SEDIMENTOLOGY AND GRAPTOLITE BIOSTRATIGRAPHY OF THE VIOLA GROUP (ORDOVICIAN), ARBUCKLE MOUNTAINS AND CRINER HILLS, OKLAHOMA

By

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INTRODUCTION

General Statement

The Viola Group is a middle to upper Ordovician carbonate sequence exposed in the Arbuckle Mountains, Wichita Mountains, and Criner Hills of southern Oklahoma. It is an extensive rock unit in the subsurface being present as far north as South Dakota, and in Kansas, Colorado, Texas, as well as throughout Oklahoma. The Viola Group is over 700 feet thick in the Arbuckle Mountains and 800 feet in the Criner Hills. Its lower part varies from siliceous, laminated, calcareous mudstones to coarse-grained skeletal calcilutites, its middle part is calcarentic wackestones and packstones, and the upper part consists of coarse-grained calcarenites and fine calcirudites.

The Viola Group in Oklahoma was considered until recently as the Viola and "Fernvale" Limestones. Taff (1902) first named and described the Viola Limestone in Johnston County, Oklahoma, and numerous studies have been conducted on the Viola since then. Previous investigators have disagreed on the age and stratigraphic boundaries of the Viola. Glaser (1965) elevated it to group status and in doing so recognized three basic lithostratigraphic units. Recently, Amsden (1979) and Amsden and Sweet (1983) have proposed the names Viola Springs and Welling Formations in place of the Viola and misnomer "Fernvale" Limestones. This latest revision has helped to end the confusion regarding the stratigraphy of the Viola Group.

Although a number of researchers have prepared definitive studies on the Viola Group, notably Glaser (1965), Alberstadt (1967), Amsden and Sweet (1983), none have described exposures of the unit in the Criner Hills except Decker (1933). The brachiopod, conodont, and chitinozoa faunas of the Viola have been recently described by Alberstadt (1967), Sweet (1983), and Jenkins (1969), respectively. However, these studies were restricted to single sections or parts of the Viola. The abundant graptolites, perhaps the most important fossils for biostratigraphy in the Viola, have not been examined in any detail since Ruedemann and Decker (1934). In addition, excellent exposures of the section have been made available since Glaser's (1965) lithostratigraphic study as a result of the construction of Interstate Highway 35 through the Arbuckle Mountains.

Purpose of Study

The aims of this study are to identify the prominent lithostratigraphic subdivisions of the Viola

Group (after Glaser 1965) along Interstate 35, to recognize them in the Criner Hills, and to correlate the subdivisions on the basis of graptolite biostratigraphy. Close examination of the lithostratigraphy and biostratigraphy of these sections provides a basis for interpreting the history of sedimentation and depositional environments for the Viola Group. The upper and lower contacts with the Sylvan Shale and the Bromide Formation, respectively, have also been examined for their sedimentological nature and time-stratigraphic significance.

Previous Investigations

Stratigraphy

The Viola Limestone was first named and described by Taff (1902). The type section is located near the now abandoned village of Viola five miles west of Wapanucka in Johnston County, Oklahoma. Taff's earliest descriptions of the Viola included some of the present upper Bromide Formation. Taff (1903, 1904) later subdivided the formation into three members. Ulrich (1911) assigned the name Fernvale Limestone to the uppermost unit. Edson (1927) recognized the same three lithologic subdivisions of the Viola similar to those of earlier researchers. Decker and Merritt (1931) studied the Simpson Group and reassigned the lowermost portion of the Viola to the Bromide Formation. Wengerd (1948) studied insoluble residues in the Viola

Limestone and established four lithologic members. He was the first to apply a shelf and basin depositional model for the formation. Glaser (1965) elevated the Viola to group status in a comprehensive lithostratigraphic study. He recognized three members: unit 1L (basin laminites) grading shelfward into 1C (calcarentites); unit 2 (calcarentic mudstones and wackestones); and unit 3C (former "Fernvale" Limestone) (coarse-grained skeletal calcarenites) grading basin-ward into 3CM (calcarenitic mudstones and coarse-grained skeletal calcarenites). Amsden (1979) proposed that use of the name "Fernvale" Limestone be discontinued for the unit overlying the Viola Limestone and, in its place, the Welling Formation be substituted. Fernvale is a slightly younger formation in Tennessee that was once thought to be equivalent to the Oklahoma formation. Amsden and Sweet (1983) redescribed the Viola and proposed the name Viola Springs Formation (units 1 and 2 of Glaser). Figures 1 and 2 are a summary of Viola classification of the above workers.

Unconformities

Taff (1902 1904) noted the abrupt contact of the Viola with the Sylvan Shale and suggested that it is uncoformable. Ulrich (1911) recognized an unconformity between the Viola and the "Fernvale" Limestones. Edson (1930) later identified three unconformities associated with Viola strata: at the Bromide-Viola; Viola-Fernvale; and

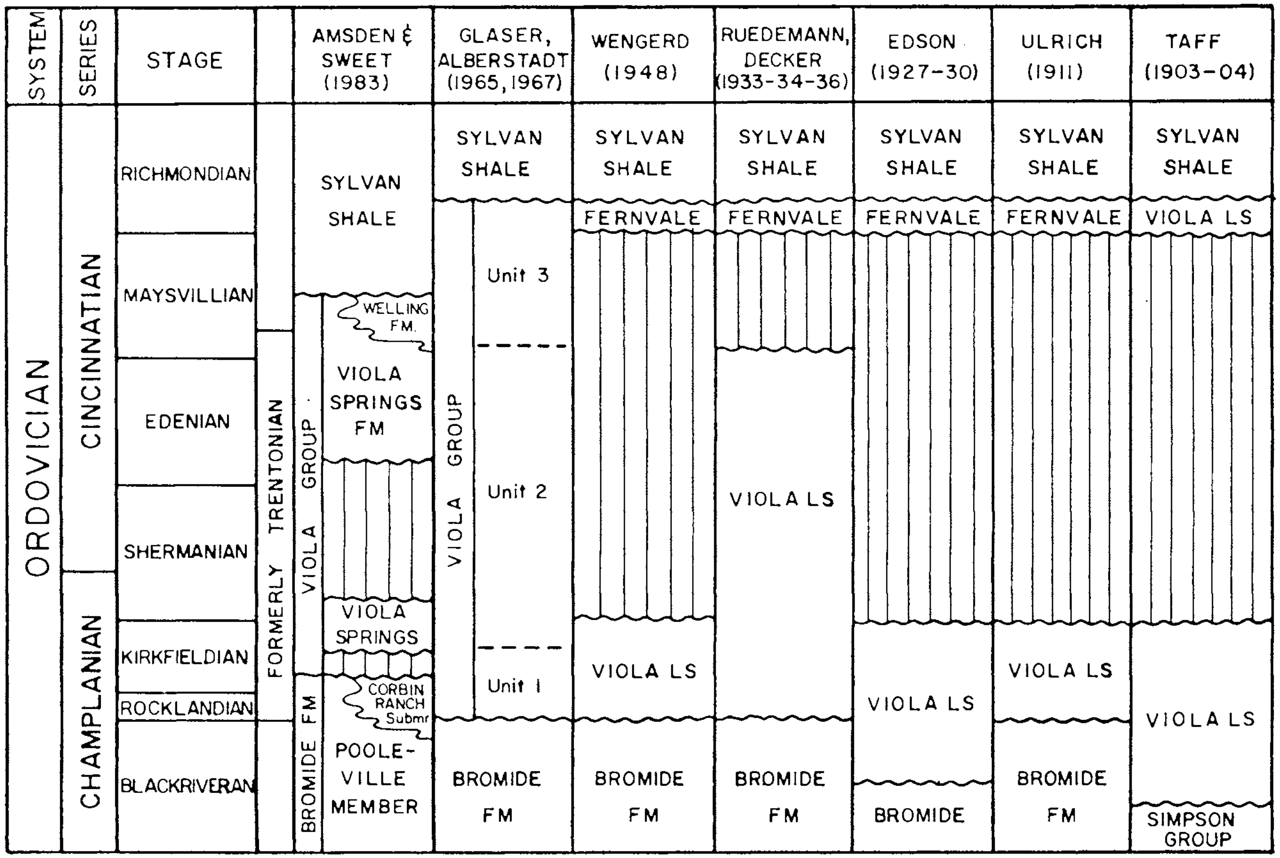


Figure 1. Comparative Correlation Chart for the Viola Group

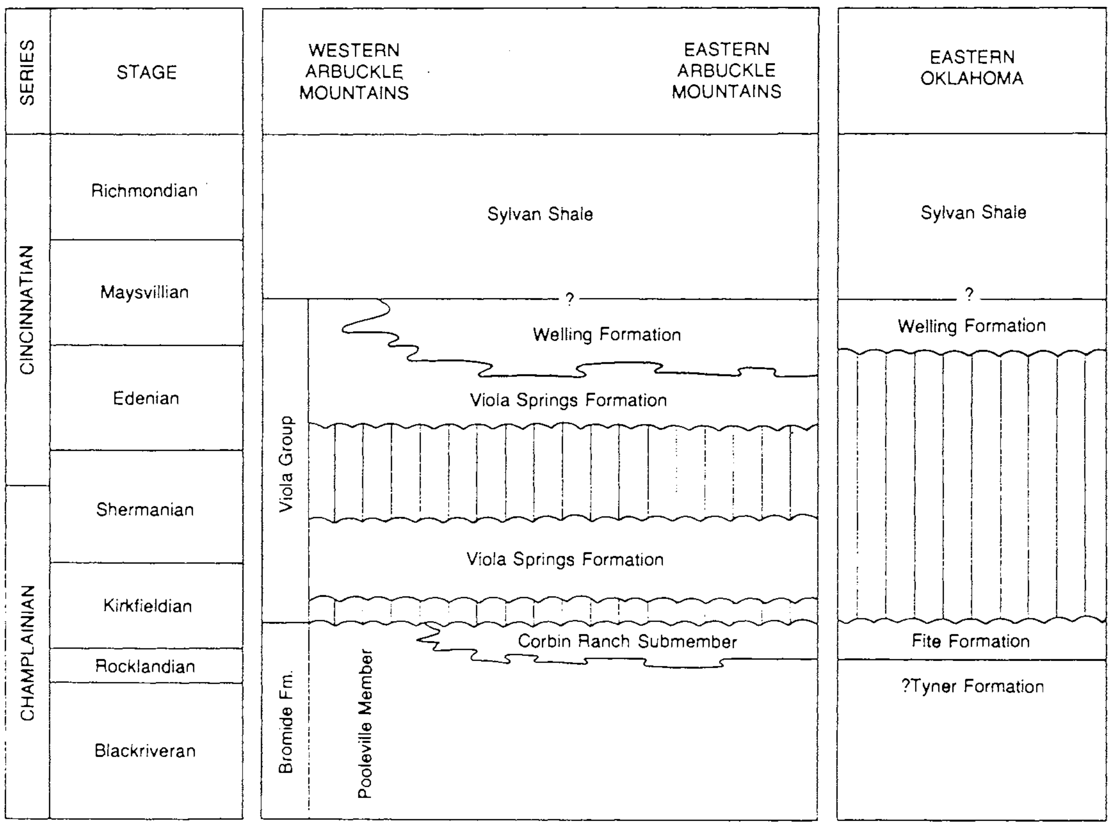


Figure 2. Correlation for the Viola Group in Oklahoma after Amsden and Sweet (1983)

Viola-Sylvan contacts. Decker and Merritt (1931), in redefining the Simpson Group, described an unconformity at the Bromide-Viola contact based on lithologic evidence. Wengerd (1948) concurred with Edson on the position and number of unconformities in the Viola. Glaser (1965) recognized unconformities at the Bromide-Viola and Viola-Sylvan contacts but found no physical evidence suggesting a break within the unit. Alberstadt (1967) proposed that the Viola Group represented continuous sedimentation with no unconformities within it. Jenkins (1969) found the Viola Limestone nearly continuous with the exception of a hiatus in the upper part. Amsden and Sweet (1983) recognized the basal unconformity as well as a major faunal break within the Viola Springs (unit 2). Gagnier (1984; in progress) is studying the pre-Viola unconformity geochemically. She reports that major transgression temporarily thwarted, sedimentation allowing a hardground to develop on the uppermost Bromide. Later pressure solution accentuated the irregular microkarstic Bromide Formation surface.

Biostratigraphy

Ulrich (1911) first identified and described the Viola fauna. Decker (1933) studied graptolites in the Arbuckle Mountains and concurred with Ulrich's preliminary correlations. Ruedemann and Decker (1934) described 30 species and varieties of graptolites.

Correlations based on their study suggested the lower unconformity encompassed early Trentonian time. Decker (1936) correlated the basal Viola to the Womble and Stringtown Shales and the upper Viola to the Big Fork Chert of the Ouachita Mountain region on the basis of graptolites. Alberstadt (1967) established brachiopod zones for the Viola which did not indicate the presence of the Eden-Maysville hiatus suggested by earlier workers. Jenkins (1969) studied the chitinozoa and was able to recognize a hiatus of indeterminable magnitude within the Viola, rather than at formation contacts. Most recently, Sweet (in Amsden and Sweet (1983)) correlated the Bromide, Viola Springs and Welling Formations of the Arbuckle Mountains to the Tyner and Fite Formations of eastern Oklahoma on the basis of conodonts (Figure 2).

Sedimentology

Reid (1980) studied the depositional history and diagenesis of the Viola Limestone and suggested, contrary to Glaser (1965), that the unit represented an upward deepening sequence. Smith (1982) conducted a similar investigation, but concluded that the Viola represented an upward shallowing carbonate sequence. Galvin (1982) established microfacies in the Viola and studied diagenetic events affecting the unit. Grammer (1983) concurred with Smith, Reid, and Galvin with respect to the depositional environment and diagenesis.

Geologic Setting

A great thickness of lower Paleozoic sediments is present in southern Oklahoma. This thickness is a direct result of the formation and evolution of the southern Oklahoma aulacogen which developed and began receiving sediments during the upper Cambrian (Hoffman 1974). The axis of the aulacogen trends roughly northwest-southeast (Figure 3). Stratigraphic units thicken appreciably from northeast to southwest into the aulacogen as a reflection of the difference in rates of subsidence and sedimentation between the craton and aulacogen. The Viola Group was deposited in this setting during the middle and upper Ordovician.

The Viola Group possibly represents the deepest-water carbonate facies of the lower Paleozoic rocks in southern Oklahoma, suggesting that sedimentation was not keeping up with subsidence in the aulocgen during Viola time. Galvin (1982) interpreted the depositional environment as that of a carbonate ramp transitional from a shallow to deep water setting. Sections of the Viola Group on the craton (carbonate platform) are thin and coarse-grained; they represent a shallow water facies. Toward and into the aulacogen (basin), sections rapidly thicken and become finer-grained and represent a progressively deeper-water facies (Figure 4).

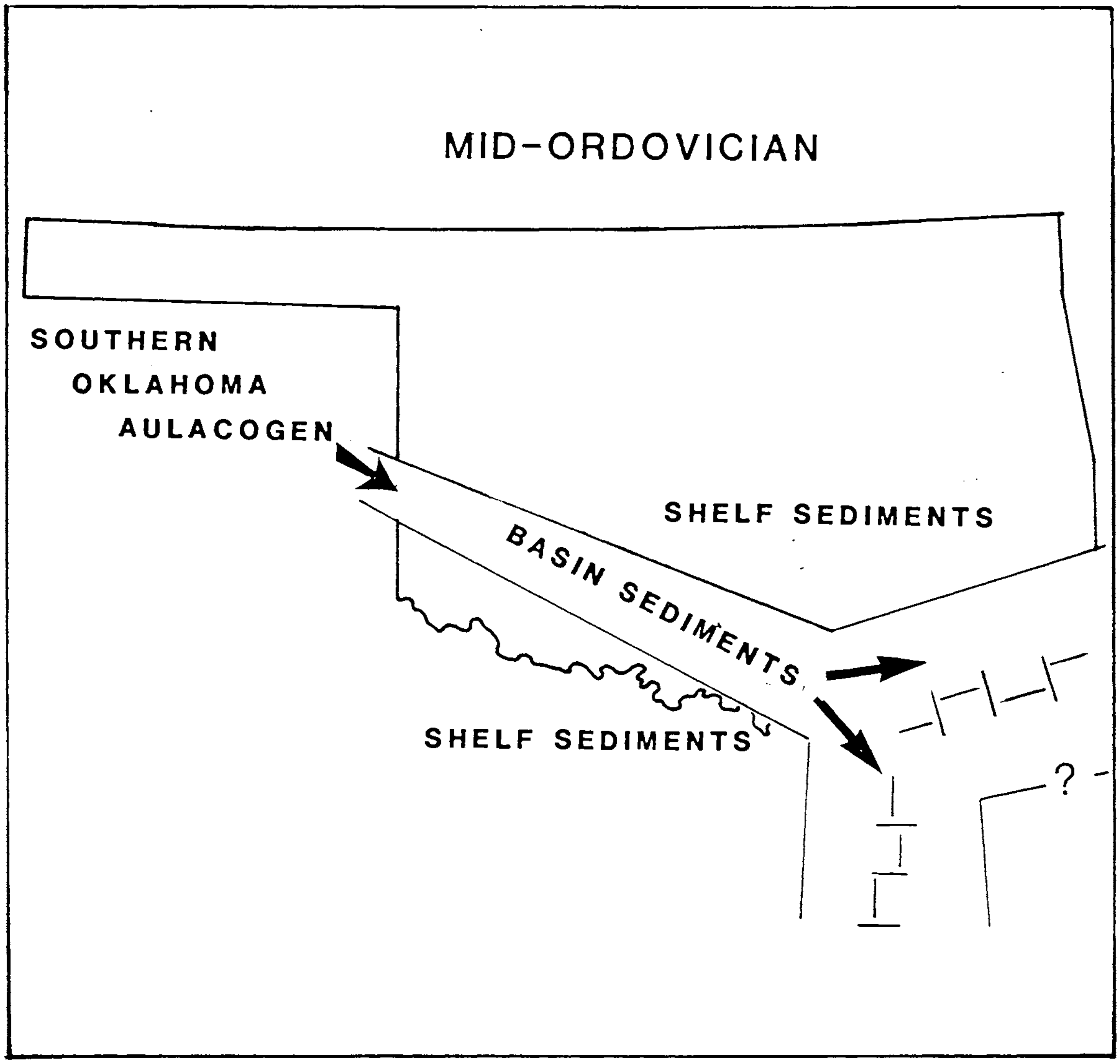


Figure 3. Location of the Southern Oklahoma Aulacogen During Middle Ordovician Times (after Hoffman, Dewey and Burke, 1974)

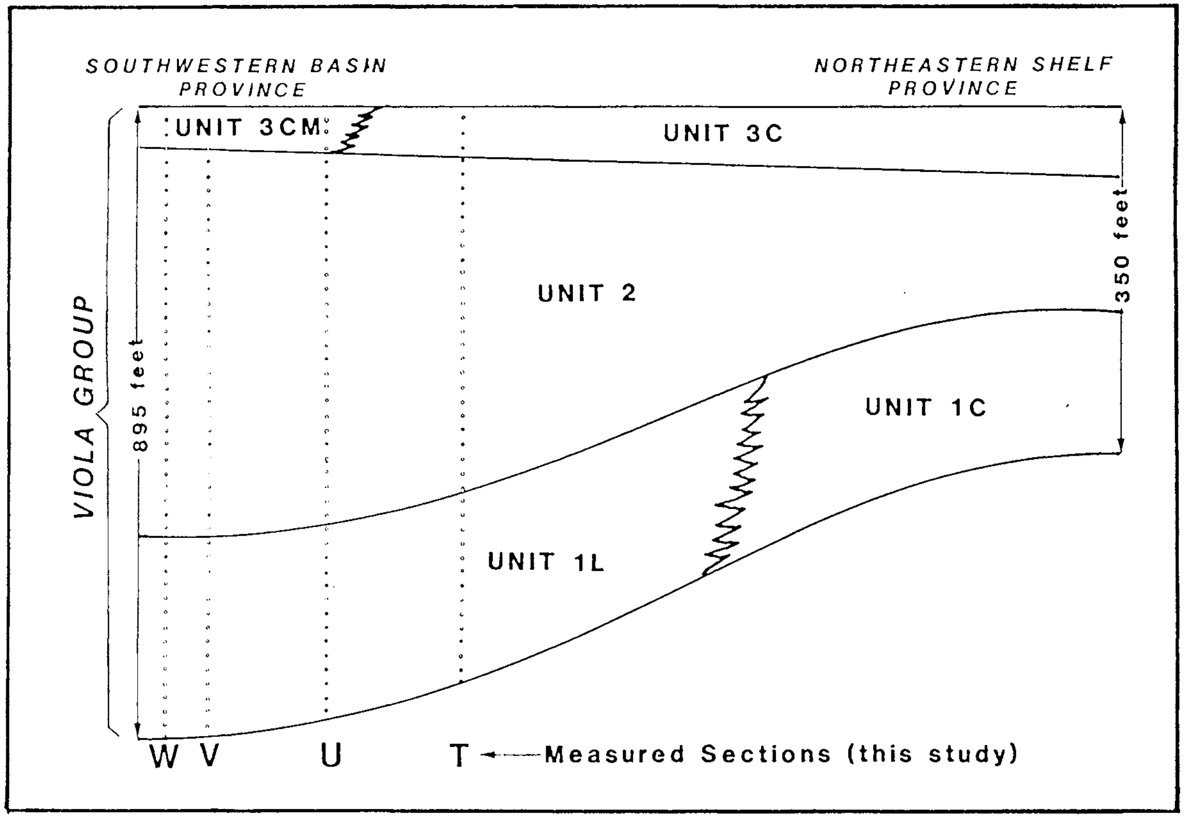


Figure 4. Thickness Variation in the Viola Group Between Northeastern Platform and Southwestern Basin (Aulacogen) Province (after Glaser, 1965)

General Stratigraphy

The Viola Group unconformably overlies the middle Ordovician Bromide Formation and underlies the upper Ordovician Sylvan Shale. The Viola generally overlies the Corbin Ranch Submember of the Pooleville Member of the Bromide. However, in some areas the Corbin Ranch is missing and the Viola rests unconformably on the Pooleville Member. The contact is lithologically abrupt-- marked by the change from the generally coarse-grained, massive limestone of the Bromide Formation to the finer-grained, millimeter laminated, medium bedded lower Viola Group limestones. The upper contact is also well defined and involves a change from the pale yellowish-brown, coarse-grained, upper Viola Group to the pale olive-green Sylvan Shale.

Three distinct lithofacies have been recognized in the Viola Group (Glaser 1965). The lowest, Unit 1L, consists of siliceous, millimeter-laminated, medium bedded mudstones and wackestones in the basin province. It grades shelfward (to the northeast and out of the study area) into 1C, which consists of coarse-grained calcarenitic packstones and grainstones. Unit 1L is characterized in outcrop by parallel, fine to medium bedded limestone containing chert and shaly interbeds. Unit 2 is continuous from the basin to the shelf and consists of calcarenitic wackestones and packstones. Wavy to almost nodular, medium bedded limestone with shaly interbedding characterizes the unit in outcrop. Nodular chert occurs locally in Unit 2. Units 1 and 2 together comprise the newly-named Viola Springs Formation (Amsden and Sweet 1983). Glaser's Unit 3C (formerly the "Fernvale" Limestone, and now the Welling Formation), is composed of well-washed, very coarse-grained, skeletal calcarenites. Unit 3CM is the extreme basinward facies consisting of the same coarse calcarenites of 3C interbedded with calcarenitic wackestones. It was encountered in a portion of the study area. In outcrop, the unit is characterized by somewhat wavy, medium to thickly bedded limestone that contains some shaly interbeds.

Location of Study Area

Four sections were measured through the Viola Group, two in the Arbuckle Mountains, and two in the Criner Hills (Figure 5). The main section, to which the others are compared, is located on the south limb of the Arbuckle anticline along Interstate 35 in Carter County. Another section was measured along U.S. 77 north of the Arbuckles in Murray County. The Criner Hills sections are located at Rock Crossing and at an abondoned gravel quarry owned by Mr. Harold Rudd, Carter County.

Location of Measured Sections

Four measured sections were examined along a roughly

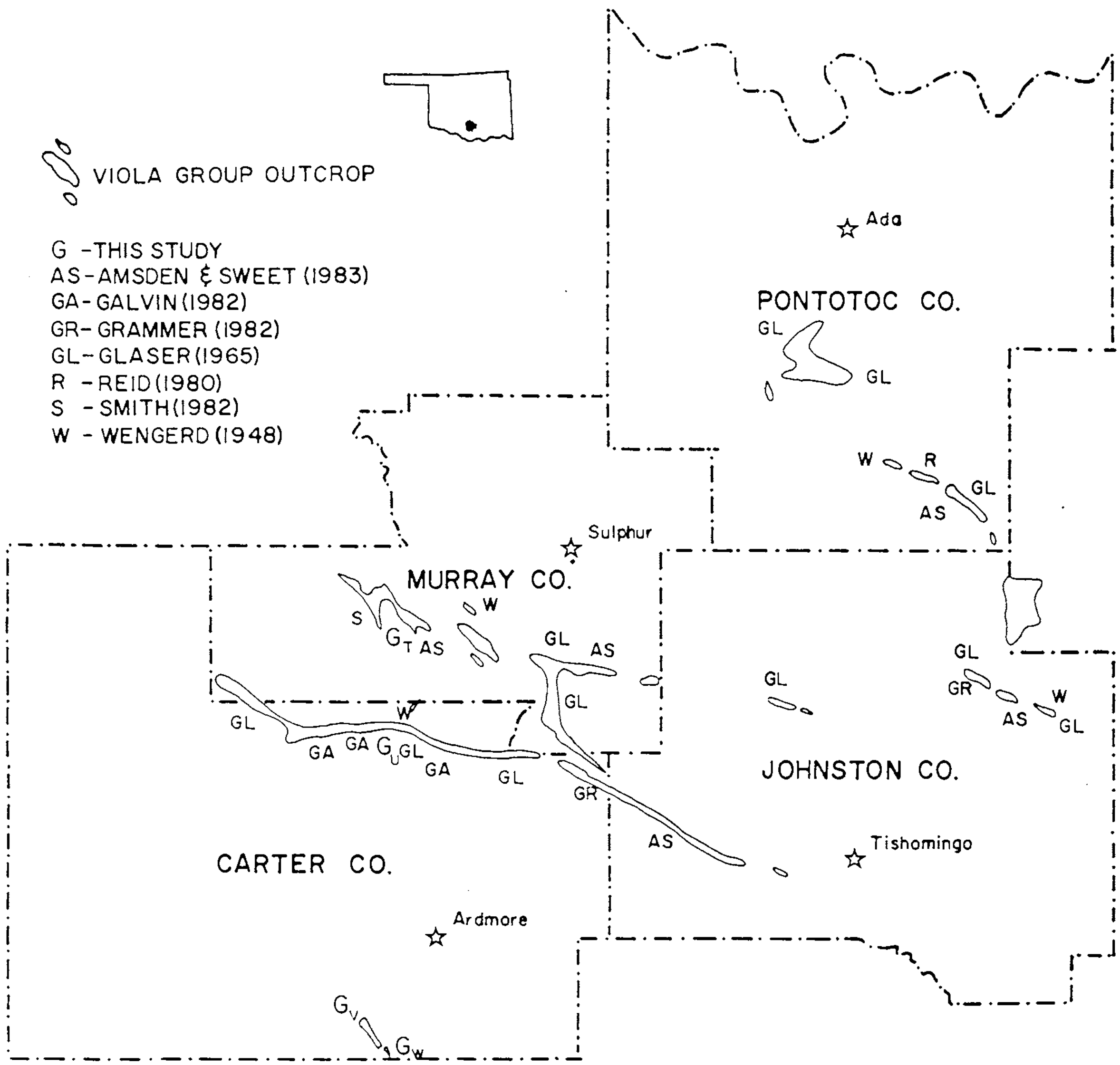


Figure 5. Location of Present Study Area and Previous Investigations

north-south line from the north side of the Arbuckle Mountains to the southern part of the Criner Hills. The sections are designated by letters continuous with the scheme used by Glaser (1965). The northern-most is Section T, located on the north flank of the Arbuckle Anticline in a road-cut along the west side of U.S. Highway 77 (C N1/2 Sec. 30, T.1 S., R.2 E.) in Murray County (Figure 6). The upper 160 feet of the Viola Springs Formation and a 24 foot thickness of the Welling Formation are exposed as steeply dipping and faulted beds. Although it is not a complete section, this outcrop was examined because the contact with the overlying Sylvan Shale is excellently exposed. Total thickness measured is 185 feet.

Section U affords the best exposure of the Viola Group. The relatively new road-cut created by the construction of Interstate 35 provides a fresh outcrop of nearly continuous Viola Group. Its location is on the south side of the Arbuckles along the south-bound lane of the highway (SW1/4 Sec. 25, T.2 S., R.1 E.) in Carter County (Figure 7). The outcrop consists of two long exposures separated by about 200 feet of cover created by the infilling of a small draw during road-bed construction. Only 150 feet of the middle of the 700 foot thick Viola Springs Formation is covered. Both the upper and lower contacts are superbly exposed. There are 150 feet of Unit 1L, 550 feet of Unit 2, and 27 feet of Unit 3CM (Welling Formation) present. The beds uniformly dip 49^{o}SW,

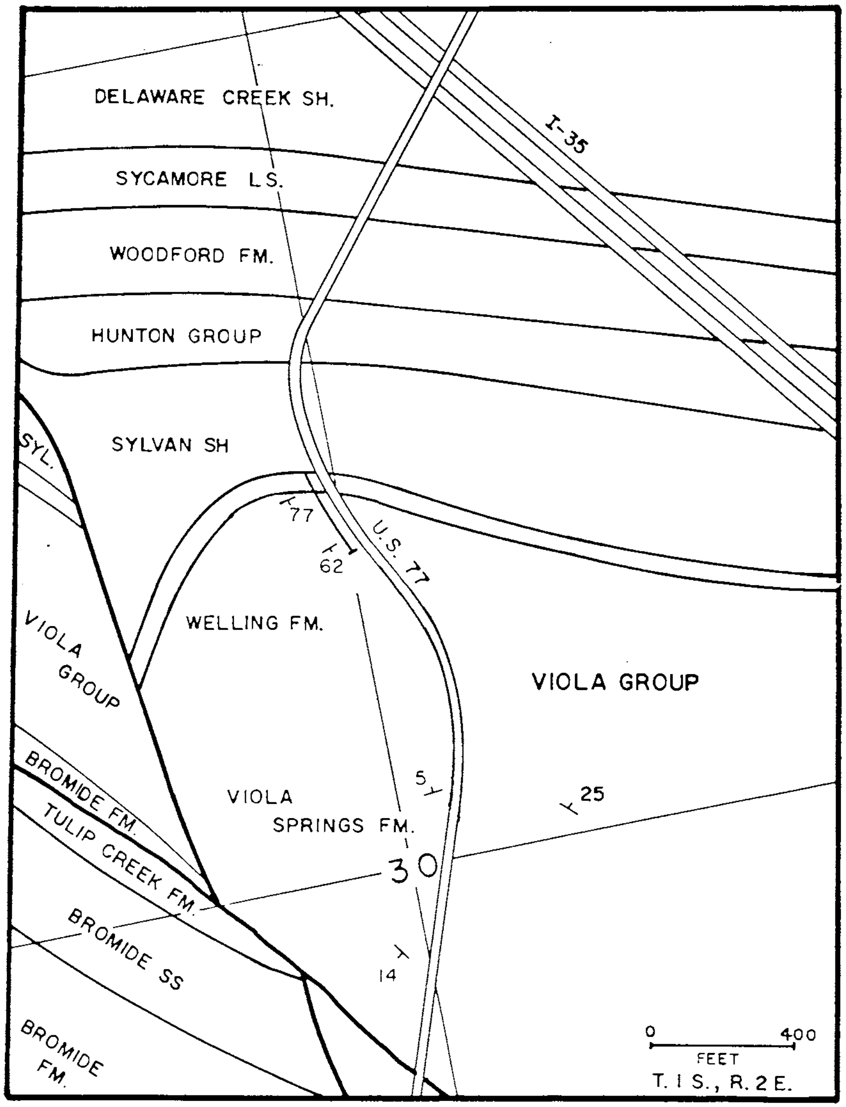


Figure 6. Location of Study Section T

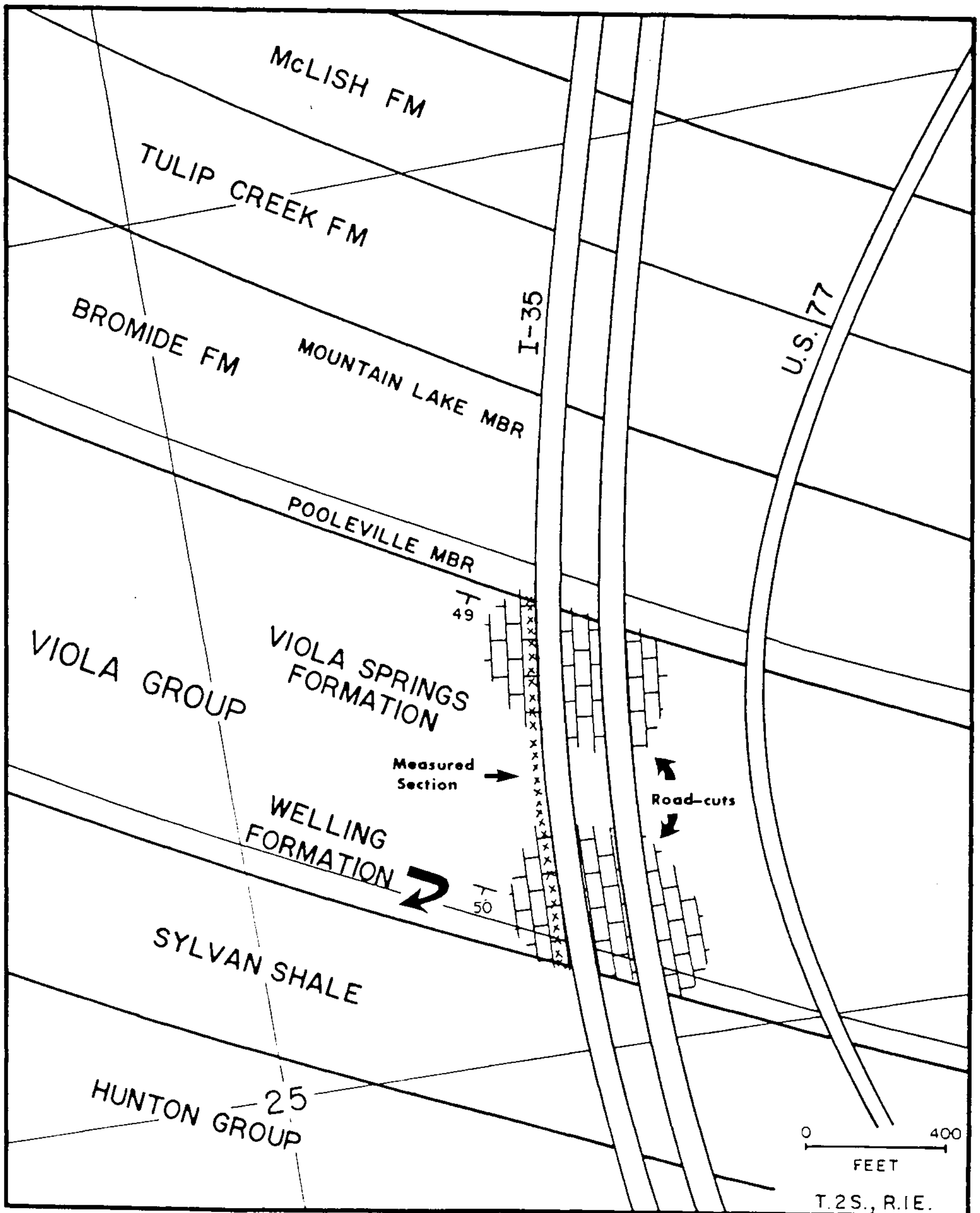


Figure 7. Location of Study Section U

and although they are highly jointed, no major faulting has disturbed them.

Section V is located at the north end of the Criner Hills (SW1/4 Sec. 22, T.5 S., R.1 E.) in southern Carter County (Figure 8). It was measured across a north-south trending ridge of Viola upon which an abandoned gravel quarry is situated. The lower 100 feet of Viola Springs is well exposed in a cliff above a small creek that flows along the north end of the ridge. Unfortunately, the lower contact with the Pooleville is not exposed here, although its position can be approximately located. The portion of the section along the creek can be tied into the outcrop well exposed in the quarry on the ridge. However, outcrops west of the quarry representing the upper part of the Viola Group were scattered and covered. The upper contact with the Sylvan Shale is not well exposed, but its position can be located with some confidence. Still, stratigraphic thicknesses could be measured. The beds dip uniformly 43^0SW, and no major faults disrupt the section. Total thickness is 840 feet, including 791 feet of Viola Springs and 49 feet of Welling.

The southern-most section was measured at the well known fossil locality of Rock Crossing on Hickory Creek (Figure 9). Section W is about one and one half miles south of Section V (C Sec. 35, T.5 S., R.1 E.) in Carter County. Nearly 85 feet of basal Viola Springs was measured along the south bank of the creek. The lower contact with

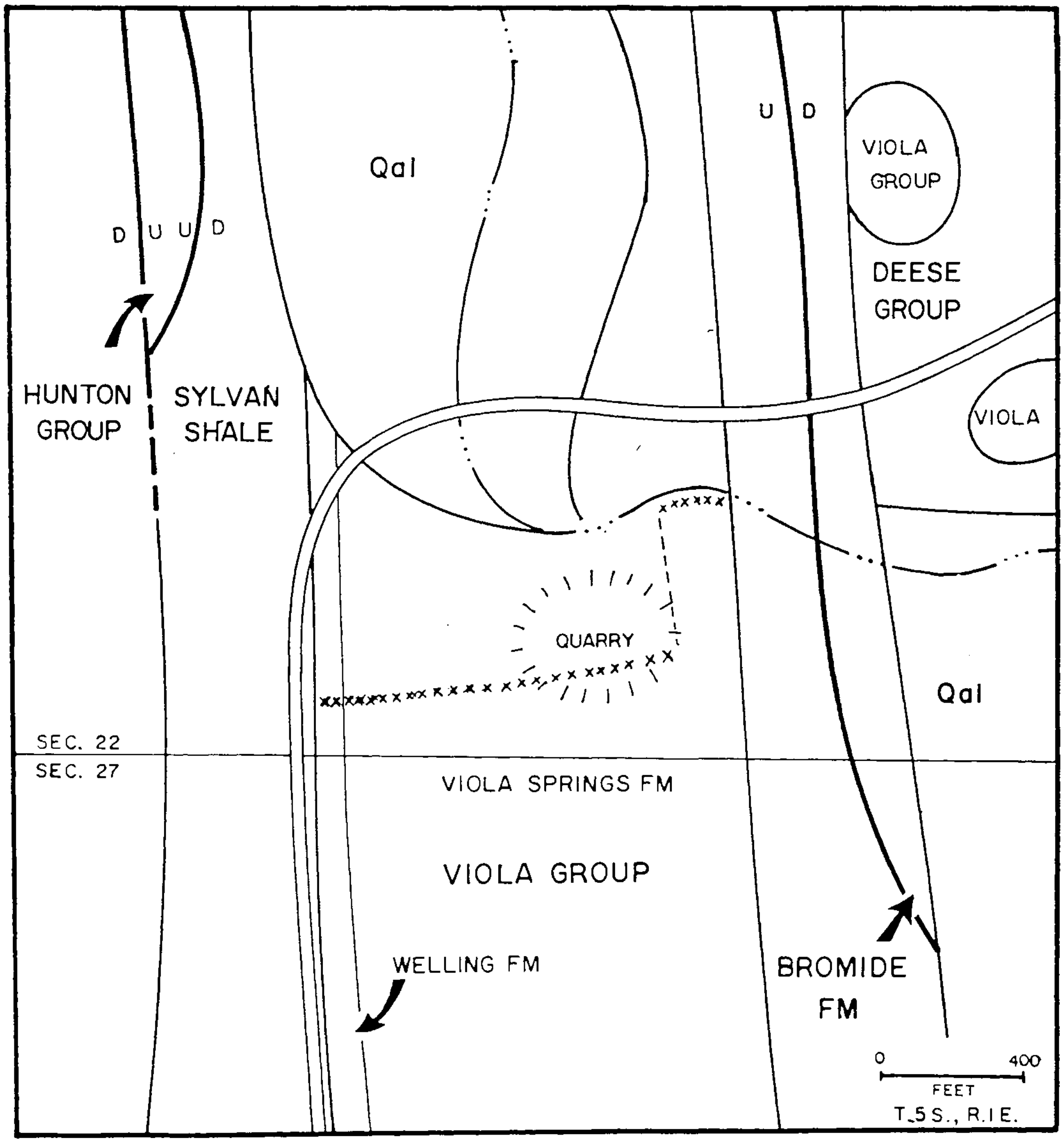


Figure 8. Location of Study Section V

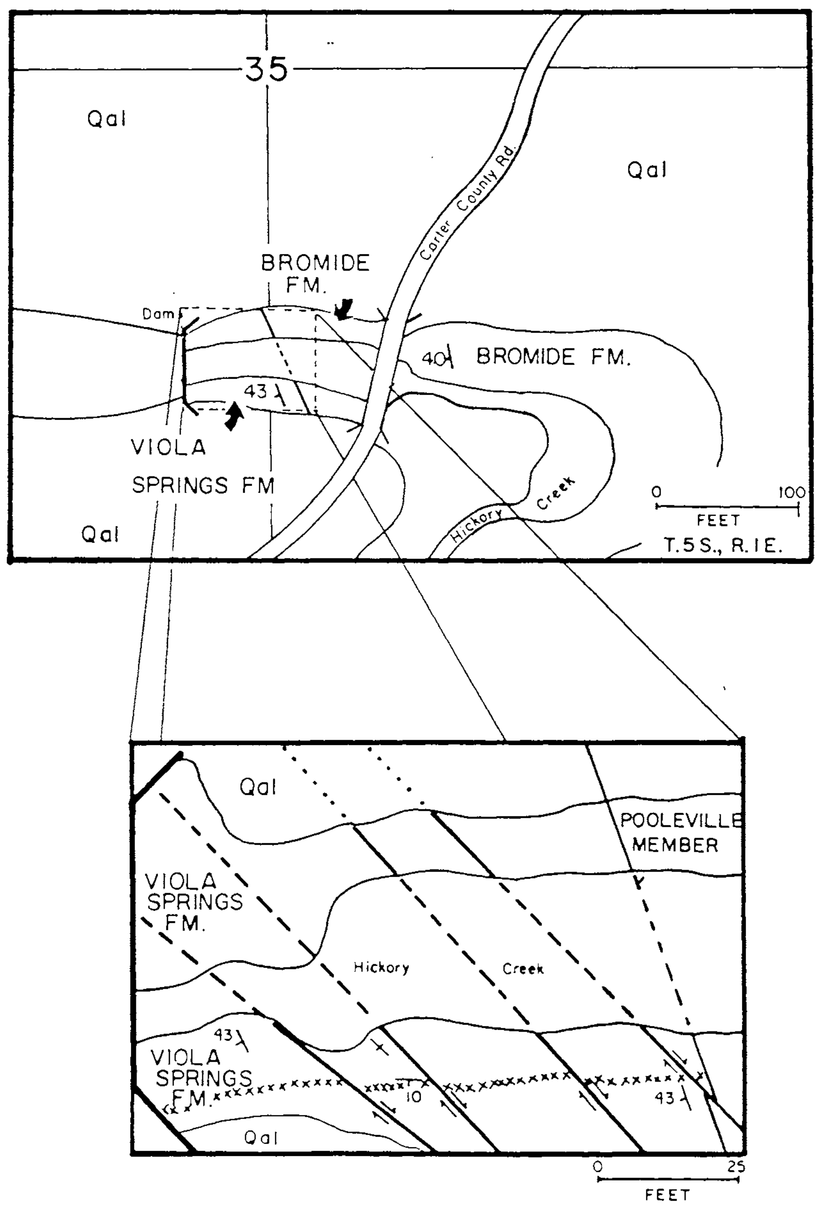


Figure 9. Location of Study Section W

the Bromide Formation is exposed, but above 80 feet, the Viola Springs is covered by a small dam and was probably faulted away. The exposed beds dip 43°SW and are cut by several small faults. The faults trend roughly northwest-southeast and have a maximum displacement af approximately two feet. Although limited, this outcrop was studied because of its fairly well defined lower contact and exceptionally abundant graptolites.

Methods of Investigation

Detailed stratigraphic sections were measured through the Viola Group at the localities noted above. Thin-sections were prepared from samples collected at regular intervals representative of the major lithologies. Graptolites were collected bed-by-bed from measured sections. Their identification by Dr. Stanley Finney and the author has allowed dating and correlation of the lithologic subdivisions. In addition, the petrography and fossil content immediately above and below the upper and lower contacts for the Viola Group were closely examined.

Rock colors were judged against the standards adopted by the Geological Society of America Rock-color Chart Committee (1979). Bedding thicknesses were determined in accordance with the classification proposed by Ingram (1954) (Figure 10). Dunham's (1962) carbonate rock classification scheme was used to describe the rock in thin-

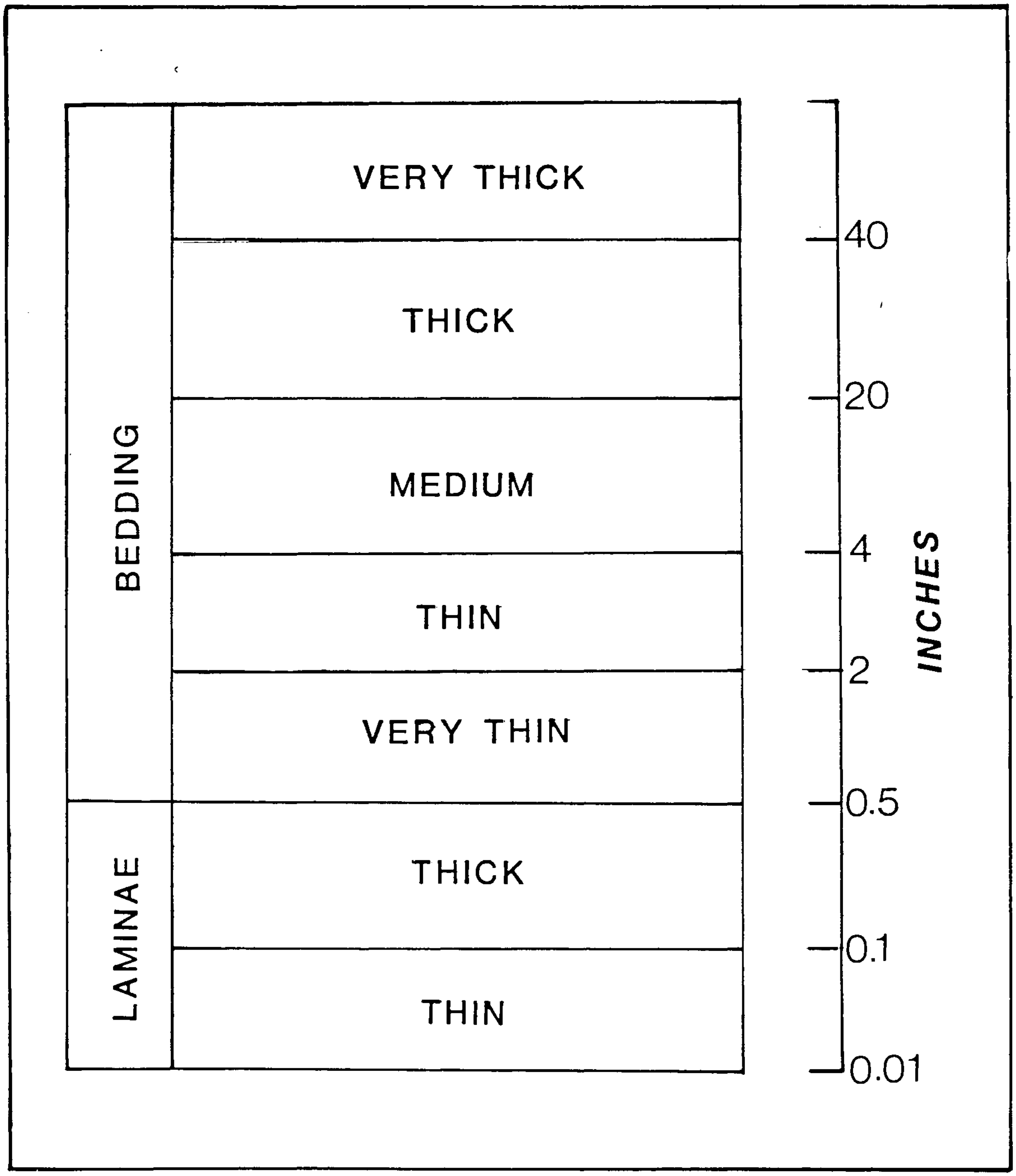


Figure 10. Nomenclature of Bedding Thickness (after Ingram, 1954)

section. Allochem and crystal sizes were determined after Folk (1962).

CHAPTER II

SEDIMENTOLOGICAL ASPECTS OF THE VIOLA GROUP

Description of Measured Sections by Lithologic Units

Unit 1L

Unit 1L is present in three of the four sections studied. It is best exposed at Section U, where it attains a thickness of appproximately 150 feet. Here, the lower contact with the Corbin Ranch Formation is especially clear being marked by a weathered crust of pyritic and phosphatic material. The basal seven feet of Unit 1L consist of thinly wavy bedded, calcarenitic packstone interbedded with shaly limestone are especially distinctive (Figure 11). The packstones are brownish-gray to olive-gray finely laminated, and petroliferous. They include fossil grains of abundant ostracods and sponge spicules and traces of graptolites, chitinozoa, and articulate brachiopods. The chert is light-gray to black and nodular and sublaminar. Where sublaminar, the chert occurs as beds about two inches thick. Nodules are as large as eight inches in diameter. The chert appears laminated

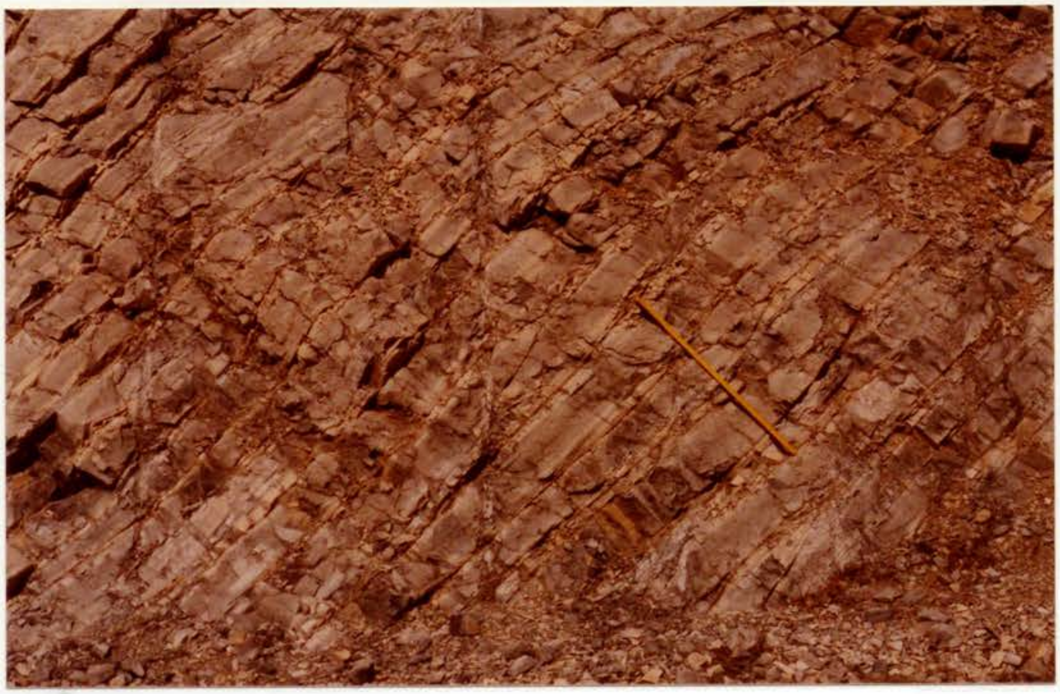
Figure 11. Photograph of Basal Seven Feet of Viola Group at Section U

(alternately light and dark gray in color resembling the lamination of the limestone beds) suggesting early formation which preserved sedimentary features. Chert comprises about ten percent of the basal seven feet. A thin (0.10 inch) pyritic/phosphatic crust separates the basal seven feet from the rest of Unit 1L.

The overlying 140+ feet of Unit 1L consists of medium bedded, siliceous limestones with thin shaly (Figure 12a) interbeds. The limestone is dark yellowish-brown and petroliferous. It is laminated calcareous mudstones in the lower part of the section becoming laminated wackestones and packstones in the upper part. One especially thick (20 inches) occurs about 100 feet above the base. It is coarser grained than the surrounding rock consisting of medium to coarse-grained calcarenitic packstone. Scours occasionally disrupt the laterally persistent bedding and laminations.

Graptolites occur abundantly in this unit, sometimes on exposed bedding surfaces with stipes oriented. Trilobites, conodonts, ostracods, chitinozoans and sponge spicules comprise the bioclastic material in the limestone.

Chert occurs as brownish-gray nodules up to eight inches in diameter. Two separate events of chert formation are seen in this unit. Clearly, some nodules were formed early (prior to compaction) as evidenced by the laminae and shaly interbeds deformed around them. By contrast, other chert nodules have primary sedimentary features, like



A

B

Figure 12. Photographs of Typical Unit 1L Lithology (a) and of Typical Unit 2 Lithology (b)

laminae, preserved within them and show no disruption of the laminae or bedding. This type represents later silicification of the limestone.

Unit 1L is 250 feet thick at Section V but lacks the distinctive lithology in the lower seven feet of Section U. The lower contact with the Pooleville is not exposed, but can be approximately located. The unit is similar to that exposed at the previous section being composed of pale yellowish-brown, medium bedded, parallel finely laminated, siliceous, petroliferous limestone with thin shaly interbeds. It becomes less petroliferous about 100 feet above the base and changes color to medium-gray. The bedding is typically six to 12 inches thick with one to three inch thick shaly interbeds. The limestone is calcareous mudstone in the lower 65 feet changing to fine to medium-grained calcarenitic wackestones and packstones. Scours were recognized at several horizons.

Graptolites, ostracods, sponge spicules, and chitinozoa make up less than 10 percent of the rock although graptolites are locally abundant. Several horizons are so rich in preserved flattened specimens that the bedding surface itself is not visible. Occasionally, the stipes are found uniformly oriented on bedding surfaces.

The basal 80 feet of Unit 1L is the only part of the Viola Group exposed at Section W. It closely resembles the comparable interval at Rudd Quarry (Section V). The rock consists of pale yellowish-brown, medium-bedded, parallel finely laminated, siliceous, petroliferous limestone with thin shaly interbeds. The limestone beds are calcareous mudstones. No nodular chert is present although the siliceous nature of the limestone makes it very brittle and tough to work. The brittleness of the rock is further illustrated by its highly jointed nature formed in response to faulting in the area.

Graptolites here too are locally abundant with a few beds each containing several horizons of mass preservation. Oriented stipes are rare. In addition to graptolites, sponge spicules, ostracods, and rare echinoderms make up the bioclastic material in the limestone. Unit 1L contains only transported skeletal material and apparently supported no indigenous fauna.

Unit 2

Unit 2 is present at three of the four sections measured. It is best exposed at Section U where it is 550 feet thick. The unit consisits of brownish-gray to olive-gray, medium wavy bedded limestone with thin shaly interbeds. The limestone beds range in thickness from six to 12 inches and consist of medium to coarse-grained, calcarenitic, skeletal wackestones and packstones. The bedding is very wavy to almost nodular. The shaly interbeds are continuous and surround the nodular limestone. This bedding of Unit 2 readily distinguishes it from the other units (Figure 12b). The waviness is due to deformation in response to overburden stress and subsequent diagenetic alteration (pressure solution). Stylolites in the shaly interbeds which parallel bedding are a result of the pressure solution. Removal of calcium carbonate through pressure solution from the limestone which did not undergo early cementation accentuates wavy bedding. The shaly/ clayey interbeds are the insoluble residue from limestone dissolution, and thus are probably not a primary textural feature. Glaser (1965) reported a dolomitic composition for this material. Late authigenic dolomite is present along stylolites as seen in thin-section (Figure 24).

Echinoderms, ostracods, trilobites, sponge spicules, brachiopods, bryozoans, orthoconic cephalopods, and graptolites constitute up to 20 percent of the rock. Graptolites are much less common in this unit than in the underlying one. Orthoconic cephalopods occur only at one horizon 640 feet above the base where they are bimodally oriented east and west. A few feet below, a single bed contains abundant fragments of the trilobite Vogdesia cf. bromidensis almost two inches in diameter. Bioturbation is common in and characteristic of Unit 2. It is represented by primarily horizontal burrows 0.10 to 0.75 inches in diameter and several inches long. The burrowing is extensive having disrupted bedding and rearranged bioclasitic material in the limestone. Chert occurs sporadically throughout Unit 2, but is concentrated in the upper 200 feet. It is nodular to sublaminar and bluish-gray in color. Nodules are two to five inches in diameter; sublaminar forms are two to three inches thick and up to three feet long. At Section T, only the uppermost 160 feet of Unit 2 is exposed. It consists of dark yellowish-brown to brownish-gray, medium wavy to nodular bedded limestone with shaly interbeds. Bedding thicknesses of the limestone are six to twelve inches with one to two inch thick shaly interbeds. The limestone is similar in lithology to that at Section U being composed of medium to coarse-grained, calcarenitic wackestones and packstones.

The fossil assemblages are virtually the same as the previous section except for the absence of orthoconic cephalopods. Only a few badly fragmented graptolites were identified at this section. Bioturbation is common as in Section U.

Chert is present as dark bluish-gray irregularly shaped nodules two to three inches in diameter with sublaminar chert less common. At Section V, Unit 2 is nearly 600 feet thick. It consists of dark yellowish-brown to dark yellowish-orange, fine to medium bedded limestone with shaly interbeds. Limestone bedding thicknesses range from two to six inches. The unit is poorly exposed at this section making it difficult to study.

It apparently is less fossiliferous than at other sections. Graptolites are nearly absent, with echinoderms, trilobites, brachiopods, ostracods, bryozoans, and sponge spicules together comprising up to 15 percent of the rock.

Large (one to three inch) fragments of *Vogdesia* cf. *bromidensis* are abundant in a single bed 680 feet above the base. This occurance is roughly correlatable with the similar bed described at Section U above. Slabs taken from this unit are mottled with primarily horizontal burrows ranging in size from 0.1 to 0.5 inches in diameter and up to several inches long.

Chert is rare at Section V, occuring only as yellowish-gray irregularly shaped nodules up to six inches in diameter and a few sublaminar forms two inches thick. Chert is found only in a horizon about 50 feet thick 650 feet above the base. Silicified skeletal remains of gastropods and brachiopods are also exposed in positive relief on bedding surfaces associated with this interval.

Unit 3 (Welling Formation)

Unit 3 is found at three of the four localities. At Section T, it is 24 feet thick and consists of pale-brown medium to thickly wavy-bedded limestone with some shaly interbeds. The limestone is coarse calcarenitic to fine calciruditic skeletal grainstone in beds six to 24 inches thick. The coarse texture readily distinguishes Unit 3 from Unit 2. The biolclastic material is principally echinoderms, trilobites, and brachiopods with minor quantities of ostracods, gastropods, and bryozoans. Graptolotes are present mostly as unidentifiable fragments.

Unit 3 at Section U represents a different facies from that at Section T and is refered to as 3CM by Glaser (1965). It is 27 feet of greenish-gray to yellowish-gray, medium to thickly bedded limestone with few shaly interbeds. The limestone is coarse-grained, calcarenitic grainstone in the basal eight feet grading into medium-grained skeletal packstone in the upper 19 feet (Figure 13a). The coarser-grained limestones are medium bedded (six to 10 inches thick) with the finer-grained limestones are more massive (12 to 24 inches thick).

The bioclastic material is the same in composition and quantity as the previous section. Traces of vertical burrowing 0.5 inches wide and 1.5 inches long are present in the lower portion of the unit (Figure 13b). Stylolites probably contributed to the waviness of the bedding. Possible cross bedding of skeletal sand is seen in the basal part of the unit.

Unit 3CM is also recognized in the northern Criner Hills (Section V). It is 49 feet thick and consists of greenish-gray to yellowish-brown, medium wavy bedded limestone with fine to medium shaly interbeds. The beds are uniformly six to eight inches thick and the interbedding, though mostly inaccessible as they form weathered recesses, are about four to six inches thick. The limestone consists of coarse calcarenitic skeletal grainstones and fine to medium-grained calcarenitic packstones and wackestones. These two lithologies interfinger throughout the unit rather than grade into one another as above.

A

B

Figure 13. Photographs of Typical Unit 3 Lithology (a) and of Vertical Burrows in Unit 3CM (b)

Bioclasts are primarily echinoderms, brachiopods, trilobites, ostracods, and bryozoans. No graptolites were seen in this unit.

Lithologic Correlations

The above lithologic units are readily correlated between measured sections even though complete Viola Group sections were not present at all localities. All of the units show a general thickening basin-ward (Plate I). The greatest increase occures in Unit 1L, which thickens from 150 feet at Section U to over 250 feet at Section V. Unit 2 thickens from 550 feet at Section U to about 600 feet at Section V. Unit 3C, 24 feet thick at Section T, grades into Unit 3CM which is 27 feet thick at Section U and 49 feet thick at Section V. The subunit at the base of Section U is not present at other sections studied. It is recognized by Galvin (1982) at two other localities west of the study area, but does not extend south into the basin.

The boundaries between the units are gradational, often over an interval of 10-20 feet. For purposes of this study, the unit boundaries are placed at the first occurence of the gradational interval.

Unconformities in the Viola Group

Three unconformable surfaces are associated with the Viola Group: the lower contact with the Corbin Ranch Submember or the Pooleville Member of the Bromide Formation, a bed about seven feet above the base, and the upper contact with the Sylvan Shale. The unconformities at the base and upper contact have been recognized by earlier workers on the basis of sedimentological and paleontological evidence. The unconformity just above the base is recognized by Galvin (1982) as an "ommission surface". These surfaces are described below.

The unconformity at the base of the Viola Group is best exposed at the fresh road-cut in Section U where it is an irregularly corroded, iron stained horizon which separates the basal seven feet of Unit 1L from the underlying Corbin Ranch Submember of the Pooleville Member of the Bromde Formation. Where exposed, the upper surface of the Corbin Ranch exhibits many of the features of corrosional hardgrounds proposed by Bathurst (1971). Truncated fossils, in particular Receptaculites, planed off by erosion are found on the irregular bedding surface (Figure 14a). The upper-most bed of the Corbin Ranch is highly bioturbated with randomly oriented burrows infilled with dolomitic, bioclastic material. No clear evidence of encrusting or boring organisms is visible. Pebble-sized, dark reddish-brown, phosphatic-pyritic nodules occur scattered across the pitted bedding surface (Figure 14b). An orange-brown, one inch thick shaly bed of similar composition overlies the nodule-covered bedding surface and conspicuously separates the lowest Viola limestone bed from the Corbin Ranch. The shaly material is reported by Galvin (1982) and others as

A

B

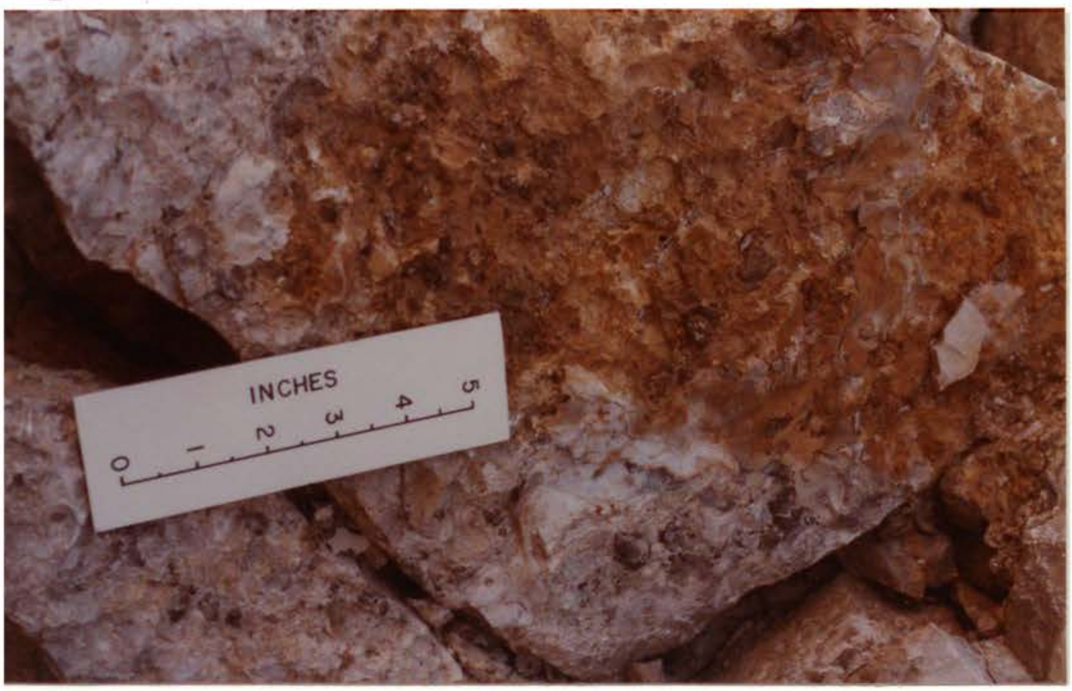


Figure 14. Photographs of Upper Bedding Surface of Corbin Ranch Submember of the Bromide Formation (a) and of Pebble Conglomerate at Viola-Corbin Ranch Contact (b)

insoluble residue from pressure solution along this horizon.

The overlying basal seven feet of Unit 1L consist of organic-rich, laminated, cherty, phosphatic, medium grained, calcarenitic packstone. The high organic carbon and phosphate content indicate dyaerobic, if not anaerobic, conditions explaining that absence of encrusting or boring organisms. The phosphatic-pyritic composition of the shaly material suggests that this unconformity is a submarine corrosional hardground rather than a result of emersion (Bathurst, 1975).

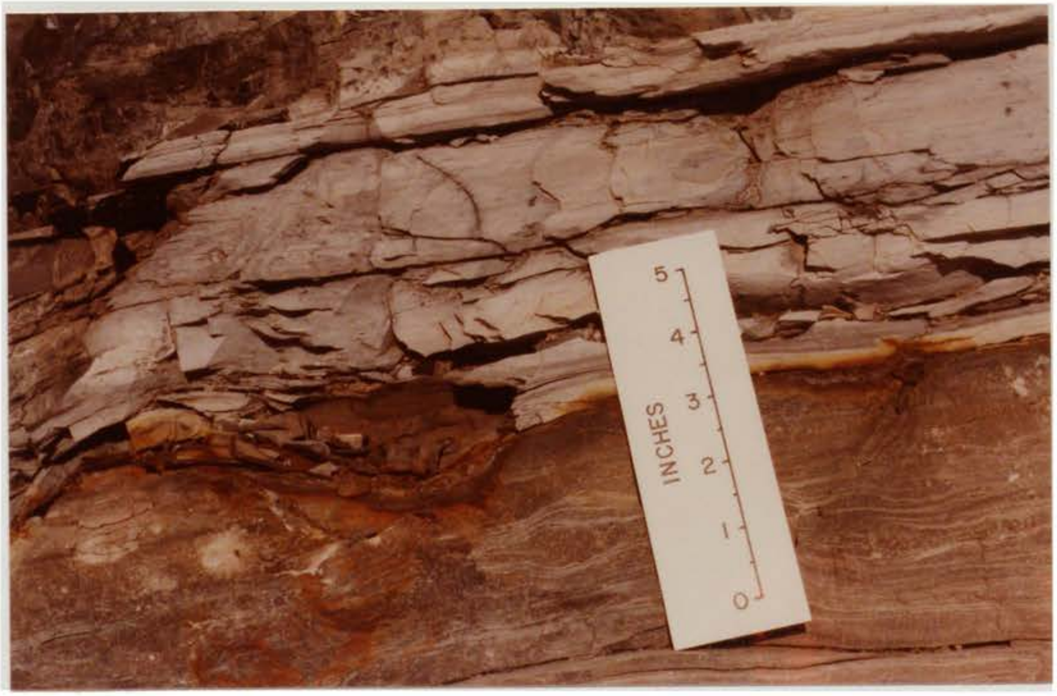
Alberstadt (1967) recognized this unconformity at the base of Unit 1L and correlated it with the lower Trentonian Stage. Sweet (Amsden and Sweet, 1983) recognized the same unconformity farther to the east (Section D and F of Glaser, 1965) and assigned it to a part of the Kirkfieldian Stage which is equivalent to the lower Trenton (Sweet, 1984). On the basis of Sweet's (1984) graphic correlation techniques, the duration of the hiatus is approximately four to eight million years. Jenkins (1969) reported a faunal break well below the the top of the Viola Springs Formation on the basis of chitinozoa, but not at formational boundaries.

At Section W, the Viola Springs Formation rests unconformably on the Pooleville Member of the Bromide Formation. The unconformity is marked by a six inch thick horizon of shaly limestone. On the basis of graptolites, the base of the Viola Springs Formation is roughly equivalent to or slightly younger than the same interval at

Section U (this study, chapter IV). Longman (1976) reports that possibly up to six meters of Pooleville is missing.

Another iron-stained horizon is visible seven feet above the base only at Section U (Figure 15a). The basal seven feet of medium-grained packstone is separated by this marker from the overlying 140+ feet of calcareous mudstones of Unit 1L. The horizon is wavy with up to two inches of relief. It is covered with an irregular thickness of phosphatic and pyritic crust up to 0.10 inches thick. It is best seen in thin-section (Figure 15b). The percentage of subhedral pyrite within the ostracod-rich, sparry-cemented packstone increases toward the unconformity surface where it dominates the compostion. Amber, nearly isotropic phosphorite encrusts the pyritic rock beneath it. A few pieces of the crust were ripped up by currents forming a micro-conglomerate in some places. Calcareous, millimeter laminated mudstone rich in organic carbon and containing very fine sand-sized phosphatic pellets drape over the irregular crust surface. No evidence of encrusting or boring benthic organisms is present.

The thinness of this horizon suggests it represents a hiatus of relatively short duration compared to the basal unconformity. It is therefore more appropriately termed an "omission surface" (Galvin, 1982). It was recognized by earlier workers only in the Arbuckle Mountains and seen only at Section U of this study area. No paleontologic breaks occur in association with it.



A

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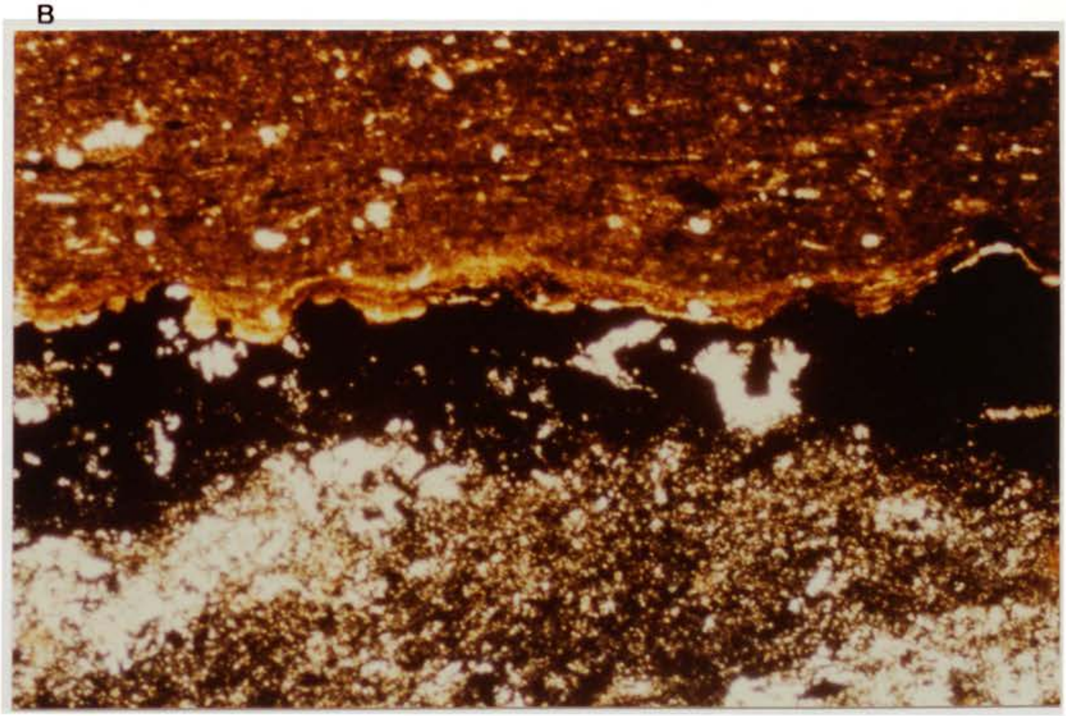


Figure 15. Photograph of Unconformity Surface Seven Feet Above Base of Viola Group (a) and Photomicrograph of Phosphatic Crust on Unconformity Surface (b) 40X

The upper contact of the Welling Formation with the Sylvan Shale is not considered unconformable by all who have examined the Viola Group. The contrast of the shallow water facies Welling Formation with the deeper marine Sylvan Shale is conspicuous. The top of the upper-most bed of the Welling Formation is wavy and pitted. The limestone is bioturbated to a degree but no signs of encrusting organisms are visible. Glaser (1965) reported pyritic and phosphatic, shaly material similar to that found at the base of the group at some of his sections. Even though this contact is not freshly exposed at any localities in this study area, no traces of such material is visible. The calcareous fissile shale rests directly on the packstone and wackestone.

No biostratigraphic evidence supporting the existance of an unconformity at this horizon exists. The sharp lithologic contrast here probably represents nothing more than marine transgression. No biostratigraphic evidence supporting the existance of an unconformity at this horizon exists. The sharp lithologic contrast at this horizon probably represents marine transgression and nothing more.

Paleocurrents in the Viola Group

Graptolites are abundant in the lower Viola Springs Formation and on many bedding surfaces they are obviously oriented. Although Galvin (1982) proposed a pelagic model of sedimentation on a deep carbonate ramp for the lower Viola Springs Formation, scours and small-scale cross-bedding suggest that pelagic sedimentation was disturbed by occasional bottom currents. Oriented graptolite rhabdosomes also suggest the influence of currents on the sediments as shown in other areas by Jones and Dennison (1970), Schleiger (1968), and Williams and Rickards (1984).

Smith (1982) measured the orientations of scours in the lower Viola Springs Formation and recorded a predominantly northwest-southeast trend. Both he and Galvin (1982) reported oriented graptolites on bedding surfaces. The directions and character of these orientations are recorded and related to the basinal setting.

Character of the Data

Eight slabs bearing oriented graptolites were analyzed in detail (Figure 16). Three of the slabs are from outcrops along Interstate 35 (Sec. 25, T.2 S., R.1 E.) in the Arbuckle Mountains. The remainder were collected from the banks of an unnamed tributary of Hickory Creek in the northern Criner Hills (Sec. 27, T.5 S., R.1 E.). Specimens are stored in the Department of Geology at Oklahoma State University. The major modes of oriented graptolites on 30 additional bedding surfaces were recorded in the field. All readings were corrected for tectonic tilt. The orientation and length of 385 graptolite rhabdosomes and fragments were measured on the eight slabs; orientation was recorded with respect to the direction of the proximal end of each graptolite. Rhabdosome length was plotted on a histogram

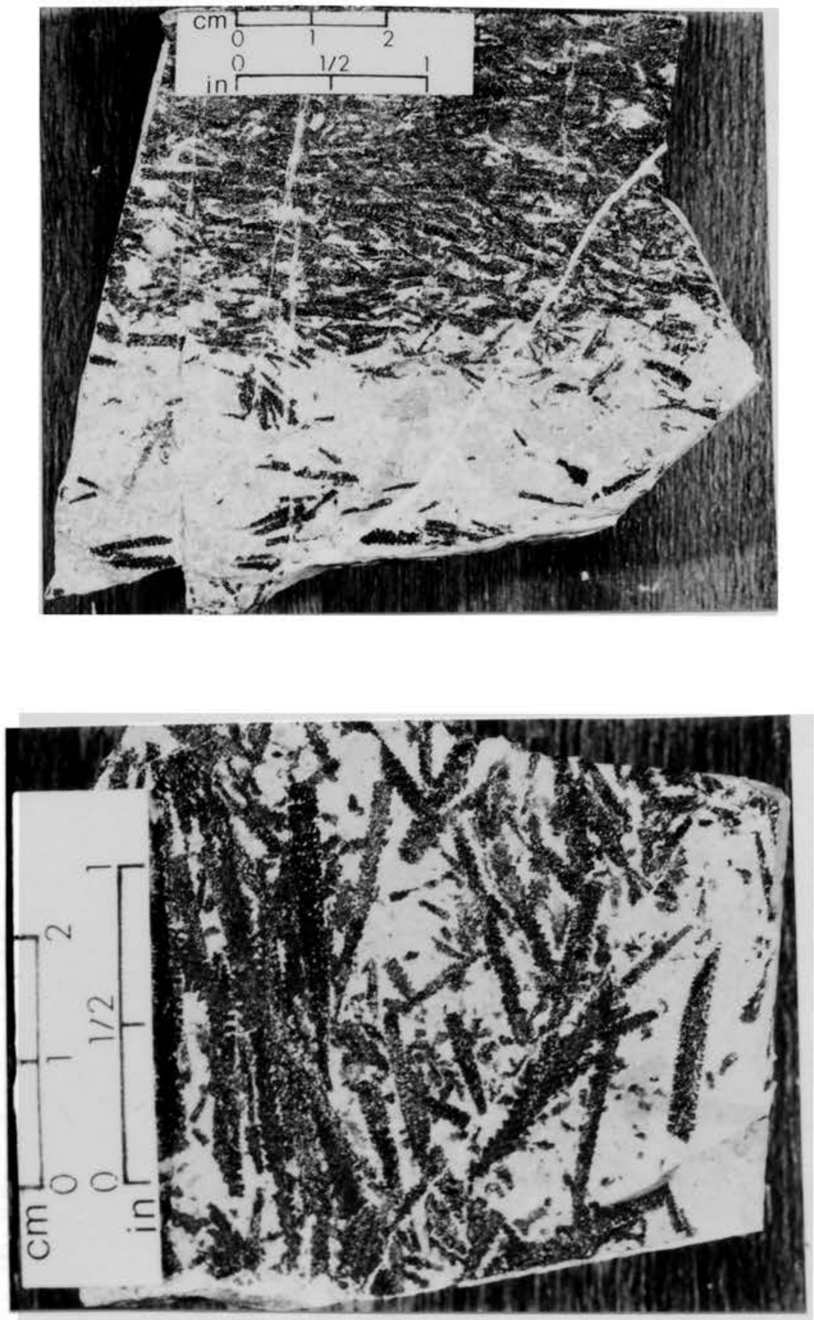


Figure 16. Photographs of Bedding Surfaces Bearing Oriented Graptolite Stipes, Arrow Points North

in order to illustrate the size distribution of the population (Figure 17). The orientations of the individuals were plotted on rose diagrams (Figure 18). Most of the specimens observed were assigned to Climacograptus typicalis Hall and Orthograptus amplexicaulis Hall.

Discussion

Stripes found oriented on bedding surfaces ranged from from three to 44 millimeters in length (Figure). Schleiger (1968) suggested that short rhabdosomes aligned normal to the current direction and long ones aligned parallel with the proximal end pointing into the current. Such relationships were not seen in the present study. It is assumed that the major modes record alignment parallel to the current direction as suggested by Jones and Dennison (1970) and Schleiger (1968).

The major mode of orientation on all the graptolite bearing slabs is approximately east-west (Figure 18). Minor modes may either be a result of random orientation due to suspension sedimentation or a record of subtle current variations. It is significant that the major trend coincides with that of the sedimentary basin of the Viola Springs Formation (i.e. the southern Oklahoma aulacogen). The paleocurrent direction indicates that currents orienting the graptolites were parallel to the axis of the aulacogen and thus flowed parallel to the contours of the basin. By uniformitarian anology, these currents may have

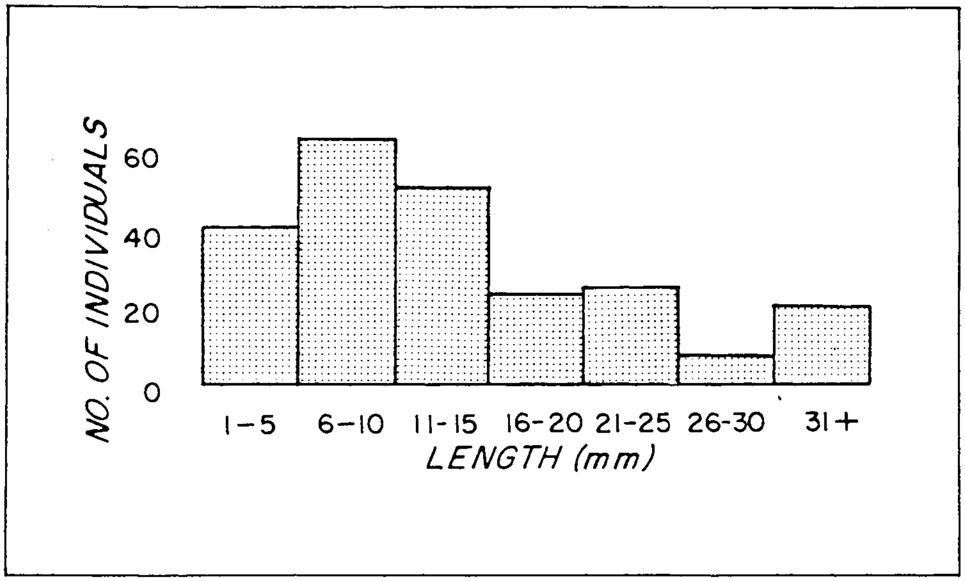


Figure 17. Histogram of Size Distribution of Population of Graptolites Measured for Length and Orientation

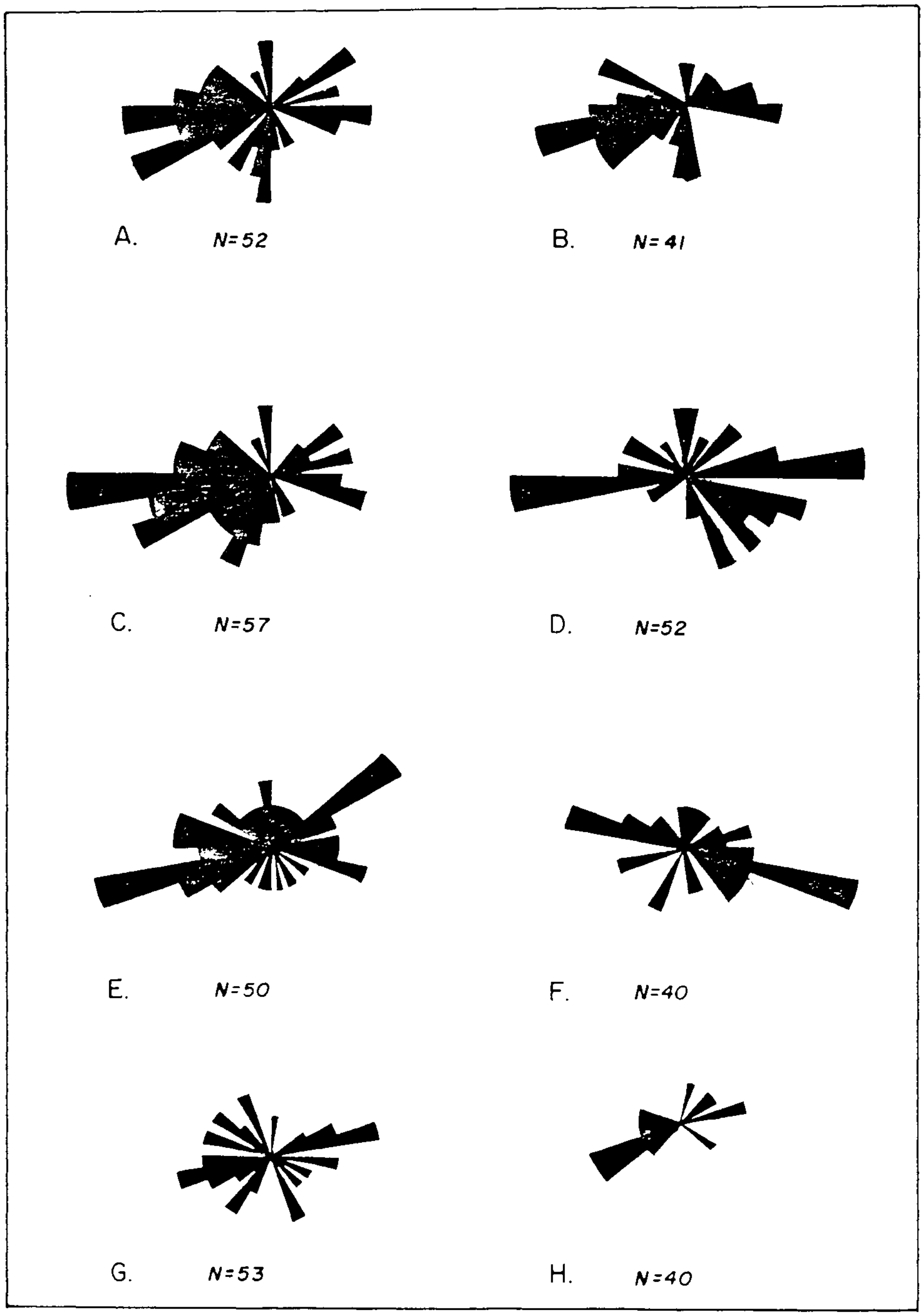


Figure 18. Rose Diagrams Illustrating Major Modes of Orientation of Measured Graptolite Stipes. A-E Represent Slabs Collected from Section V and F-H from Section U.

been induced by thermohaline density differences or strong winds.

Such bottom hugging contour currents have been recognized in modern ocean settings by Heezen and Hollister (1964) and Heezen, Hollister, and Ruddiman (1966) and as a dispersal mechanism in ancient sediments by Bein and Weiler (1966) and Bouma (1972). Bouma (1972) lists the following characteristics as typifying sediments deposited by contour-parallel currents: relatively thin bedding, fine lamination, cross-bedding, fine-grain size, and good sorting with a low matrix percentage. Only the last named characteristic is difficult to demonstrate in the Viola Springs deposits, largely due to the extensive diagenetic alteration of the original rock texture. Where present, oriented graptolites on bedding surfaces in the Viola Springs Formation indicate a current flow with an east-west trend. Variations in the length of the individual rhabdosome are not related to the orientation modes. The approximate east-west orientations reflect current movement subparallel to the elongation of the southern Oklahoma aulacogen. Incorporation of the sedimentary features mentioned above with the paleocurrent data is sufficient evidence that some parts of the lower Viola Springs Formation represent contour current deposits.

CHAPTER III

DIAGENESIS OF THE VIOLA GROUP

The sediments of the Viola Group have undergone thorough diagenesis. Much of the original sedimentary character has been altered and all primary porosity eliminated. Glaser (1965) extensively examined the Viola Group petrographically as exposed in the Arbuckle Mountains. Reid (1980), Smith (1982), Galvin (1982), and Grammer (1983) reported the salient diagenetic changes of the rock in the same region. Analysis of the Viola Group exposed at Sections V and W yielded slightly different conclusions about digenetic changes than those reported by previous workers in the Arbuckle Mountains. Those differences are reported below along with observations concurring with earlier studies. The following diagenetic events are recorded in the Viola Group: neomorphism, phosphatization, pyritization, pressure solution, cementation, dolomitization, silicification (Figure 19).

Neomorphism

Aggrading neomorphism is prevalent throughout the section at all localities examined. It commonly occurs as neomorphism of primary micrite to microspar (5-10u) and

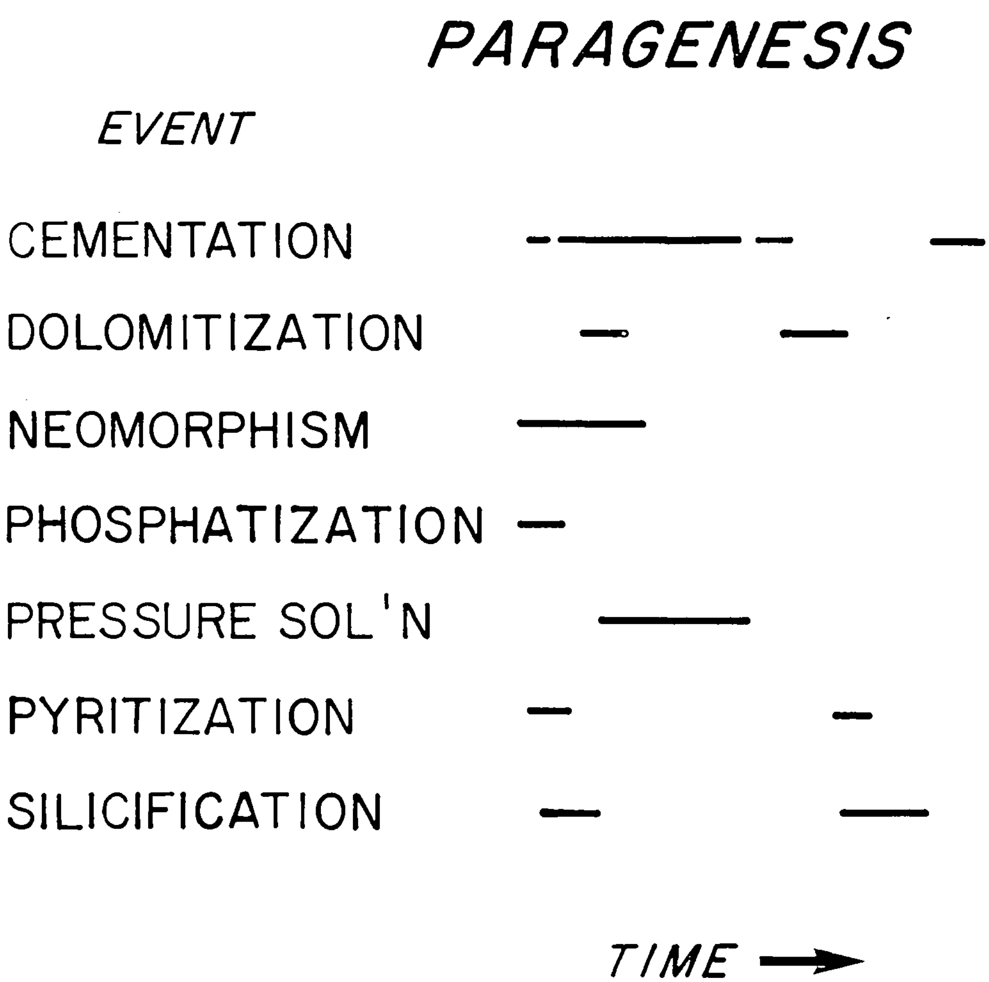


Figure 19. Paragenetic Sequence for the Viola Group

pseudospar (10-50u), and replacement of skeletal grains by mosaic sparite. Neomorphism of calcareous sediment is controlled by the presence of interstitial solutions and their magnesium/calcium ratio (Bathurst, 1975). The Viola sediments were originally deposited as microcrystalline high-Mg calcite or aragonite in normal marine waters (Glaser, 1965). Early diagenesis of the aragonite to micrite expels some Mg ions which remain in the interstices of the sediment. The presence of these ions prevents further recrystalization to microspar (Folk, 1974; Longman, 1978). Interstitial solutions must be present to mobilize Mg ions from the sediment in order for recrystallization to continue. Magnesium can be removed from sediment by fresh water moving through the formation, absorbtion by clay minerals, or by meteoric water flushing during weathering. Longman (1978) and others introduced the possiblity of a lower Mg content of sea water during the Ordovician. If the original carbonate mud deposited was low in magnesiuim, then it would readily recrystallize, thus requiring none of the aformentioned flushing mechanisms.

Neomorphism in Unit 1L is extensive. The original calcareous mudstones have been partially to nearly completely recrystallized into microspar and pseudospar (Figure 20a). Little if any true micrite remains except in a horizon a few feet thick about eight feet above the base of the Viola Group at Section U. The rest of the unit consists of "clotted limestone" (Bathurst, 1975) or

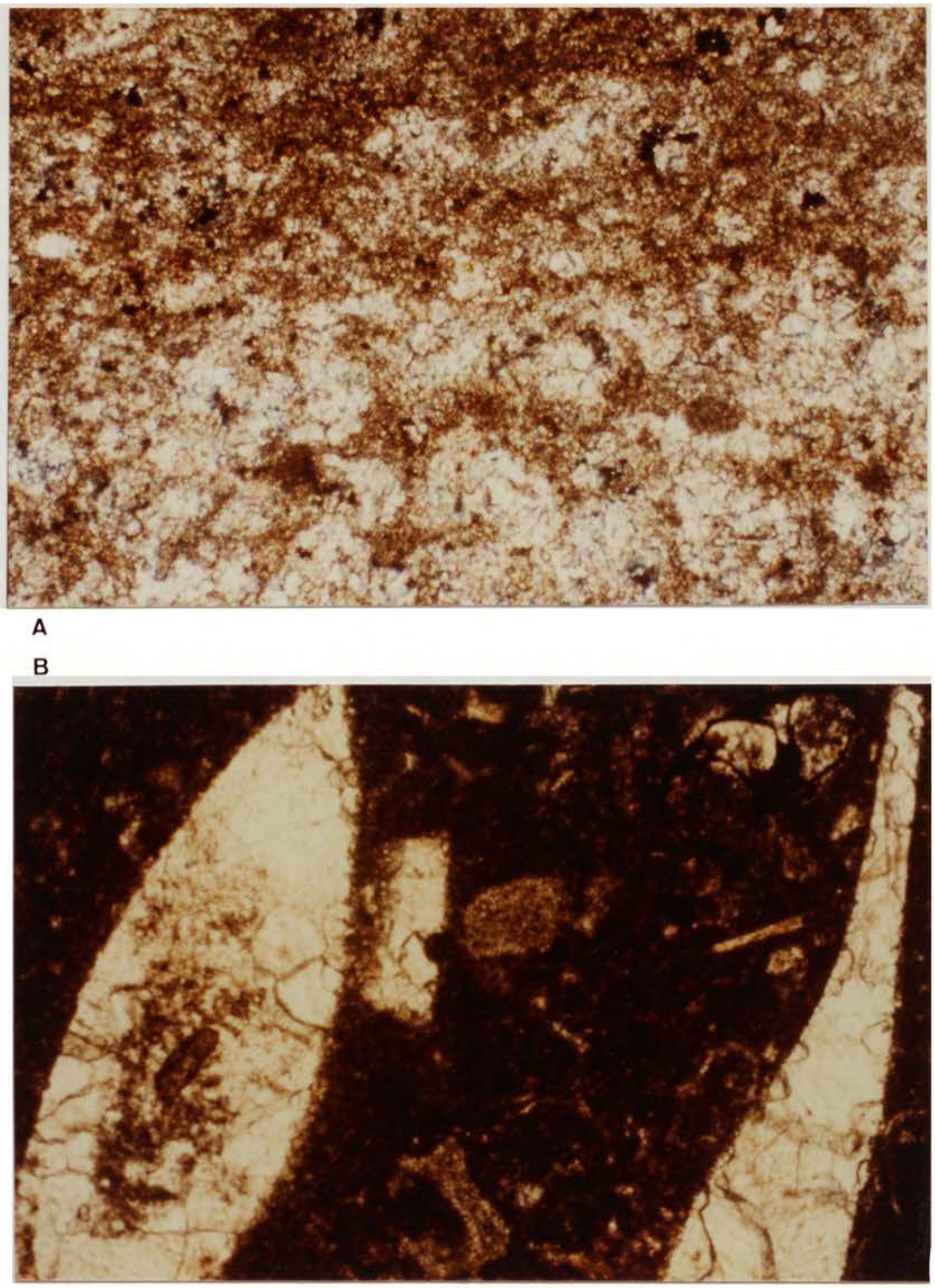


Figure 20. Photomicrographs of Neomorphic Pseudospar and Microspar in Unit 1L (a) and Replacement of Skeletal Grains by Neomorphic Sparite (b) 100X

structure grumeleuse. Galvin (1982) reported the rocks of this unit as pelsparite. Though open to speculation, I believe that partial recrystallization resulted in patches of microspar resembling pellets floating in pseudospar and sparite. The pellet-like patches sometimes appear merged with each other, which is not characteristic of a primary fabric (Bathurst, 1975). As there is no evidence of pellet producing organisms in the unit, the pelsparite as an original fabric is difficult to explain. To be sure, the neomorphism has altered and masked the original rock texture rendering it indiscernable. Replacement occurs sparsely, primarily in upper Unit 2 and Unit 3 where bioclastic material is a more common constituent. Original aragonitic skeletal fragments are seen completely replaced by sparite (Figure 20b). This is observed in some thin sections and more rarely in outcrop.

Phosphatization

Phosphate is concentrated in lower Unit 1L as very fine sand-sized pellets, as a crust on hardground surfaces, and in Units 2 and 3 as a replacement for skeletal fragments. It is an early diagenetic event (Figure 21). Pyrite occurs in association with phosphate in this unit. Nathan and Neilson (1980) relate the formation of phosphate with sulfate reduction by anaerobic bacteria. Judging by the amount of organic matter preserved in Unit 1L, anaerobic conditions certainly prevailed during much of the deposition of this unit.

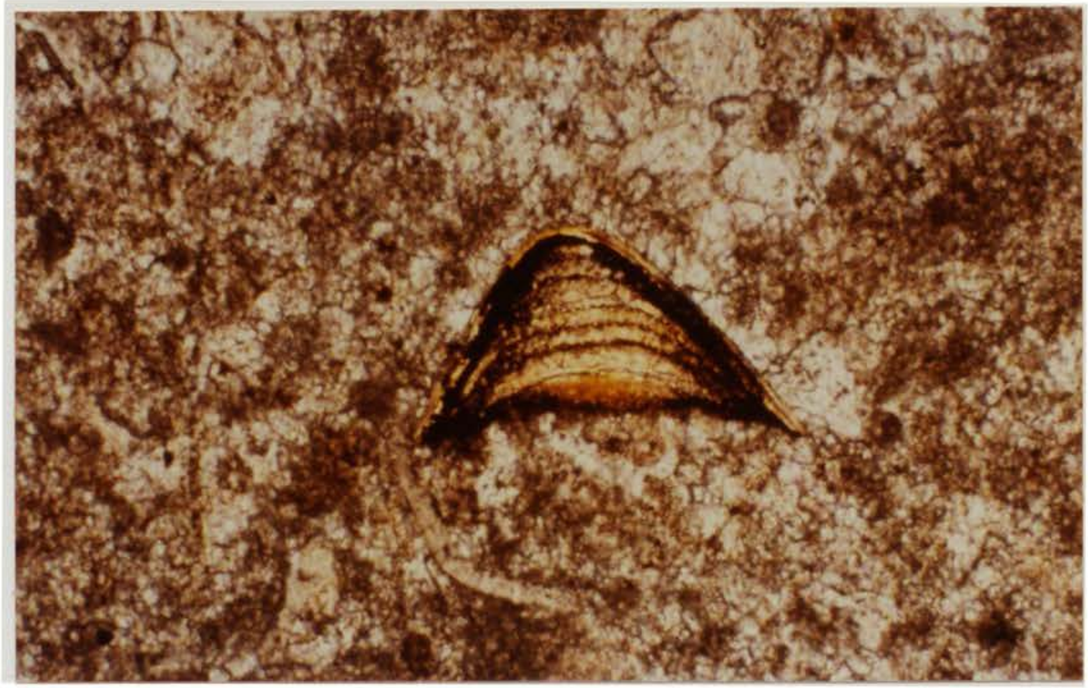
Skeletal fragments are sometimes replaced by amber-colored, nearly isotropic, phosphatic material in Units 2 and 3 (Figure 21a). Galvin (1982) and Grammer (1983) report gastropods completely infilled with this material though none were observed by the author. Linguloid brachiopod tests originally composed of chitinophosphate are observed throughout the Viola Group.

Pyritization

Pyrite replaces skeletal grains and occurs as isolated euhedral crystals (Figure 21b) in association with phosphate in hardground crusts. As noted above, phosphate and pyrite formation are interrelated. Pyrite is found in Unit 1L anaerobic sediments and hardgrounds and replacing skeletal grains in Units 2 and 3. It is more common at localities in the Arbuckle Mountains, where its weathering often produces ferric iron stains on outcrops, than in the Criner Hills.

Pressure Solution

The effect of pressure solution on the Viola Group is probably the most obvious of all the diagenetic events recorded. Both sutured and non-sutured seam types are present. The non-sutured solution is responsible for the wavy to nodular bedding of Unit 2 (Figure 22). Wanless (1979) desribes the formation of nodular texture in the



A

B

Figure 21. Photomicrographs of Skeletal Grains Replaced by Phosphate (a) and Pyrite as a Replacement Mineral in Association with Silica (b) 40X

A

B

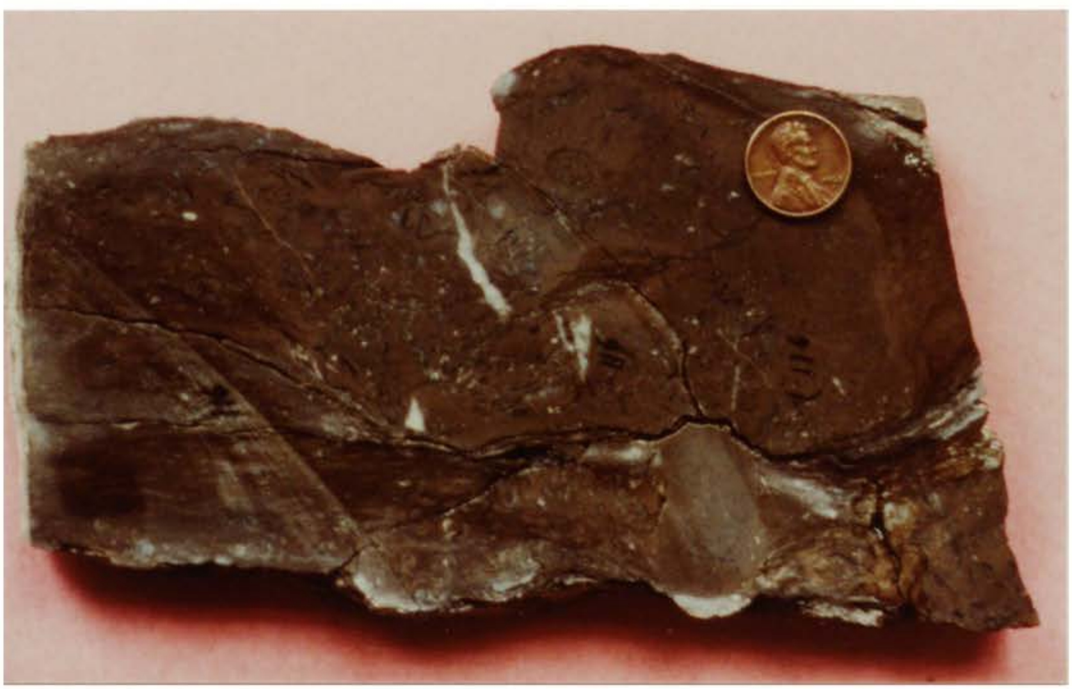


Figure 22. Photographs of Slabs of Highly Stylolitized Viola Springs Formation

Chambersburg Limestone (Ordovician) of Maryland which is remarkably similar to that in the Viola. Microstylolite swarms disrupt the limestone and produce the nodular texture. The swarms form as a result of overburden pressure that preferentially dissolves silty limestone and areas where the sediment is uncemented. Stylolitization does not penetrate the chert nodules. The shaly interbeds characteristic of the Viola are insoluble residue from the pressure solution. Coarse-grained skeletal material also tends to be preferentially preserved along these interbeds.

Sutured seam stylolites are oriented normal to bedding (this study, Galvin, 1982; Smith, 1982; and Grammer, 1983). This type of pressure solution is a result of tectonic stresses (Wanless, 1979) and in the Viola is a product of the Arbuckle Orogeny. Calcite cementation and dolomitization are other diagenetic events related to pressure solution in the Viola Group.

Cementation

The most obvious cement occurs in Units 2 and 3 as syntaxial calcite overgrowths on echinoderm fragments. Very fine-grained, mosaic sparite cement is also present in the section. The grainstones of the lower Welling Formation (Unit 3) best illustrate this type of cement (Figure 23a). The very coarse-grained pelmatazoan fragments have clear, coarsely crystalline, sparite cement grown in optical continuity from them. The cementation is complete and

A

B

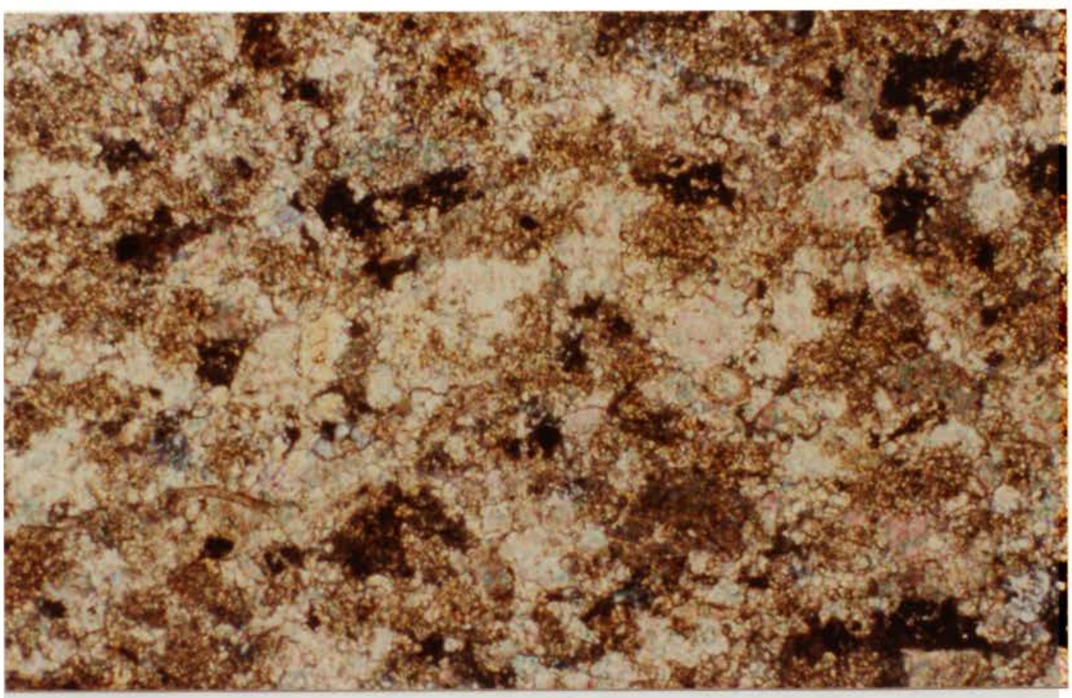


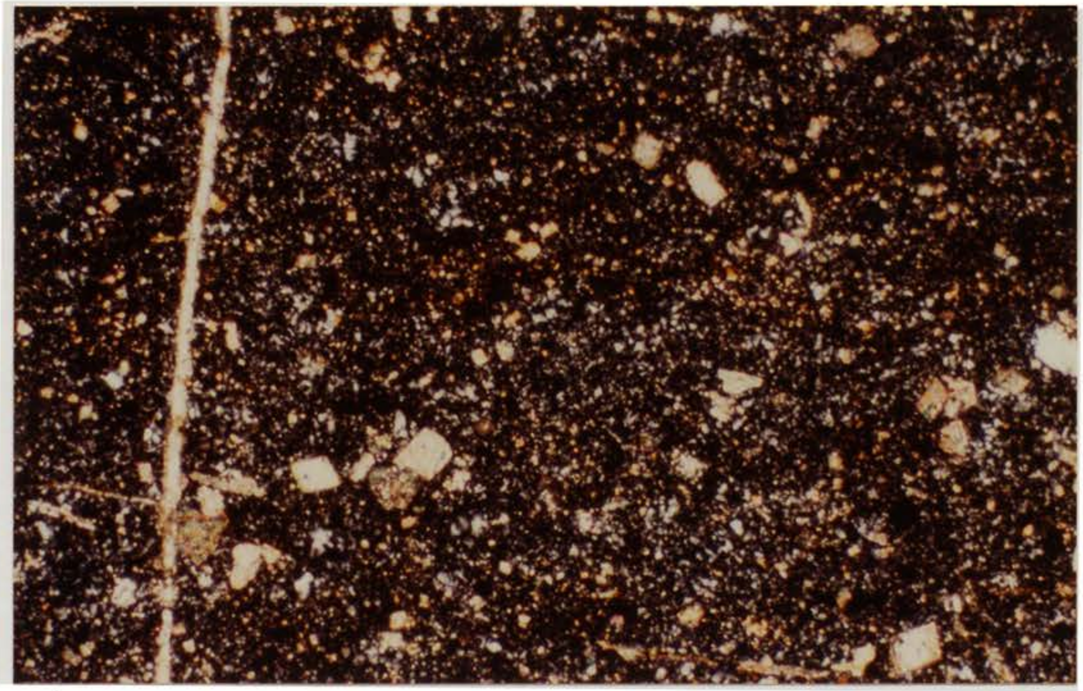
Figure 23. Photomicrographs of Syntaxial Calcite Overgrowths on Echinoderm Grains (a) and Interparticle Calcite Cement (b) 40X

occludes all porosity. Finely crystalline mosaic sparite is present in Units 1L and 2 as an interparticle cement (Figure 23b).

The source of calcium carbonate for the mosaic cement is probably pressure solution of the limestone. The carbonate mobilized from the stylolitized portion of the rock moved through the formation and was later precipitated as mosaic cement. Syntaxial overgrowths probably formed earlier than the mosaic cement from calcium carbonate-rich seawater. The Viola Group is completely cemented for all practical purposes. The thorough cementation may also be a reflection of how great the effect of pressure solution has been on the strata.

Dolomitization

Dolomite is rare in the Viola. It is found in association with the nodular chert and along some stylolites (Figure 24 a & b). The dolomite and chert formation could be contemporaneous, but this creates some difficulty in explaining their presence. Both can be formed in ground water-marine water mixing zones (Knauth, 1979). However, much of the dolomite-bearing chert occurs in the deep-water facies of Unit 1L--far away from the environment Knauth describes. A possible scenario for the formation of cherts in the euxinic environment is as follows. Decay of organic matter in the deep anaerobic basin would lower the pH of the water, allowing precipitation of silica. The decay may also



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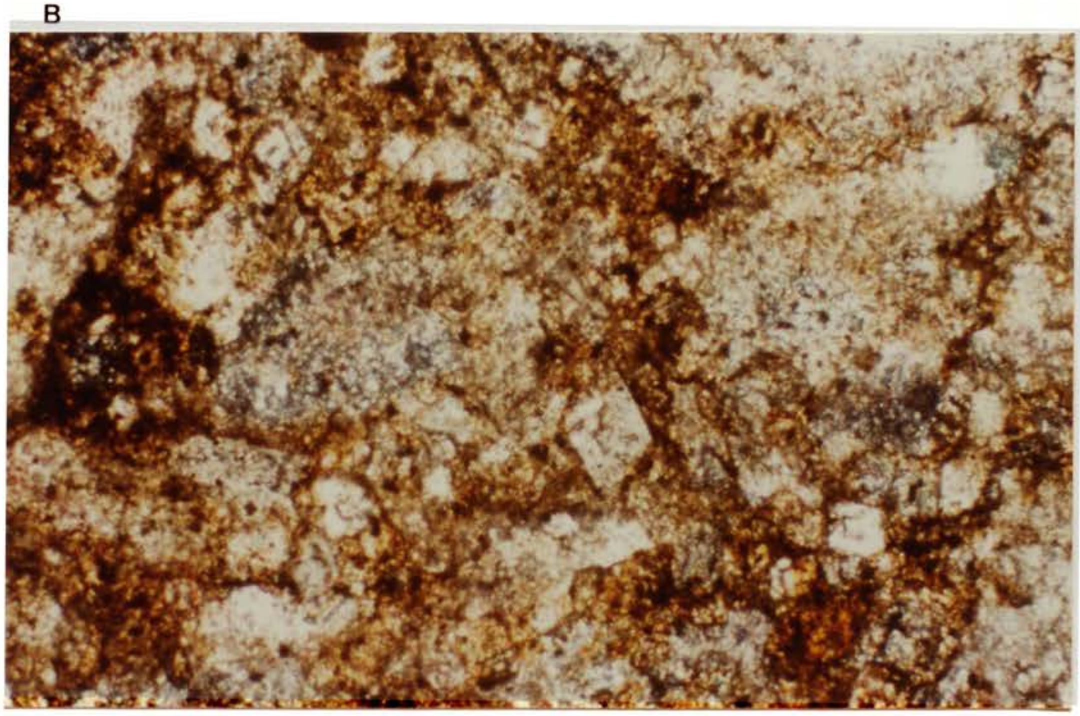

Figure 24. Photomicrographs of Euhedral Dolomite in Association with Chert (a) and in Stylolitized Areas (b) 100X

release magnesium from the plant tissue (possibly chlorophyll) into the water. If the pH were not to fall below about 8 and if a Mg/Ca ratio of 3:1 could be sustained, dolomite might also precipitate. The author recognizes the many variables that must be satisfied by this hypothesis make it speculative.

The dolomite occuring along stylolites is a product of the pressure solution (Wanless, 1979). Mg ions are released during pressure solution of high-Mg calcite. Under the correct conditions, the presence of free Mg ions in contact with carbonate solutions will precipitate dolomite. This dolomite is rare--occuring only along a few stylolites in upper Unit 2 (Figure 24b). It is a relatively late diagenetic event.

Silicification

Several events of silicification produced two types of silica in the Viola. The first and most common type is nodular and sublaminar chert. These occur in the lower Unit 1L and the upper Unit 2 in the Arbuckle Mountains, but are only found within a horizon 20-30 feet thick about 650 feet above the base in the Criner Hills. The chert represents both early and late diagenetic events. The early chert was formed prior to sediment compaction. The softer sediment is draped around the nodules--laminae within the sediment pinch and swell around the nodules (Figure 25a). Early diagenetic chert is seen only in the lower portion of

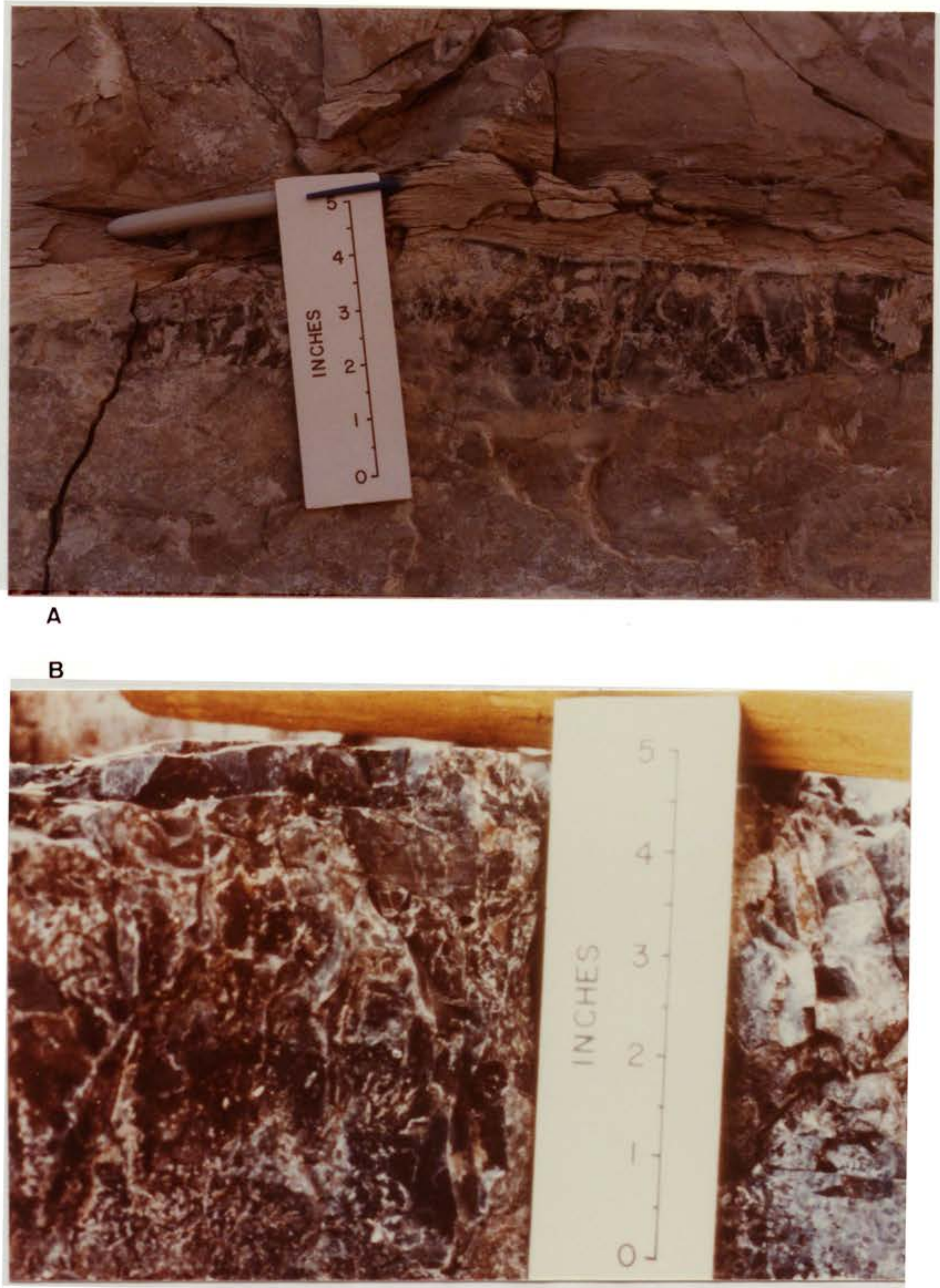

Figure 25. Photographs of Early Diagenetic Chert (a) and Silicified Limestone (b)

Unit 1L. Late diagenetic chert is represented by irregular zones where the limestone has been completely replaced by silica (Figure 25b). Where present, laminations in he limestones can be traced through the chert nodule. This type of chert occurs in the lower portion of Unit 1L and the upper 200 feet of Unit 2 in the Arbuckle Mountains but it is the only nodular chert occuring in the Criner Hills.

The second and less common type of diagenetic silica present in the Viola occurs as replacement of skeletal grains. Trilobite and brachiopod tests are the most commonly affected. Euhedral pyrite is sometimes seen within silicified shell fragments, suggesting that pyritization preceded this type of silica digenesis. A few gastropod and brachiopod tests that have been replaced by silica are observed in close association with the isolated chert nodules in the Criner Hills (Figure 26).

The source of the silica is, no doubt, tests of siliceous organisms. Sponge spicules are present to some degree throughout the section at all localities. Partially corroded milky-white spicules were a common component of the insoluble residue during graptolite processing. Despite the wide distribution of sponge spicules, diagenetic silica does not occur commonly in the Criner Hills localities. Proper geochemical conditions facilitating mobilization and reprecipitation of silica were rarely achieved in the rocks at these localities.

Figure 26. Silicified Fossil Grains on Bedding Surface at Section V

CHAPTER IV

GRAPTOLITE BIOSTRATIGRAPHY

General Statement

Graptolites are locally abundant in the Viola Group. The fossils were collected bed-by-bed from all localities studied. Hand quarrying of the rock produced quantities of excellently preserved flattened specimens. The shaly interbeds mentioned above were easier to work than the tough siliceous limestone and yielded fine samples. Where identifiable flattened specimens were not obtainable, samples of the limestone were collected for processing in the laboratory. Dissolving the calcium carbonate in diluted hydrochloric acid produced a residue from which graptolites could be hand picked. Once isolated, they were easily identified and preserved in glycerin-filled containers. Isolated specimens from the limestone tend to be preserved three dimensionally. The detailed morphology is intact and subsequently their identification can be made with greater confidence. Less than ideal angles of preservation of flattened material on bedding surfaces can make specific identifications difficult. Figures 27 through 30 show the stratigraphic ranges of the species found in each section.

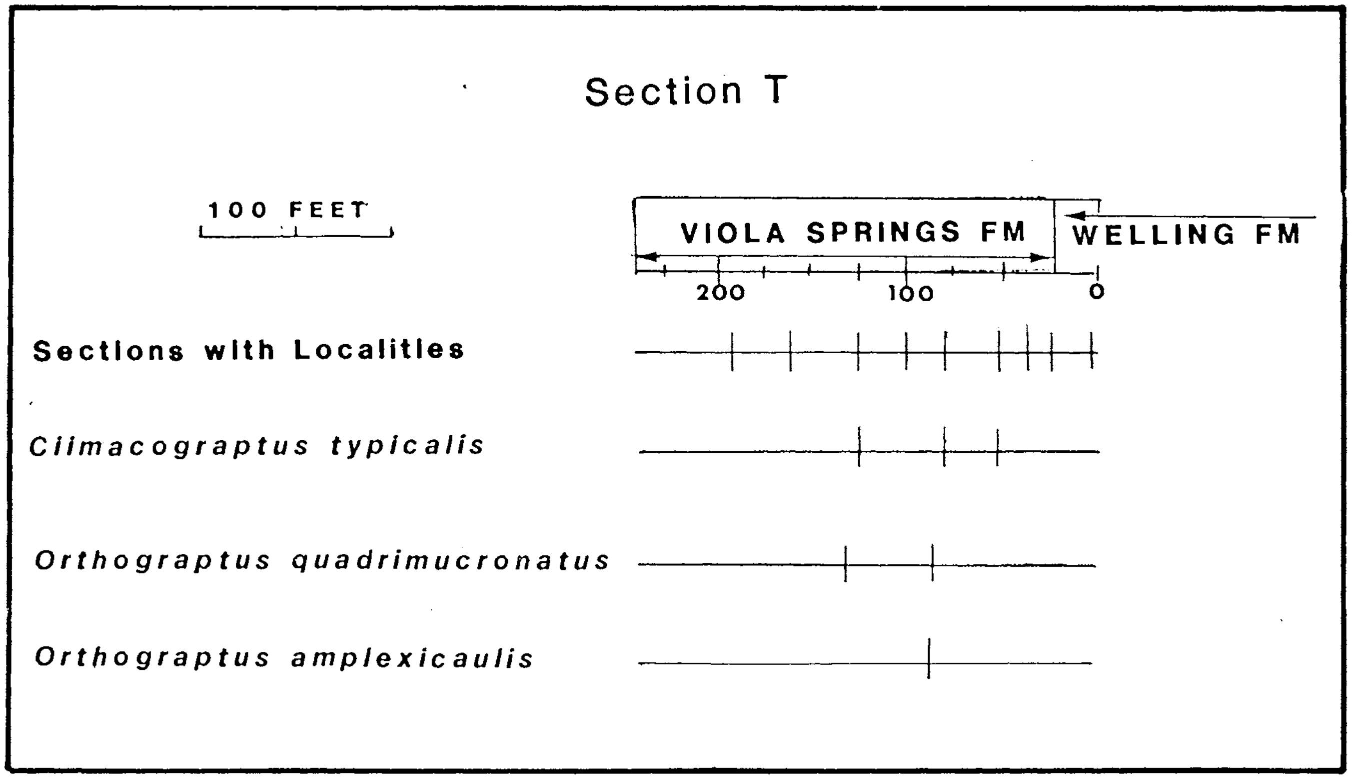

Figure 27. Stratigraphic Ranges of Graptolite Collections at Section T

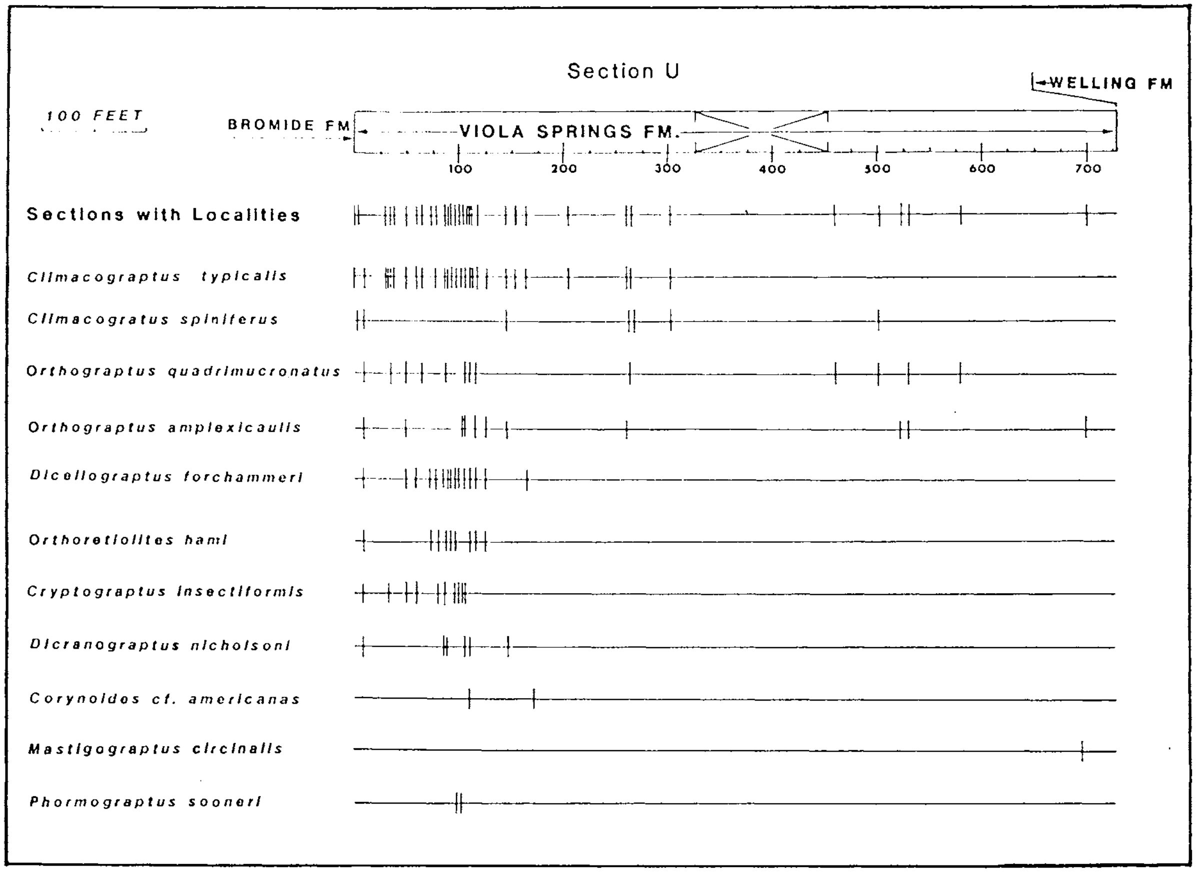

Figure 28. Stratigraphic Ranges of Graptolite Collections at Section U

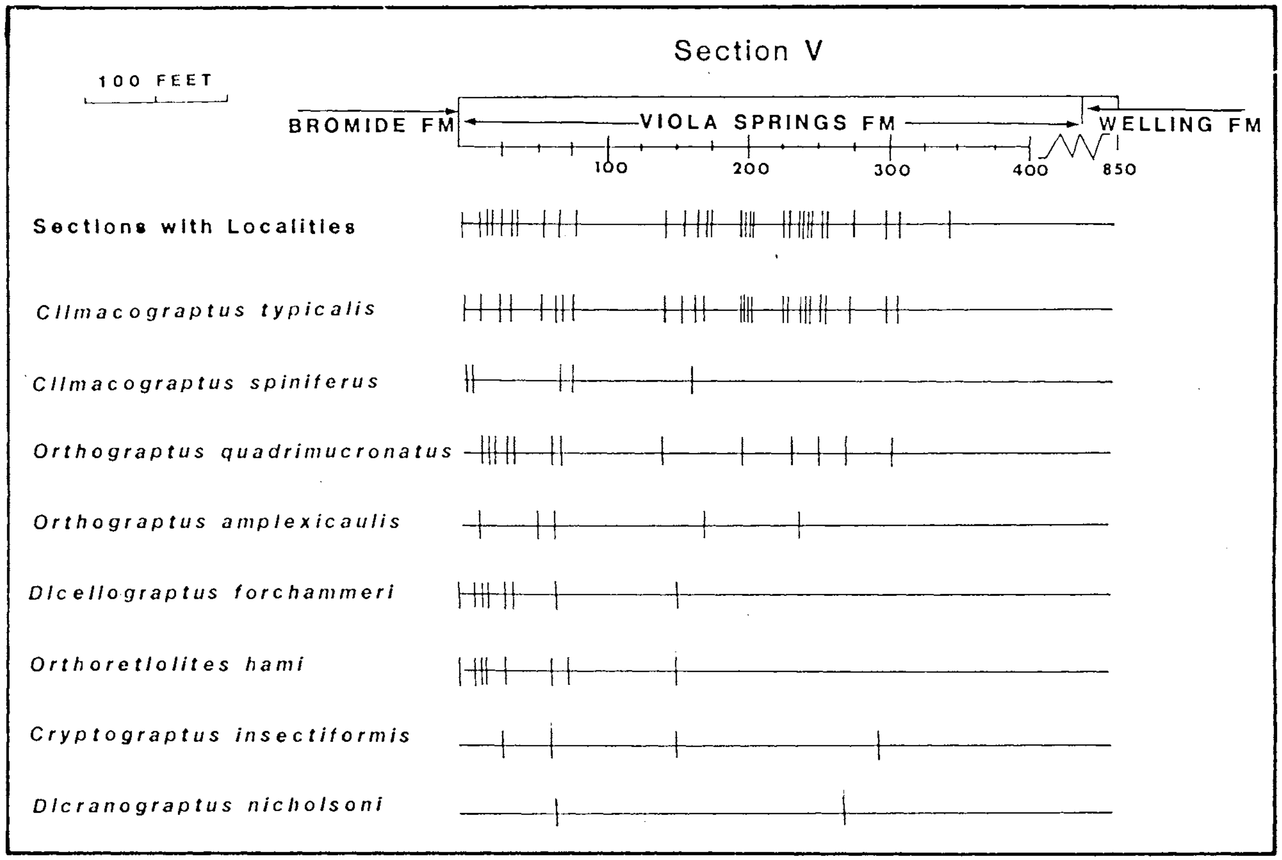

Figure 29. Stratigraphic Ranges of Graptolite Collections at Section V

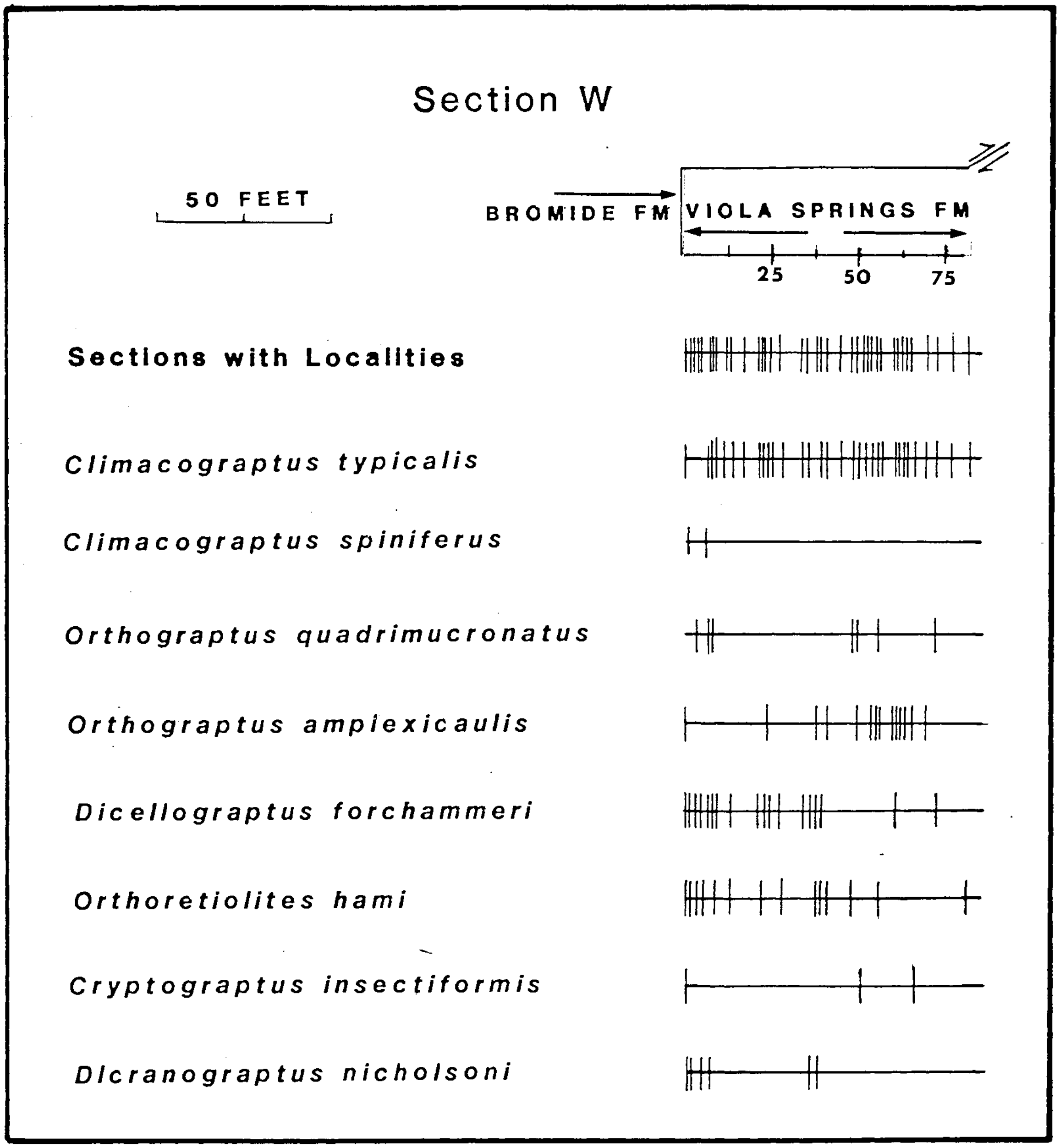

Figure 30. Stratigraphic Ranges of Graptolite Collection at Section W

Stratigraphic Ranges of Collections

Section U yielded the greatest number and range of specimens. Forty horizons contained identifiable graptolites. Section V yielded fewer good specimens over a narrower stratigraphic range. Graptolites abruptly ceased to appear 350 feet above the base. Section W is the shortest measured section but yielded the greatest density of collections. Good specimens were taken nearly every two feet stratigraphically. In general, the lower 300 feet of the Viola contained 90 percent of the specimens collected. Above this level, graptolites were scarce and badly fragmented making identification difficult. Only six localities 300 or more feet above the base yielded graptolites at Section U and only three each at Sections T and V. Decreasing occurrence of graptolites higher in the section may be attributable to the shoaling upward of depositional environment. Higher energy environments reduce the probability of preservation for these delicate fossils. The organic skeleton of graptolites is rapidly decomposed in well oxygenated water and was an attractive food source for scavengers, bacteria, and fungi. Mechanical abrasion and breakage by wave action may also be responsible for their scarcity.

The collections consist of a fairly uniform assemblage of species with little variation between the sections. Long-ranging species include: Climacograptus typicalis, C. spiniferus, Orthograptus quadrimucronatus, and O.

amplexicaulis. Dicellograptus forchammeri, Orthoretioltes hami, and Cryptograptus insectiformis are stratigraphically restricted to the lower 150 feet but occur abundantly. More rarely, Dicranograptus nicholsoni, Phormograptus sooneri, and Corynoides cf. americanus are found in the lower 200 feet of the section. P. sooneri and C. cf. americanus were found only at Section U. A single specimen of Mastigograptus circinalis occured 695 feet above the base also at this section.

Regional Correlation

Detailed studies of graptolites in the last two decades have led to revision and establishment of new biostratigraphic zones for the Middle and Upper Ordovician. Three diferent workers (Berry, 1960; Riva, 1974; and Carter and Churkin, 1977) studying the graptolite biostratigraphy in different areas of North America have produced three different zonations. Completeness of section, presence of unconformities, and graptolite provincialism all influence the validity of each set of zones. Recognition of provincialism in graptolites has made it necessary to establish zones for each major province. An attempt to correlate the Viola Group with these is shown in Figure 31 and is discussed below.

Riva (1974) revised the Middle and Upper Ordovician graptolite zonation of eastern North America based on collections from the Utica Shale of New York. Comparison

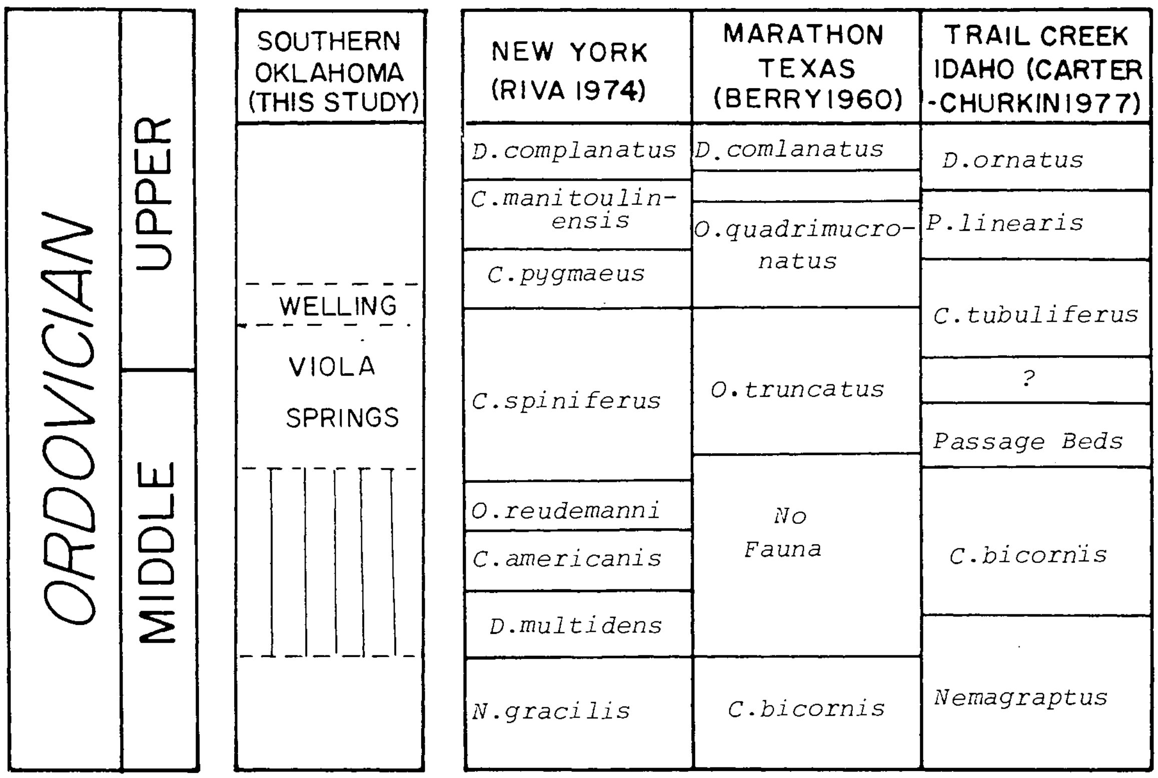

Figure 31. Regional Correlation of the Viola Group on the Basis of Graptolite to the Major Provincial Zones in North America

of the graptolite fauna of the Viola Group with that of New York (Riva, 1974) indicates assignment to the *Climacograptus spiniferus* Zone. In addition to *C. spiniferus*, the presence of *C. typicalis*, *Orthoretiolites hami*, *Cryptograptus insectiformis*, *Dicranograptus nicholsoni*, *Orthograptus amplexicaulis*, and *O. quadrimucronatus* support such a correlation.

Fifteen graptolite zones were delimited in the Marathon, Texas region by Berry (1960). Zone 13 (*Orthograptus truncatus*), in the Maravillas Chert, was established by a "burst of large Orthograpti" which include in addition to *O. truncatus*, *O. quadrimucronatus*, *O. calcaratus*, *Climacograptus typicalis*, *C. spiniferus*, *Dicellograptus forchammeri*, and *Dicranograptus nicholsoni*. The Viola graptolite assemblage closely correlates with this zone. Zone 14 (*Orthograptus quadrimucronatus*), in the Maravillas Chert, includes species similar to those in the Viola Group, but is above the ranges of *Dicranograptus nicholsoni* and *Climacograptus spiniferus*.

Study of graptolites by Carter and Churkin (1977), in the Phi Kappa Formation near Trail Creek, Idaho, led to the establishment of 10 new zones. This particular section is said to represent a continuous graptolitic succession containing no stratigraphic breaks from Lower Ordovician through Middle Silurian. For this reason, Carter and Churkin believe that the Trail Creek section is the most accurate graptolite reference section in North America.

The Viola Group correlates with an interval above their fifth zone (*Climacograptus bicornis*) and including their "passage beds" and sixth zone (*Climacograptus tubuliferus*). The passage beds are described as a 90-foot thick shale unit containing only scattered occurrences of any one species. Included are some dicellograptids, the last of the dicranograptids, and the incoming of *Orthograptus quadrimucronatus* and *O. amplexicaulis*. This unit correlates well with the lower 200 feet of the Viola Springs Formation on the basis of the highest occurances of dicranograptids and dicellograptids. The *C. tubuliferus* Zone contains the following species also common to the Viola Group: *Orthoretiolites hami*, *O. amplexicaulis*, and *O. quadrimucronatus*.

Correlation of Sections

Viola Group sections in the Arbuckle Mountains and Criner Hills are readily correlatable on the basis of graptolites. The presence of the same assemblage of species in the basal portion of Sections U, V, and W suggest that the base is equivalent across the study area. Last occurrences of *D. forchammeri*, *C. insectiformis*, *D. nicholsoni*, and *O. hami* are found within a limited stratigraphic interval about 100 feet above the base at Sections U, V, and W.

Climacograptus spiniferus is present at but a few localities. The last occurrence of the species is much at Section U than at any section in the Criner Hills. This might suggest different subsidence or sedimentation rates between the Arbuckles and Criner Hills. Although it is an important zone fossil, the poor graptolite representation in the upper Viola Group in the Criner Hills seriously limits any conclusions that might be drawn.

The upper Viola Group is easily correlated between Sections T, U, and V on the presence of C. typicalis, O. quadrimucronatus, and O. amplexicaulis.

Description of Species

Orthograptus amplexicaulis (Hall) is a typical orthograptid that is common in the Viola Springs Formation. It has a maximum width of 2-3.5 mm with 12 to 16 thecae per 10 mm. It is distinguished from other orthograptids found by its lack of thecal spines although they can occur occasionally on the first two thecae. O. amplexicaulis exhibits a long stratigraphic range especially at Section U where it was found high in the section. In the upper reaches of Section W, it is the only species present along with Climacograptus typicalis (Hall). The species is common to Ordovician sediments in Texas, New York, and Nevada.

Orthograptus quadrimucronatus (Hall) is much like O. amplexicaulis but can be distinguished by its paired apertural spines on every theca (Figure 32a). Specimens occuring at the base of the Viola Springs

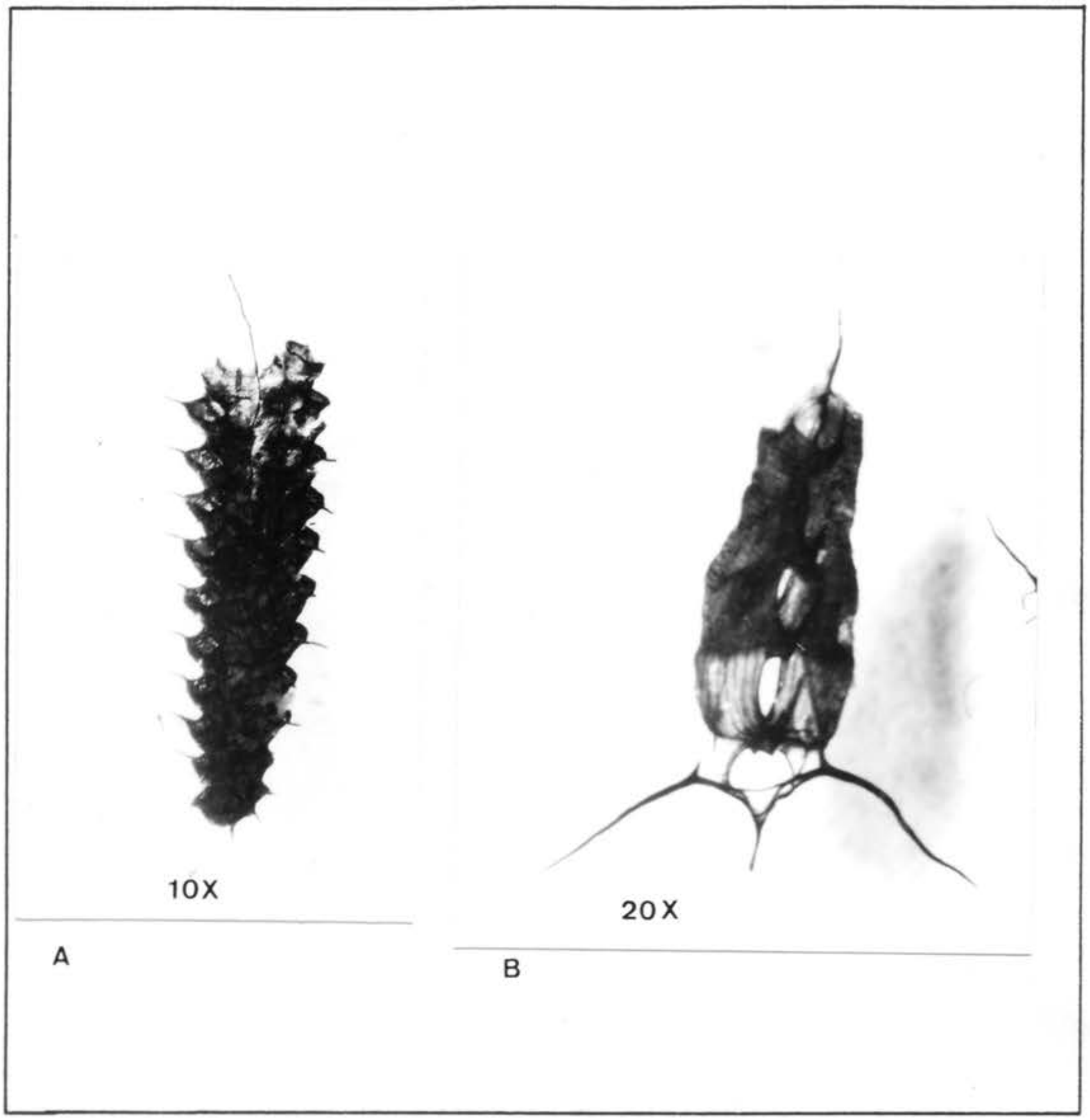

Figure 32. Photographs of Orthograptus quadrimucronatus Hall (a) and Cryptograptus insectiformis Ruedemann (b)

Formation are comparatively large--up to several centimeters long and 3 to 4 mm wide. Its distribution is similar to that of *O. amplexicaulis* in the study area. The species has a world-wide distribution being found in Australia, Great Britain, as well as New York, Arkansas, Nevada, and Texas.

Climacograptus spiniferus (Ruedemann) is a particularly good index fossil in the Viola Group sections (Figure 33b). Although its distribution within the section is scattered, it occurs at three of the four sections and thus can be use in correlating across the study area. Specimens are typically large biserial rhabdosomes up to 2.8 mm wide and almost a centimeter long. It is distinguished from other species of this genus by having two spines on the proximal end. One is a thecal spine on the first theca, the other is the virgella. *C. spiniferus* is found in Ordovician strata in New York, Texas, Nevada, and parts of Australia.

Dicellograptus forchammeri (Geinitz) has long thin stripes 0.4-0.9 mm wide up to 10 cm long (Figure 34a). Thecal apertures are isolated and introverted. The sicula is upright with the first theca of each stripe horizontal. Stripes diverge horizontally at first but become gradually reclined. Occasionally, stripes are nearly scandent and entwine. *D. forchammeri* is common but limited to the lower 100 feet of the Viola Springs Formation. Some beds at Sections U, V, and W contained

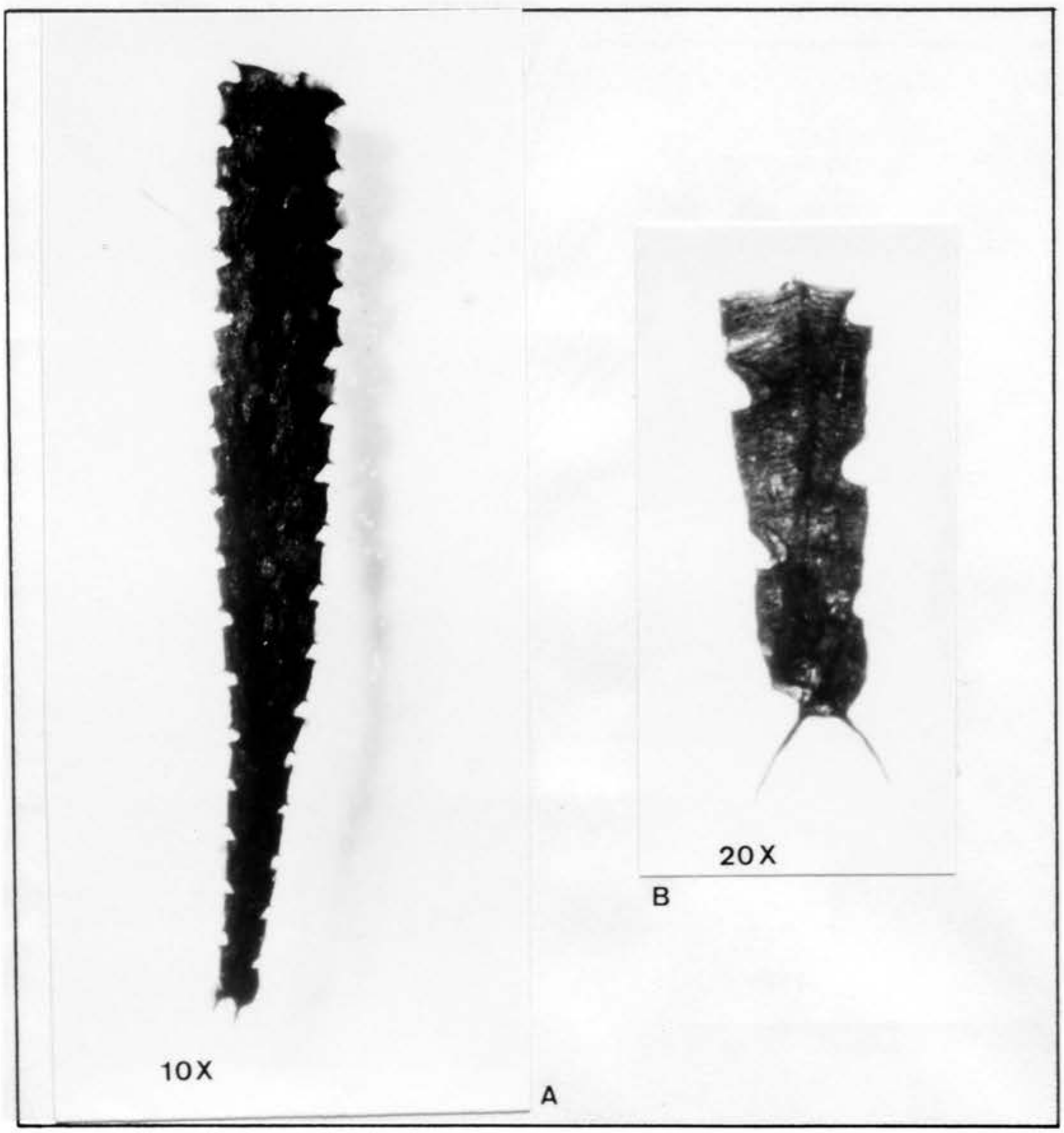

Figure 33. Photographs of Climacograptus typicalis Hall (a) and Climacograptus spiniferus Ruedemann (b)

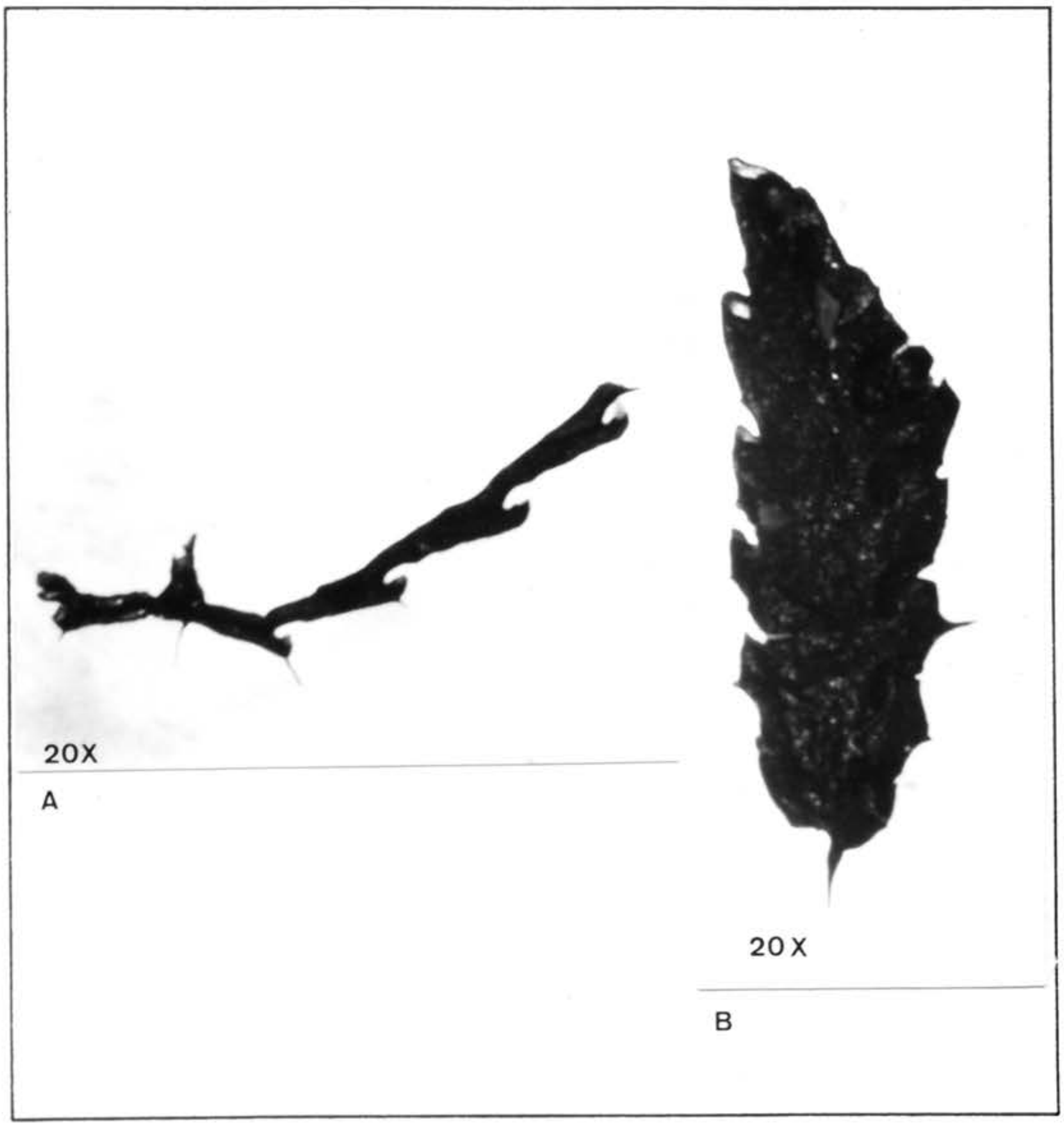

Figure 34. Photographs of Dicellograptus forchammeri Geinitz (a) and Dicranograptus nicholsoni Hopkinson (b)

horizons of mass preservation composed exclusively of this species. It has a world-wide distribution--found in Scotland, Scandinavia, Australia, and in West Texas and Nevada.

Dicranograptus nichosoni (Hopkison) occurs sparsely in the lower Viola Springs Formation (Figure 34b). The rhabdosome has a long, biserial proximal end containing up to 12 pairs of thecae and nearly 1 cm long. Maximum width of the biserial part is 2 mm. Two uniserial stipes diverge at an angle of 60 to 90 degrees and can attain a length of 8 to 10 mm. It is well known worldwide occurring in Great Britain, Australia, as well as North America in Texas, New York, Arkansas, and Nevada.

Cryptograptus insectiformis (Ruedemann) is characterized by its short rhabdosome (less than 10 mm) and thin periderm (Figure 32b). Three prominant spines are visible on the proximal end. It is found in the lower Viola Springs at Section U and up to the middle Viola Springs at Section V. It has a worldwide distribution including Great Britain, Australia, and Texas, Nevada, and Arkansas.

Climacograptus typicalis (Hall) ranges throughout the Viola Springs Formation at all localities, often current oriented (Figures 33a & 16). It has very large biserial rhabdosome up to 4 mm wide and up to 10 cm long. Thecae have a characteristic genicular flange. The rhabdosome tapers to a narrow 0.4 mm wide proximal end. The first theca is characteristically saxaphone-shaped.

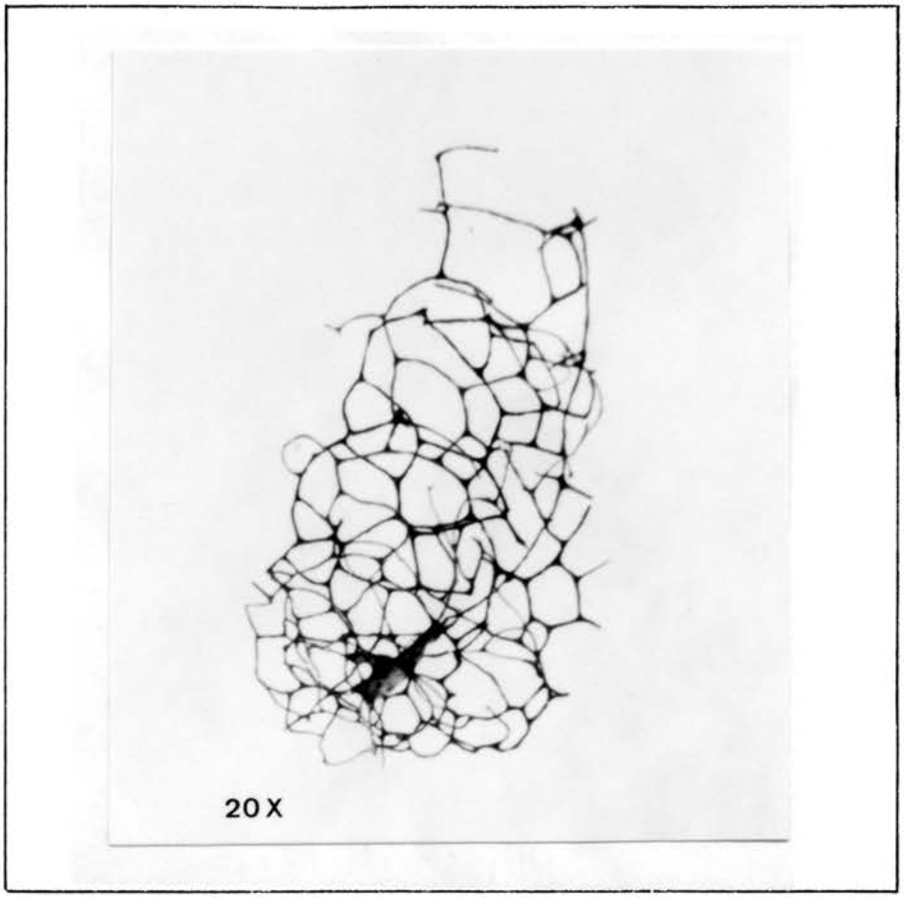

Figure 35. Photograph of Phormograptus sooneri Whittington

Three spines are present on the proximal end--two anti-virgellar spines and the virgella. No other spines appear on the species. *C. typicalis* has been reported from Australia, Scandinavia, and New York, Texas, and Nevada.

Orthoretiolites hami (Whitington) has a distinctive rhabdosome preserved as a "chickenwire" skeleton lacking any periderm except the sicula which is skeletonized Rhabdosomes are small, usually less than 5 mm long with sicular spines. It occurs abundantly but is restricted to the lower 100 feet of the Viola Springs. *O. hami* is known only from the Viola Springs Formation.

Phormograptus sooneri (Whittington) resembles *O. hami* in that the periderm is also reduced to a network of lists (Figure 35). However, their arrangement is very complex. Rhabdosomes are usually less than 5 mm long with no presence of any type of spines. The sicula is skeletonized. This delicately ornate species is known only from the Viola Springs Formation.

CHAPTER V

ENVIRONMENTS OF DEPOSITION AND GEOLOGIC HISTORY

General Statement

Synthesis and interpretation of the preceding observations permit statements about the geologic history and environments of depostion. Galvin (1982) and others proposed a transitional deep to shallow carbonate ramp setting. They established that the Viola setting was analogous to the model for a carbonate ramp proposed by Ahr (1973). No evidence was found to the contrary; however, refinement of the interpretation is made by incorporating another depostional model with the one adopted by previous workers.

The simplified model drawn by Galvin (1982), Smith (1982), and Grammer (1983) applies Walther's Law (intrerpreting a vertical succession of facies as being laterally equivalent) recognizing the presence of some type of sediment flow. It does not portray effects of contour currents with respect to sedimentation. Bein and Weiler (1966) constructed a model for the Talme Yafe Formation (Cretaceous) of Israel which is described as a contour current shaped prism of calcareous detritus. Although the

Talme Yafe does not strictly represent a carbonate ramp in the sense desribed by Ahr, it is similar to the Viola Group. The model adopted in this study is a marriage of the Ahr model and the Bein and Weiler model (Figure 36).

A brief introduction to the carbonate ramp setting and the Talme Yafe setting is followed by a discussion of the specific environments of deposition. Temporal data obtained from the biostratigraphic correlation permits brief discussion of the geologic history of the Viola Group.

The Ahr Model

Ahr (1973) established the following criteria to describe a cabonate ramp:

1) Shallow, gently sloping platform (<1 degree) that lacks a major break in slope.

2) Grainstones in an updip position, which may be associated with local downdip build ups.

3) Absence of continuous reef trends; only discrete and separate buildups present.

4) Downslope sediment gravity flows containing shallow platform derived clasts absent, except adjacent to local buildups.

This definition contrasts to that of a carbonate shelf in that shelves are shallow platforms whose outer edge contains a marked increase in slope into deeper water. Continuous carbonate buildups, like reefs, commonly form at the shelf edge. Also, sediment-gravity flows of platform-derived material dominate the downslope sediments (Ahr 1973).

As earlier workers concluded, the carbonate ramp model best fits the depositional setting of the Viola Group.

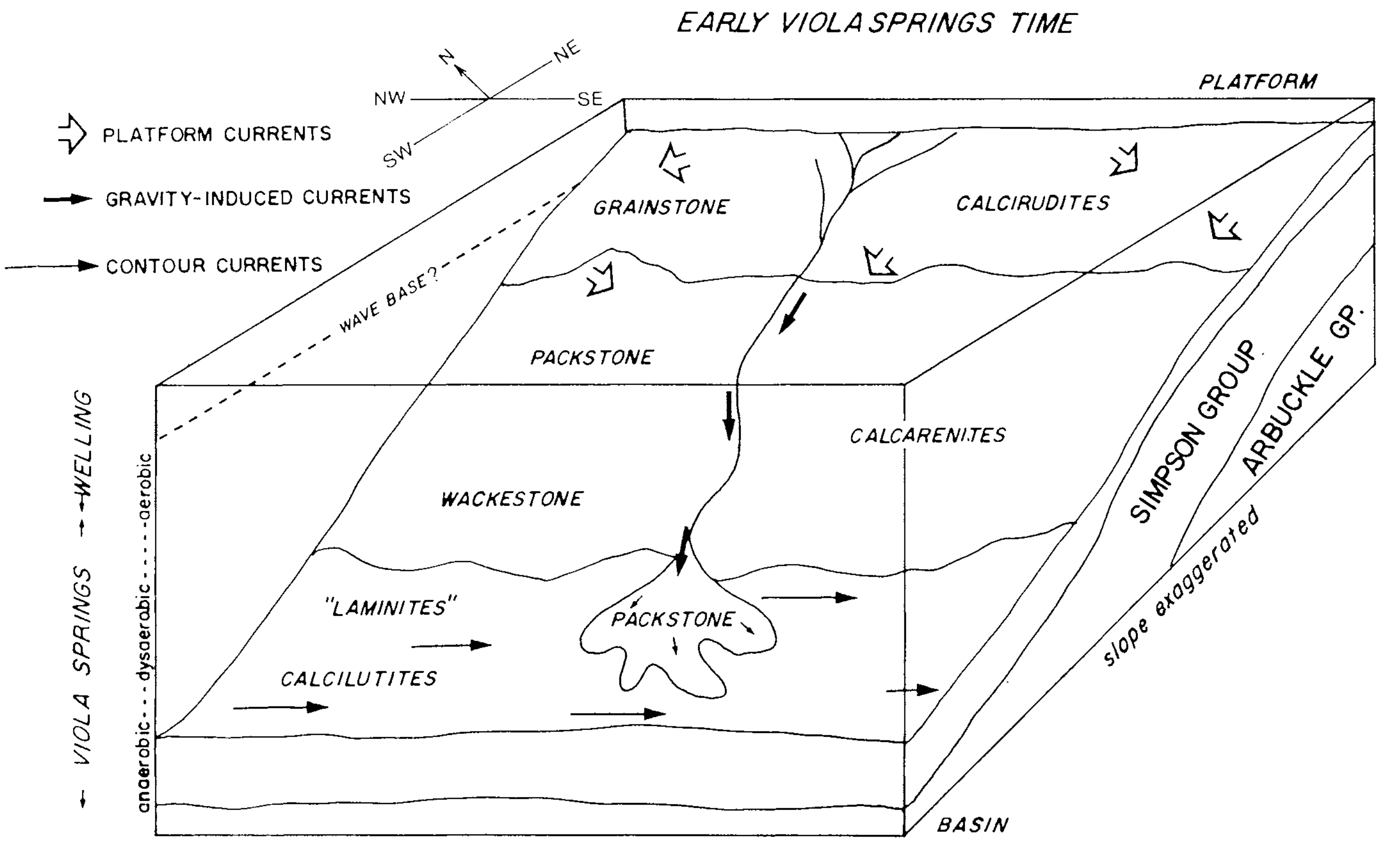

Figure 36. Schematic Depositional Model for the Viola Group (after Galvin, 1982; and Bein and Weiler, 1966)

Absence of reefs or carbonate mounds and major gravity flows, the presence of updip grainstones and generally gentle slope (calculated to be about 0.5 degrees in the Arbuckle Mountain area) can all be documented in the Viola Group. A minor change in slope (a fraction of a degree) occurs in the study area due to the difference in subsidence rates between craton and basin. Also, the basal seven feet at Section U is recognized as some type of sediment flow (Galvin 1982; this study). These represent relatively insignificant modifications of the basic model.

The Talme Yafe Formation

Bein and Weiler (1966) determined that the Talme Yafe is.a prism of calcareous sediment which was deposited and shaped by contour currents. The source of the material is believed to be biochemical carbonate and skeletal fragments formed on the adjacent platform. They were transported by tides, seasonal currents, and storms. The sediments were then dispersed on the slope by contour currents.

The shared characteristics of the Viola and Talme Yafe include:

i) dominance of shelf-derived calcareous sediment;

ii) a vertical shoaling-up sequence (calcilaminites, calcarentites, and calcirudites);

iii) few sedimentary features indicative of very shallow water deposition;

iv) a regime of sedimentation where weak and more rarely strong currents flowed (as demonstrated in the lower Viola Springs by oriented fossils and scours);

v) and a small amount of, if any, of sediment flows present in the section.

In addition, the lower Viola Springs Formation was demonstrated to compare closely with the contour deposited sediments described by Bouma (1972) in the preceding discussion of paleocurrents. It is therefore infered that the lower Viola is analogous to the Talme Yafe in mode of depostion.

Discussion of Environments of Deposition

The lower Viola sediments were deposited in a deep marine anoxic setting on a carbonate ramp (Galvin 1982; Smith 1982; Grammer 1983; this study). Evidence supporting this includes:

i) fine sediment size;

ii) absence of any shallow water depostional features;

iii) lack of evidence indicating an indigenous fauna;

iv) laminations;

v) high organic carbon content;

vi) and the presence of phosphate, pyrite, and abundantly preserved graptolites.

This setting prevailed throughout the study area during depostion of the lower 100-150 feet of Unit 1L. The anoxic nature of the environment is best illustrated by the high organic carbon content (reported to be as much as 5% by Galvin (1982) and others). The present author is not the first to record the pungent petroliferous odor emitted from a freshly broken sample of the limestone. The mass preservation of coalified graptolites also attests that the seawater of the Viola sedimentary basin was oxygen poor at that time.

The most carbonaceous sediments appear at Section U as dark brownish-black shaly limestone immediately above the hardground. The basal section at localities in the Criner Hills is less carbonaceous, although still emits a petroliferous odor when broken. Highly anoxic conditions probably occurred locally in the area of Section U. A low rate of sedimentation would have the effect of concentrating the amount of organic material. The opposite must have taken place in the Criner Hills area. A dilution effect from higher carbonate sediment input with respect to organic matter (Demaison and Moore, 1980) may have occurred. The rate of sedimentation in this area does appear to have been greater than in the Arbuckle Mountains as evidenced by a thicker accumulation of sediment.

The influence of bottom hugging currents on the sediment of the lower Viola is illustrated by oriented graptolites and occasional scours whose major mode of oriention is coincident with the trend of the contours of the southern Oklahoma aulacogen. The driving mechanism for these currents is likely thermohaline density differences and to some degree, winds. Reconstruction of Cincinnatian paleoenvironments by Ross (1976) shows that the Oklahoma area lay south of the equator and was covered covered by normal marine water. Surrounding the area to the north, northwest, and west was very shallow marine water affected by high rates of evaporation. Ross also reported that dense brines may flow downslope into deeper water as coherent masses, creating a deep ocean current. Cooling of the brine as it sinks further increases its density, causing it to hug the bottom. Also shown by Ross is the direction of the prevailing wind. As the Oklahoma area lay just south of the equator, it was probably subjected to general northwest trade-wind (again parallel to the axis of the basin). The surface water would be forced northwestward causing a buildup of water at that end of the basin which would then recirculate down and back in a southeasterly direction. A continuous circulation cell would result. As water depth decreased in the basin, the narrower water column would not allow sharp thermal or salinity differences and would also suppress the effect of prevailing wind. This would explain the absence of contour current evidence in the upper Viola Springs and Welling Formations.

During the deposition of upper Unit 1L and lower Unit 2, anaerobic conditions yielded to a dysaerobic setting. Traces of burrowing organisms, lower organic content, and a general coarsening in and abundance of bioclastic material suggest that a slight shallowing allowed increased circulation which raised the dissolved oxygen level of the water. Still, sedimentary features indicative of shallow water are lacking in these rocks. Smith (1982), this study and others propose that this represents deposition well below wave base in a poorly oxygenated marine setting.

The wackestone and packstone of middle and upper Unit 2 indicate continued shallowing in environment. Coarser grained bioclastic material of trilobites, brachiopods, and echinoderms are abundant. Bioturbation is extensive in some portions of the section illustrating that the water was well oxygenated supporting a large number of benthic organisms. This evidence of biologic activity is exceptionally abundant in the Criner Hills section. Shallowing conditions continued through depostion of the rest of the Viola Group. Decrease in water depth was achieved by more or less steady sedimentation and/or reduction in subsidence rate. Sedimentary features characteristic of deposition above wave base, i.e. cross-bedding, are absent.

Very coarse-grained, well-washed, calcarenitic skeletal grainstones mark the highest energy environment represented in the Viola Group. Cross-bedding of the skeletal material indicating some wave influence suggests an intertidal environment or just slightly below wave base. Vertical burrows (perhaps of linguloid brachiopods) are present. The large grain size and angularity indicate brief transport and close proximity to their source area. An almost total absence of carbonate mud attests to the high energy environment.

At Section T, the Welling Formation is composed entirely of these grainstones. The Welling at Section U and V suggests that the high energy intertidal environment did not prevail in the basinward province throughout its deposition. As mentioned earlier, only the basal eight feet of the Welling at Section U consist of grainstone. The upper 19 feet consist of packstones similar to those of Unit 2. Their presence above the grainstones indicates a deepening of the environment to probably below storm wave base. During depostion of Unit 3CM in the Criner Hills, interfingering of the shoal sands and deeper water carbonates (like Unit 2) indicates a series of fluctuations in water depth. Changes in both rates of subsidence and sedimentation were no doubt the cause, but why they occured can be only surmised.

Speculative paleobathymetries for the Viola Group have been reported by earlier workers. In the case of the lowest anoxic environment, analogies are drawn from studies of oxygen levels in the modern Black Sea. The Black Sea is an example of a silled basin with restricted circulation (Figure 37). Anaerobic conditions occur about 150 meters below the surface there (Caspers, 1957). Normal marine conditions with circulating currents prevailed during early Cincinnatian time (Ross, 1976). Demaison and Moore (1980)

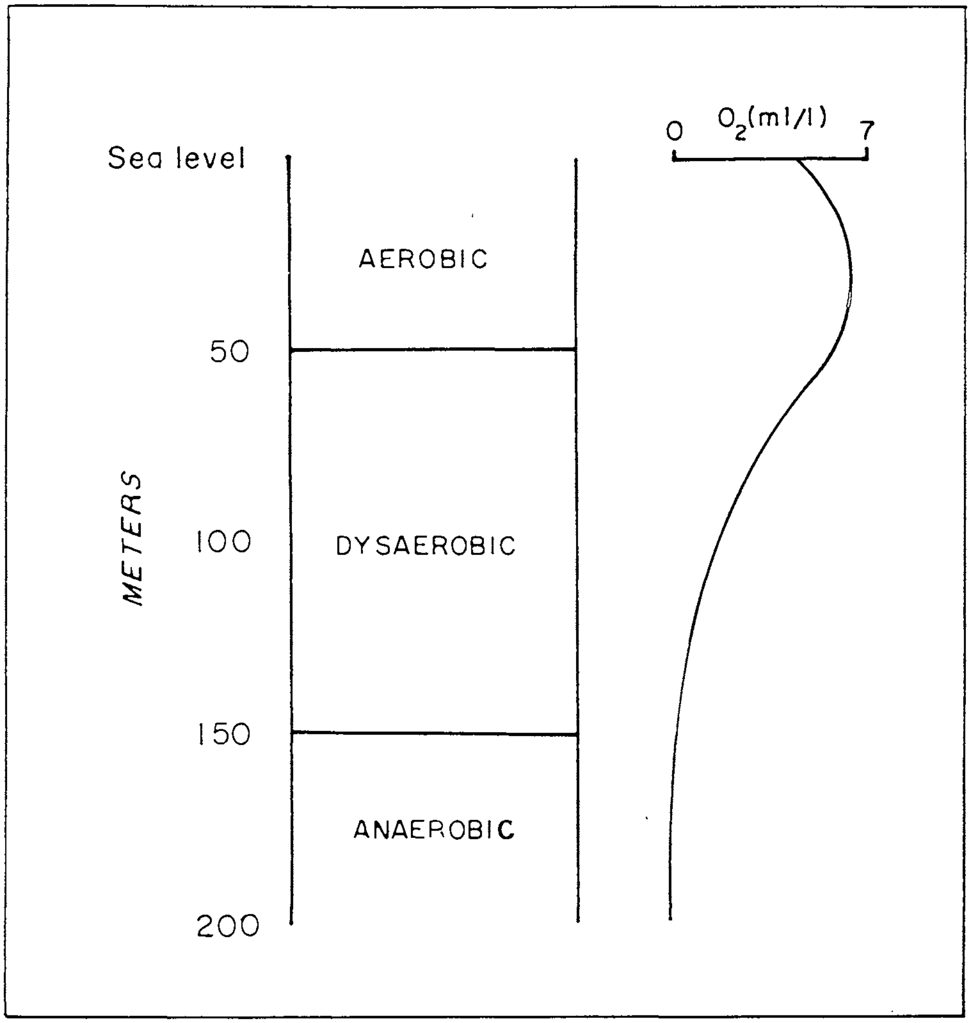

Figure 37. Dissolved Oxygen Levels in the Black Sea and Sea of Azov (after Caspers, 1957)

are careful to differentiate conditions in the Black Sea from those of open ocean in reconstructing paleobathymetries. It is therfore likely that the depth at which anaerobic conditions were present in the Viola Group was great. No attempt to establish paleobathymetries for the various environments of depostion is made here because truly accurate estimations are just that-- estimations.

Geologic History

Continued subsidence, possibly as a result of post-rift thermal subsidence in the aulacogen, and major transgression followed depostion of the Pooleville Member of the Bromide Formation. It is at this time period when the pre-Viola Group unconformity spanning middle Kirkfieldian time developed (Amsden and Sweet, 1983). Based on the presence of *Climacograptus spiniferus* at the base of the Viola at each locality in the study area, sedimentation began roughly at the same time across the basin. At section U, a sediment flow deposited platform sediments (pellets, ostracods, brachiopods, and sponge spicules) on the unconformity. In the Criner Hills, very fine-grained carbonate sediment was deposited on top of the Pooleville Member. Anoxic conditions prevailed at both the Criner Hills and Arbuckle Mountains and preserved large amounts of organic matter with the carbonate sediment. When about seven feet of debris had accumulated as a result of the sediment flow in the Arbuckles, the flow ceased. A period of nondeposition allowed a hardground to form before normal carbonate sedimentation resumed. Subsidence and deposition of fine sediments, which continued through middle Shermanian Time, gave rise to Unit 1L.

Subsidence decreased in later Viola Times although sedimentation appears to have been steady, effectively lowering sealevel and decreasing the depth of depositional environment. Evidence of this is seen as the decrease in preserved organic matter and an increase in biologic activity--in the form of tests of shelly, shallower water animals and burrows. Subsidence continued to be greater in the Criner Hills area than in the Arbuckle Mountain region. Sedimentation continued from approximately middle Shermanian to early Maysvillian in moderately deep, but shallowing water resulting in the rocks we call Unit 2.

During lower and middle Maysvillian time, the Viola ocean reached its minimum depth. The wave influenced carbonate sand shoals prevailed only for a brief time in the study area, depositing a relatively thin veneer of coarse-grained sediment as the Welling Formation.

CHAPTER VI

CONCLUSIONS

The following conclusions are drawn from this investigation:

1. The Viola Group of the Arbuckle Mountains and Criner Hills consists of three lithostratigraphic units:

Unit 1L--finely laminated, medium bedded, fine grained limestone rich in organic carbon, chert, and phosphate with shaly limestone interbeds. The sediments were deposited in a deep anaerobic environment under the influence of contour parallel currents.

Unit 2--medium grained, medium wavy bedded, burrowed limestone with shaly interbeds containing variable amounts of chert. This unit experienced a shoaling upward of depositional environments from deep dysaerobic to moderately deep aerobic but below wave base.

Unit 3C and 3CM--generally coarse grained, medium to thickly bedded limestone with shaly interbeds composed almost entirely of the disarticulated tests of trilobites, echinoderms, and brachiopods. The well washed calcarenitic sands were deposited in an aerobic environment probably a wave-influenced shoal. In the southern Arbuckle Mountains and Criner Hills, the coarse calcarenite is overlain and interbedded with medium grained sediments resembling those of the underlying unit.

2. The lithostratigraphic units are correlatable throughout the study area. A general thickening of all the units occurs from the Arbuckle Mountains basinward to the Criner Hills. The greatest increase occurs in Unit 1L which thickens by nearly 70 percent.

3. Viola Group sediments are graptolite rich. Their correlation with graptolite zones of New York and Quebec (Riva 1974) places the Viola in the *C. spiniferus* zone and allows correlation to the Maravillas Chert of west Texas and the Formation of central Idaho. The presence of this species at the base of all sections suggests the basal Viola is equivalent throughout the study area, and that initiating deposition of the Viola Group was simultaneous across the basin.

4. Diagenesis played a significant role in altering the primary rock texture. Phosphatization, pyritization, dolomitization, silicification, cementation, neomorphism, and pressure solution are the major events identified. Pressure solution was responsible for the characteristic wavy to nodular bedding exhibited in Unit 2. Aggrading neomorphism effectively coarsened the once fine grained sediments of Unit 1L producing structure grumeleuse. The diagenetic events identified differed little from those recognized in previous studies of other areas.

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APPENDIX A

THIN SECTION DESCRIPTIONS

THIN-SECTION CATALOG

Abbreviations:

brc - brachiopod	gra - graptolile
bry - bryozoan	ost - ostracod
chi - chitinozoa	spi - spicules
ech - echinoderms	tri - trilobite
gas - gastropod	qtz - detrital quartz

Section T

(Numerical suffix denotes feet below top of Viola Group)

T-175	Packstone:	ost > brc > ech > tri > qtz > bry > chi > gra
T-145	Wackestone:	ech > tri > brc > gas > bry > ost > chi > gra
T-128	Wackestone:	ech > gas > ost > tri > qtz > brc > gra
T-127	Packstone:	burrowed, stylolitized ech > tri > brc > ost > chi > gra > bry
T-100	Wackestone:	tri > ech > brc > gra > qtz > ost > chi > bry
T-65	Wackestone:	burrowed, ech > tri > bry > brc > ost > gra > chi
T-45	Wackestone:	ech > brc > bry > tri > qtz > ost > chi > spi
T-40	Mudstone:	ost > ech > brc > tri > qtz
T-25	Grainstone:	ech > tri > brc > gra
T-17	Grainstone:	ech > brc > tri > bry > qtz > spi
T-0	Grainstone:	ech > brc > tri > ost > chi > gra

Section U

(Numerical suffix denotes feet above base of Viola Group)

U-0	Wackestone:	ost > spi > chi > gra
U-7	Packstone/mudstone:	ost > spi > gra - hardground surface
U-7.1	Mudstone:	ost > spi > chi > gra > qtz
U-25	Mudstone:	spi > ost > chi > gra > qtz
U-50	Mudstone:	brc > ost > spi > chi > gra > qtz
U-100	Mudstone:	silicified, partially dolomitized brc > ost > gra > qtz
U-125	Packstone:	ech > qtz > brc > tri > ost > bry > chi > gra > spi
U-140	Mudstone:	brc > tri > spi > ost > qtz > gra > chi
U-150	Wackestone:	qtz > ost > brc > spi > gra

U-200	Wackestone:	qtz > brc > ost > spi
U-250	Wackestone:	qtz > ech > tri > ost > brc > gra
U-300	Wackestone:	burrowed, ech > qtz > tri > brc > chi > spi > gra
U-350	Packstone:	burrowed, qtz > ech > tri > brc > gra
U-550	Packstone:	burrowed, ech > brc > tri > ost > bry > qtz > gra
U-570	Packstone:	burrowed, ech > tri > brc > ost > qtz > bry > chi
U-600	Wackestone:	burrowed, qtz > ech > tri > bry > brc
U-700	Packestone:	ech > brc > tri > spi > gra
U-710	Grainstone:	ech > brc > tri > bry > qtz
U-727	Wackestone:	ech > tri > brc > bry > qtz

Section V

(Numerical suffix denotes feet above base of Viola Group)

V-5	Mudstone:	ost > spi > gra > qtz
V-50	Mudstone:	spi > qtz > ost > gra > chi
V-75	Mudstone:	spi > qtz > ost > chi > gra
V-100	Wackestone:	spi > qtz > brc > chi > gra
V-300	Wackestone:	burrowed, brc > spi > ost > gra
V-500	Wackestone:	burrowed, tri > ost > ech > brc > spi > qtz
V-600	Packstone:	burrowed, tri > ech > qtz > brc
V-700	Wackestone:	burrowed, tri > ech > brc > bry > qtz > spi
V-750	Packstone:	burrowed, ost > spi > qtz > brc > tri > bry
V-801	Grainstone:	ech > tri > brc > qtz > bry > ost
V-830	Packstone:	ech > brc > spi > tri > bry > qtz
V-835	Packstone:	ech > brc > ost > qtz > tri > bry
V-840	Grainstone:	ech > brc > tri > qtz > bry
V-849	Packstone:	ech > brc > tri > ost > bry

Section W

(Numerical suffix denotes feet above base of Viola Group)

W-5	Mudstone:	some pellets, silicified spi > chi > gra
W-30	Mudstone:	qtz > ost > spi > grap

VITA

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Master of Science

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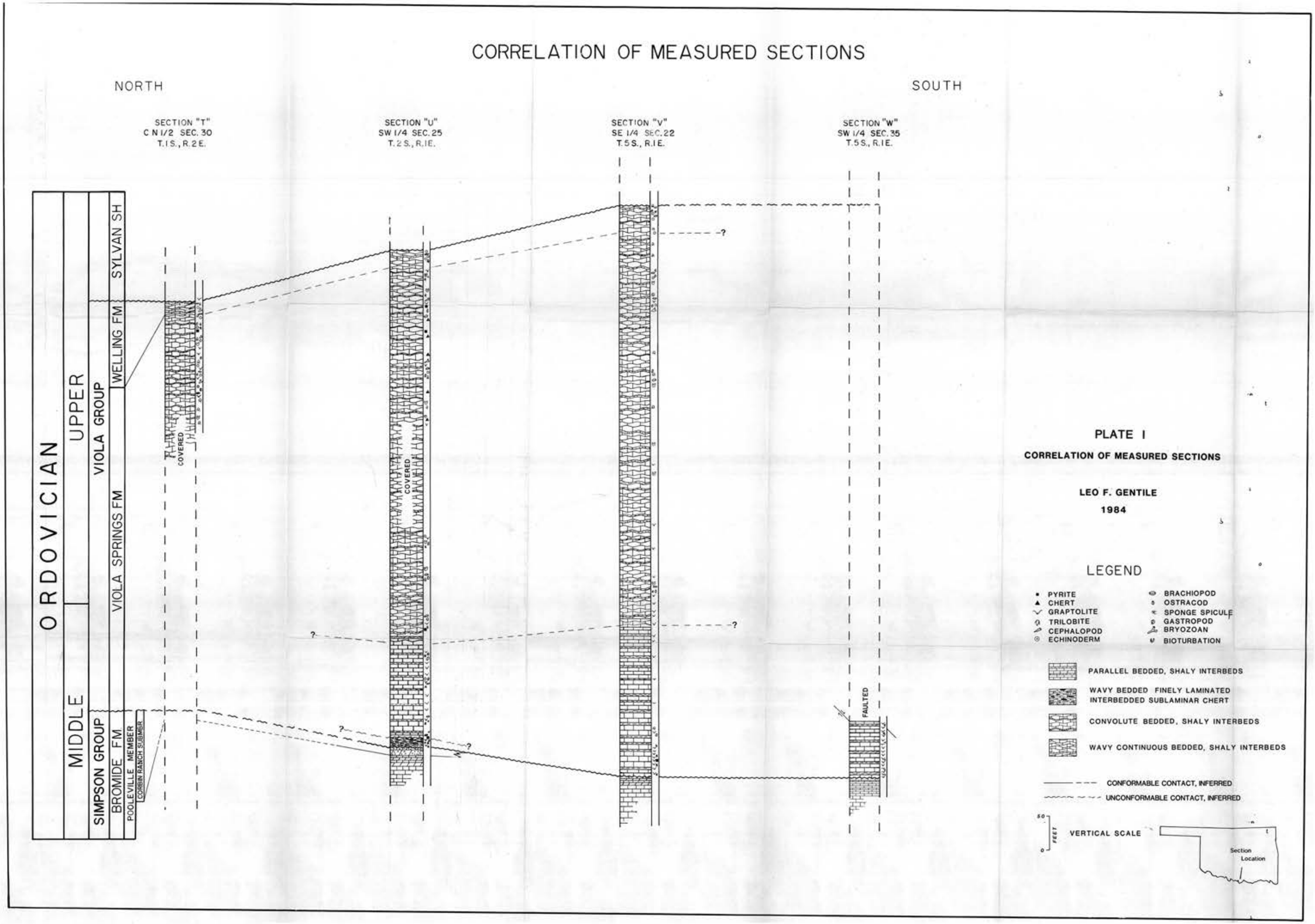
CORRELATION OF MEASURED SECTIONS
NORTH
SOUTH
SECTION "T"
C N 1/2 SEC. 30
T. 1 S., R. 2 E.
SECTION "U"
SW 1/4 SEC. 25
T. 2 S., R. 1 E.
SECTION "V"
SE 1/4 SEC. 22
T. 5 S., R. 1 E.
SECTION "W"
SW 1/4 SEC. 35
T. 5 S., R. 1 E.
ORDOVICIAN
UPPER
MIDDLE
VIOLA GROUP
SIMPSON GROUP
SYLVAN SH
WELLING FM
VIOLA SPRINGS FM
BROMIDE FM
POOLEVILLE MEMBER
CORBIN RANCH SUBMBR
COVERED
COVERED
FAULTED
PLATE I
CORRELATION OF MEASURED SECTIONS
LEO F. GENTILE
1984
LEGEND
PYRITE
CHERT
GRAPTOLITE
TRILOBITE
CEPHALOPOD
ECHINODERM
BRACHIOPOD
OSTRACOD
SPONGE SPICULE
GASTROPOD
BRYOZOAN
BIOTURBATION
PARALLEL BEDDED, SHALY INTERBEDS
WAVY BEDDED FINELY LAMINATED INTERBEDDED SUBLAMINAR CHERT
CONVOLUTE BEDDED, SHALY INTERBEDS
WAVY CONTINUOUS BEDDED, SHALY INTERBEDS
CONFORMABLE CONTACT, INFERRED
UNCONFORMABLE CONTACT, INFERRED
50
0
FEET
VERTICAL SCALE
Section Location