missourian Stage at 4.5 my, and the overlying Wolfcampian Stage (including what other authors would call "Bursumian") at about 18 my. Ross et al. (1995), on the other hand, without explaining the basis for their ages, compressed the Missourian, Virgilian and "Bursum" stages into about 10 my (Missourian, 3 my; Virgilian, 4 my; "Bursum", 3 my), and considered the duration of the Wolfcampian to be about 12 my. Such great variation in timescales obscures accurate assessment of the length of "Bursumian" time in numerical terms.

More recently, Rasbury et al. (1998), working in the Sacramento Mountains of south-central New Mexico, and using U-Pb dating of paleosols in well-studied cyclic sequences, obtained an age of 302.4 $\pm$ 2.4 Ma for the (traditional) Virgilian-Wolfcampian boundary, and 307 $\pm$ 3 Ma for the Missourian-Virgilian boundary, indicating a length for the Virgilian of 4.6 my. The duration of deposition of the Laborcita Formation, which is of earliest Wolfcampian (traditional boundary) age and coeval with the Bursum Formation (Steiner and Williams, 1968), was given as 2.4 my. Thus, Harland et al.'s (1990) and Rasbury et al.'s (1998) absolute ages for the Missourian and Virgilian, as well as the undoubted long duration of the Wolfcampian, all strongly suggest that these stages are much longer than the "Bursumian" Stage.

The fusulinacean record also supports the idea that "Bursumian" time is much shorter than Virgilian or Wolfcampian time. The "Bursumian" comprises one, or at the most two, plausible fusulinacean zones. In contrast, Myers (1988), working in central New Mexico not far north of the Bursum type section, recognized five successive Virgilian zones, compared to two "Bursumian" zones. And, the data on Midcontinent Virgilian fusulinacean ranges provided by Sanderson et al. (2001) suggests that even more well-defined fusulinacean zones could be defined there, using zone concepts similar to those used for "Bursumian" zones. Thus, if the "Bursumian" were to be accepted as a stage, it would represent a much shorter time interval than any other Carboniferous or Permian stage, and would include only one or two fusulinacean zones. Indeed, such a "Bursumian Stage" would convey no information beyond that available from the fusulinacean zones.

Based on the above observations, we conclude the following:

1. A Bursumian Stage will always lack an ideal stratotype in the Bursum outcrop belt in New Mexico.
2. "Bursumian" as now used is equal to only one or at most two fusulinacean zones and represents considerably less time than other Carboniferous-Permian stages, so the concept of a "Bursumian" stage is no more than a stage name applied to one or two fusulinacean zones.
3. The Bursum Formation has a macroinvertebrate fauna of essentially Virgilian aspect, so on macroinvertebrates alone, its affinities are Virgilian. There is no distinctive "Bursumian" macrofauna.
4. The interval called "Bursumian" may work as a substage of the Wolfcampian, comparable to but of shorter duration than the Nealian or Lenoxian, but of approximately the same magnitude as the substages of the Asselian (Harland et al., 1990). However, this does not realign the North American stage boundaries to match the new Carboniferous-Permian boundary.
5. If there is value in defining a new stage or other named chronostratigraphic unit (substage) between the Virgilian and Wolfcampian, it should be defined outside the Bursum outcrop belt (also see Davydov, 2001).

The simplest solution has already been advocated—to extend the Virgilian upward to include the traditional lower Wolfcampian "Bursumian" interval (= fusulinacean zone PW-1 of Wilde, 1990). This may not satisfy the fusulinacean workers, who recognize the "Bursumian" interval as a distinctive time of transition from typical Virgilian to typical Wolfcampian fusulinacean assemblages. However, it accords well with the macroinvertebrate faunal changes, and would allow the "Bursumian" interval , under a different name, to become a fusulinacean-based substage of the Virgilian. If this strategy is adopted, it would be desirable to define formally and name fusulinacean substages for the remainder of the Virgilian as well.

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