A paleoenvironmental reconstruction of the cretaceous Willow Creek anticline dinosaur nesting locality : North Central Montana
by William Morris Bauer Gavin

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Earth Science
Montana State University

Abstract:
The Willow Creek anticline dinosaur nesting locality is an important paleontological site in the Cretaceous (Canpanian) Two Medicine Formation. This study was done to place these finds in a paleoenvironmental setting developed by using stratigraphic columns and sedimentologic analysis.

The study area was divided into four subfacies which are part of lithofacies (d) of the southern Two Medicine Formation. The lower subfacies was deposited by anastomosing rivers with moderate aggradation rates which allowed moderate development of caliche layers. The climate was warm and semi arid. Rains came during summer when convective cells brought in moist air from the Cretaceous seaway. The rest of the year was dry. The study area was located in a rain shadow caused by the Cordilleran Mountains to the west.

The middle subfacies is comprised of the charophytiferous limestone middle subfacies and the calcareous mudstone middle subfacies. The charophytiferous subfacies is composed of lake-derived sediments from a shallow lake at the southern end of the study area. The calcareous subfacies was deposited by meandering streams with low aggradation rates which allowed extensive development of caliche horizons. High water tables and calcium carbonate-rich water allowed remarkable preservation of dinosaur eggs and embryos laid adjacent to the lake. The climate was the same as during the deposition of the lower subfacies.

The upper subfacies was deposited by anastomosing streams with a low aggradation rate which allowed extensive development of caliche layers. Climate remained the same as in the subfacies below.

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APPROVAL

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William Morris Bauer Gavin

Thisthesis has been read by each member of the thesis committee and has been found to besatisfactoryregarding content,English usage,format,citations,bibliographic style,and consistency,and is ready for submission to the College of Graduate Studies.

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ABSTRACT

The Willow Creek anticline dinosaur nesting locality is an important paleontological site in the Cretaceous (Campanian) Two Medicine Formation. This study was done to place these finds in a paleoenvironmental setting developed by using stratigraphic columns and sedimentologic analysis.

The study area was divided into four subfacies which are part of lithofacies (d) of the southern Two Medicine Formation. The lower subfacies was deposited by anastomosing rivers with moderate aggradation rates which allowed moderate development of caliche layers. The climate was warm and semiarid. Rains came during summer when convective cells brought in moist air from the Cretaceous seaway. The rest of the year was dry. The study area was located in a rain shadow caused by the Cordilleran Mountains to the west.

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The upper subfacies was deposited by anastomosing streams with a low aggradation rate which allowed extensive development of caliche layers. Climate remained the same as in the subfacies below.

INTRODUCTION

Purpose

In 1978 a team of paleontologists from Princeton University discovered large deposits of dinosaur bones and eggs in Cretaceous Two Medicine Formation sediments in the Willow Creek anticline west of Choteau, Montana. Since the original discoveries, researchers from Princeton University and the Museum of the Rockies at Montana State University have continued to excavate the area. Their discoveries have led to significant new theories on dinosaur physiology and behavior. One of the shortcomings of these studies has been a lack of understanding of the environment in which these animals lived. This study is an attempt to eliminate such shortcomings by developing a detailed paleoenvironmental reconstruction of the research area by using measured stratigraphic sections, sedimentologic analysis and climatic modeling. By placing the paleontologic finds in the study area into an environmental and geographical context, this study will enhance the understanding of dinosaurs' ecology.

Location

The Two Medicine Formation crops out along the edge of the Northern Rocky Mountain Disturbed Belt in the United States to about 40 kilometers north of Helena, Montana (Figure 1). The Willow Creek anticline is located 19 kilometers west of Choteau, Montana, in

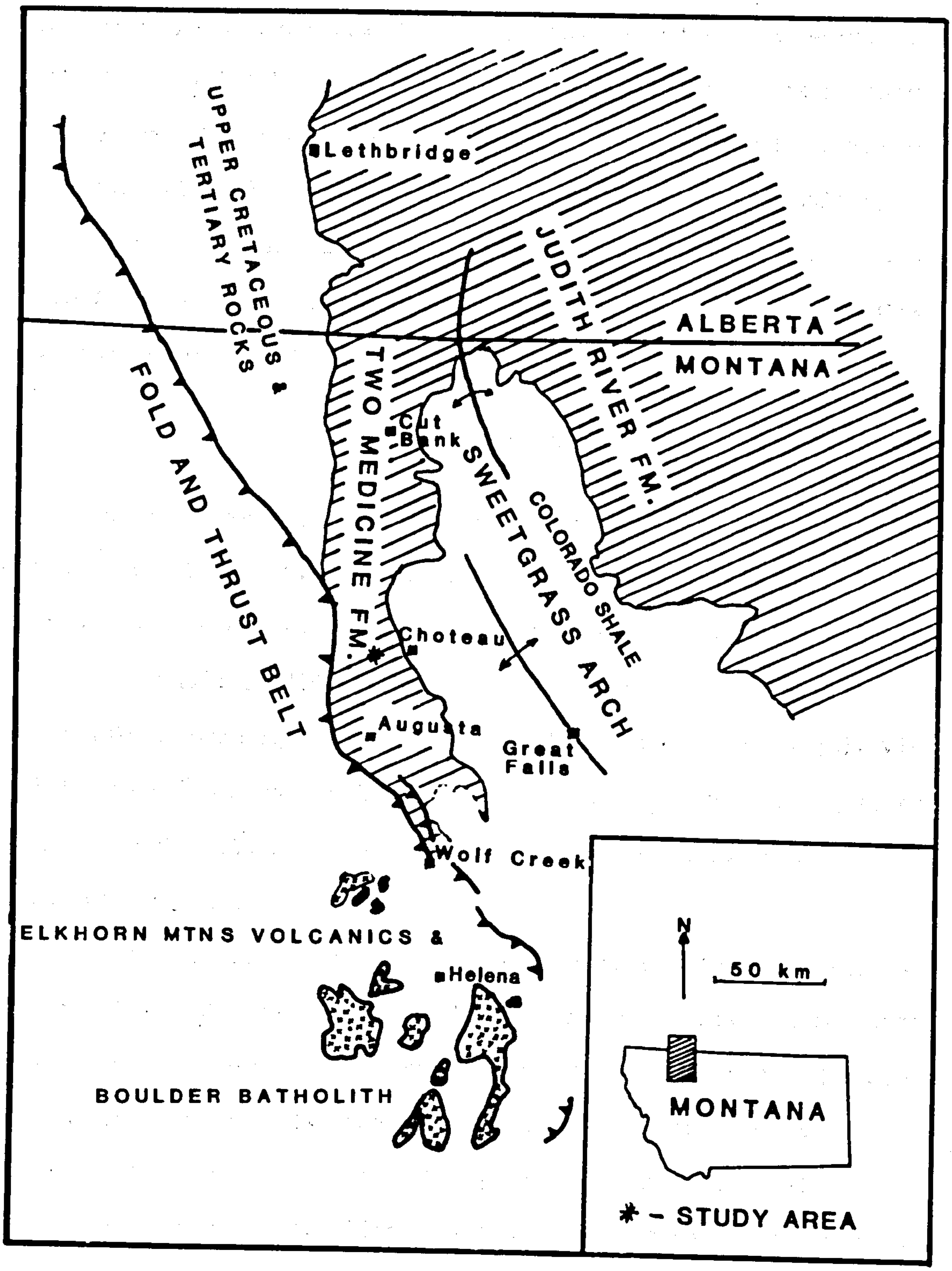

Figure 1. Index map showing general outcrop area of the Two Medicine Formation and related features (after Lorenz, 1981).

Teton County, north central Montana (Figure 2) and 16 kilometers east of the Disturbed Belt. The area emphasized in the study is roughly five square kilometers, comprising outcrops in and around the Willow Creek anticline, located in sections 19,20,29, and 30 of T.24 N., R.6 W. and sections 24 and 25 of T.24 N., R.7 W. Additional outcrops were studied near the main study area including Teton Buttes, Willow Creek and Pine Butte (Figure 3).

Previous Investigations

Upper Cretaceous strata of north-central Montana have been extensively studied over the past seventy years. Initial work on the Montana Group and descriptions of many of the units were accomplished by Stebinger (1914, 1916, 1917). Excellent papers dealing with Montana Group stratigraphy have been published by Cobban (1955), Viele and Harris (1965), and Gill and Cobban (1973). These investigations have been primarily concerned with the marine deposits of the Cretaceous seaway.

The Two Medicine Formation is included in the Upper Cretaceous Montana Group (Figure 4). At its base is the regressive marine Eagle Sandstone and at the top in most places are deposits of the Bearpaw Shale. The nonmarine Two Medicine Formation has received less attention than the rest of the Montana Group. After initial description by Stebinger, little work was done on the unit until the 1950's, when Cobban (1955) addressed the origin of the sediment in a paper on northwest Montana. Viele and Harris (1965) and Schmidt (1978) dealt with the Two Medicine near its southern limits and

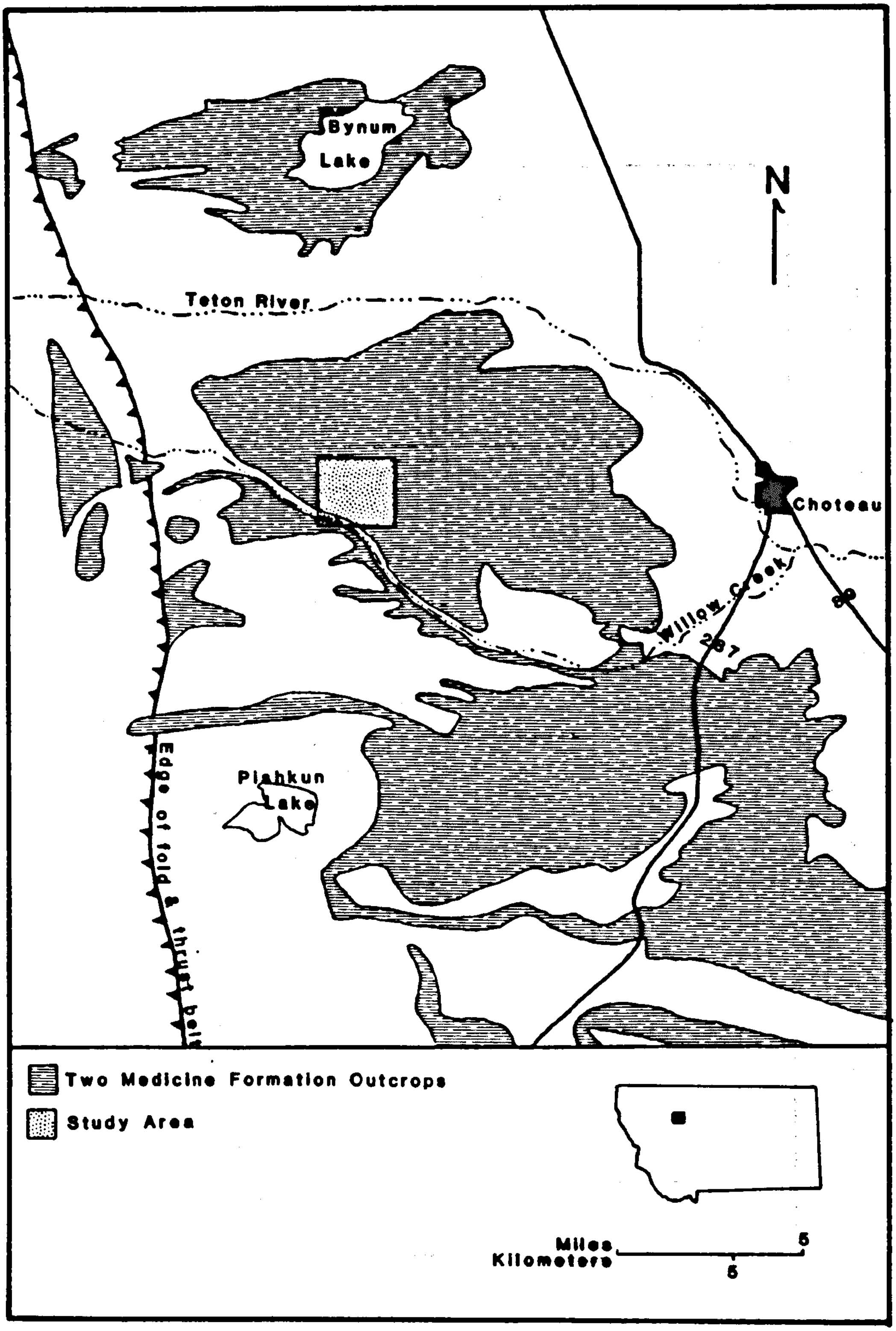

Figure 2. Two Medicine outcrops near Choteau, Montana, and the study area (after Mudge, 1979).

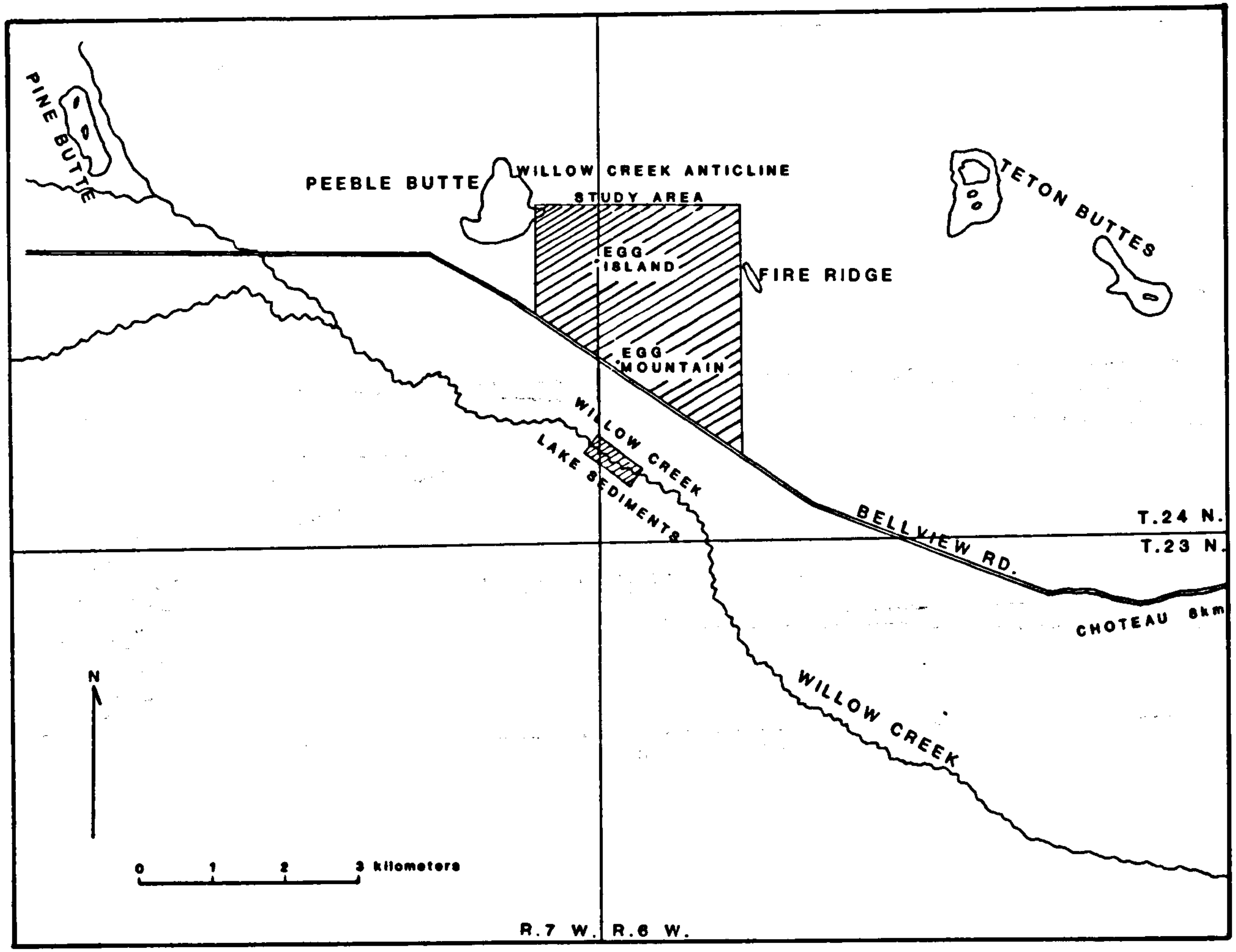

Figure 3. Map of study area and key geographic features.

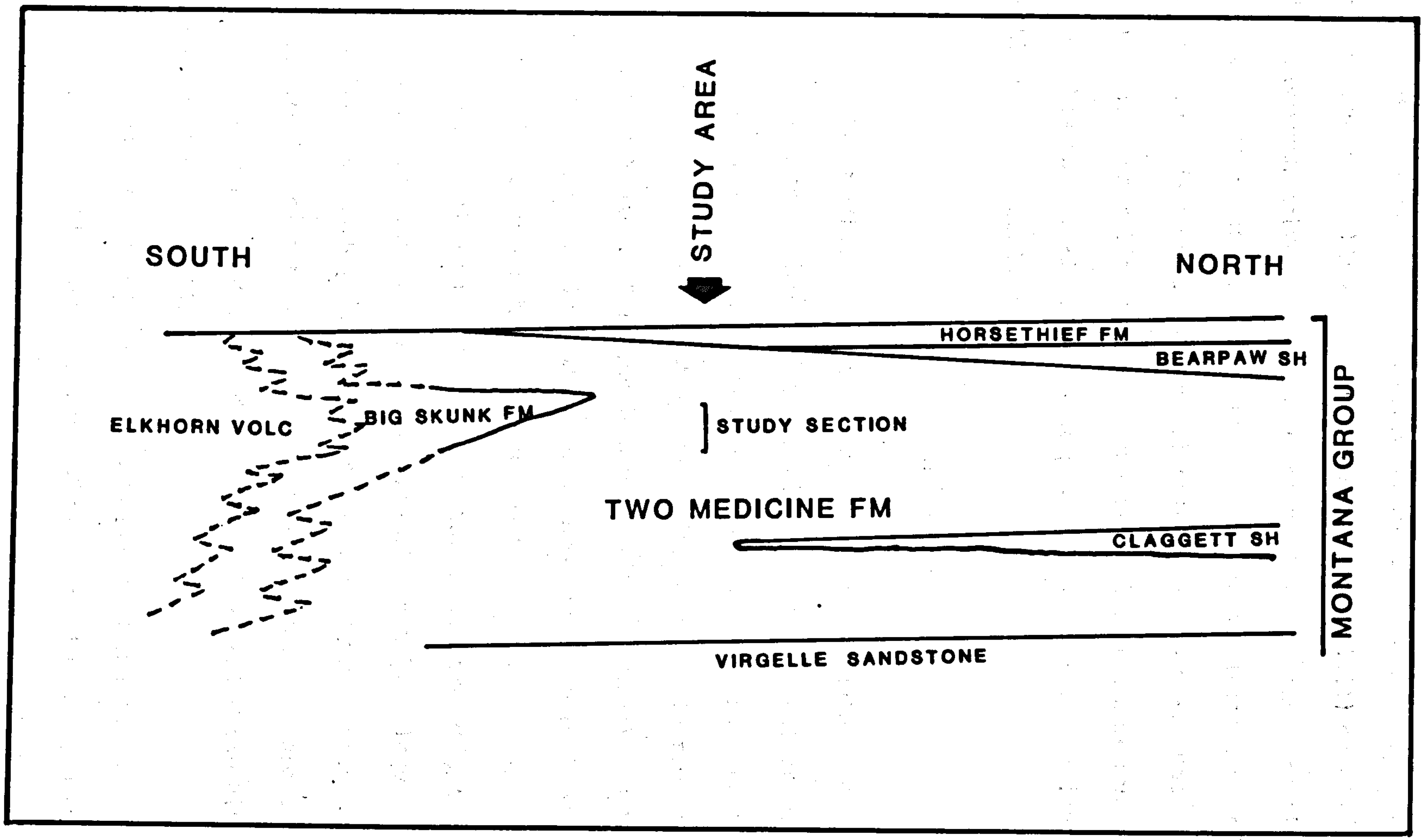

Figure 4. Generalized stratigraphic relations between the Two Medicine and adjacent formations, with the study area's location and stratigraphic level.

examined the stratigraphic relationship of the volcaniclastic member to its northern alluvial counterpart. Lorenz (1981) completed the first comprehensive study of the entire Two Medicine Formation, dealing with sedimentologic, stratigraphic, and tectonic aspects. Lorenz's thesis includes a general paleoenvironmental evaluation of the entire upper lithofacies of the Two Medicine Formation. To date, no one has addressed the specific paleoenvironmental setting for the Willow Creek anticline area.

Regional Geology

The Two Medicine Formation is a terrestrial molasse deposit shed into a foredeep in front of the Sevier thrust belts (Lorenz, 1981). The terrestrial deposits were bounded on the east and northeast by the Pierre-Niobrara seaway which extended discontinuously from Alaska to the Gulf of Mexico. This configuration with the highlands to the west accounts for an overall shift from upland facies to lowland facies and delta facies from southwest to northeast (Lorenz, 1981).

To the south in the Elkhorn Mountains, and probably to the west, there was intermittent volcanism which affected lithology and relief. The effects of this volcanism are progressively more pronounced to the south, to the point that the volcanoclastic sediments are considered a separate member of the Two Medicine Formation called the Big Skunk Member (Schmidt, 1978).

To the east, the Sweetgrass Arch affected the basin configuration. This arch, a zone of weakness dating from the Precambrian, was activated as a forebulge in front of the thrust sheets to the west during the late Cretaceous. It acted as a relative high and restricted sediment dispersal and transgressions by channelling both into a more northeast alignment (Lorenz, 1981). Mudge (pers. comm.) feels that movement on the arch after Two Medicine deposition was responsible for the series of folds that constitute the Willow Creek anticline today (Figure 5).

Lorenz (1981) divided the relatively complete section of Two Medicine strata near Choteau, Montana, into four lithofacies. He labeled those a-d from the bottom up (Figure 6). This section is approximately 660 meters thick and grades up into 30-60 meters of transitional deposits before being capped by the Horsethief Sandstone. The study area at Willow Creek anticline is located in the middle of the upper lithofacies (d) which begins approximately 250 meters above the Virgelle Sandstone and is approximately 395 meters thick. The sections studies herein begin 312 meters below the base of the Horsethief Sandstone and represent 76 meters of sediments. These deposits were laid down after the Claggett Transgression and are the remains of an alluvial apron that prograded eastward during the Campanian Stage, east of the thrust belt and volcanic highlands.

Procedure

Field work for this study was conducted during the summer of 1983. All operations were conducted out of a field camp run by the Museum of the Rockies at the Willow Creek anticline. First, a plane table map of the study area was surveyed at a scale of 1:4800. This allowed accurate location of measured sections and all paleontological

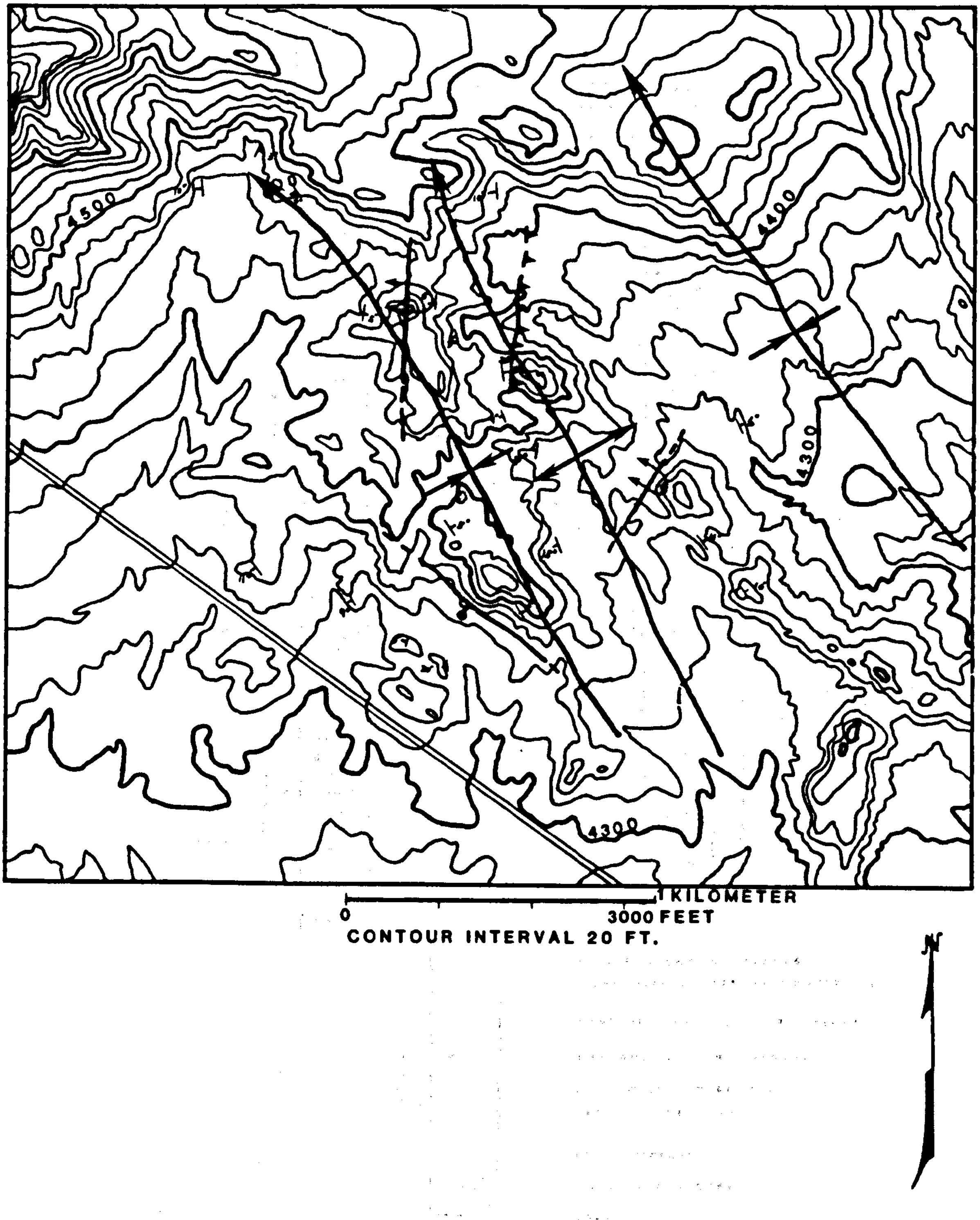

Figure 5. Structure map of the study area.

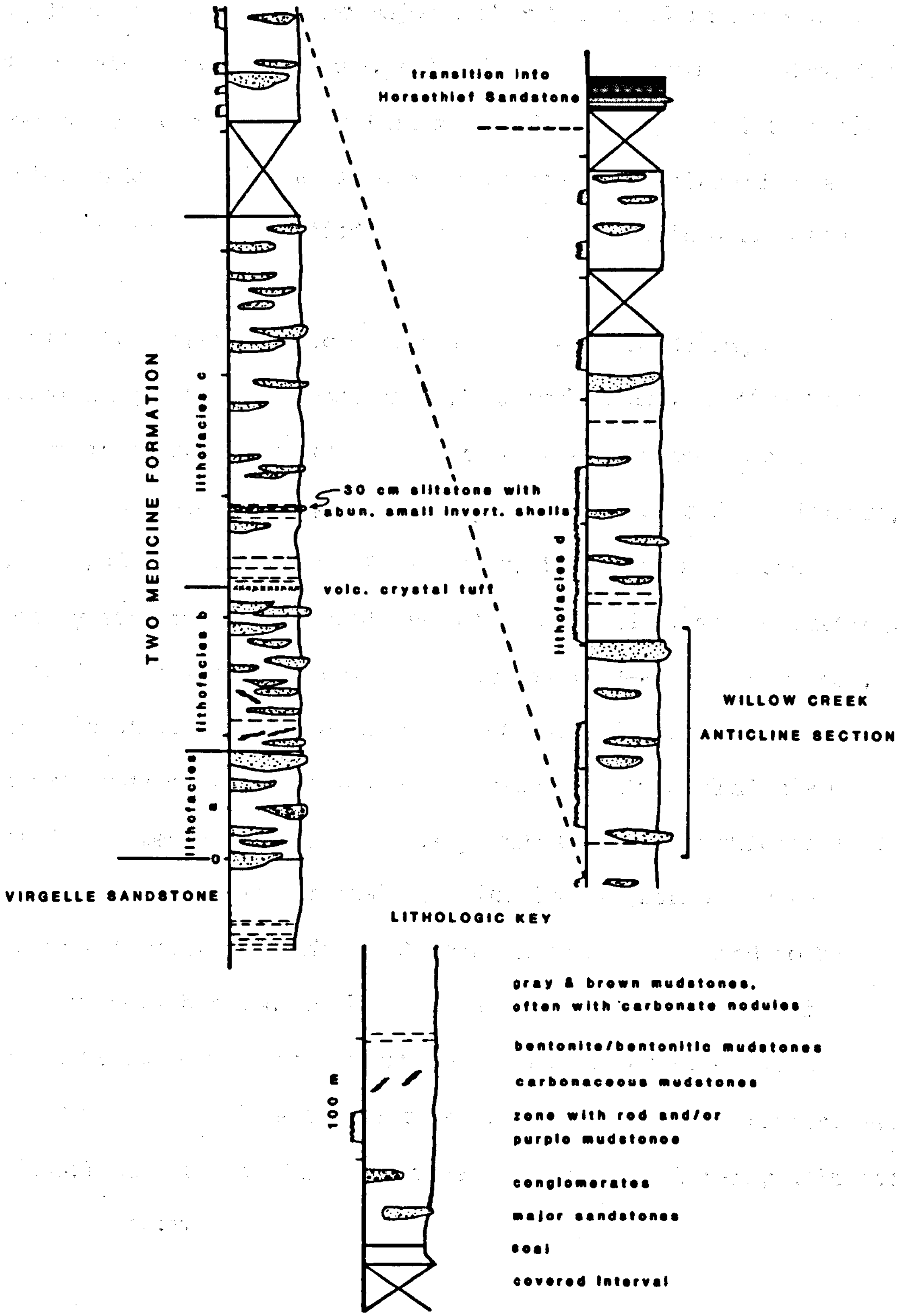

Figure 6. Composite stratigraphic column for the Two Medicine Formation near Choteau, Montana (after Lorenz and Gavin, 1984).

sites. This map also included major marker beds used in the study, structural elements in the area, and major channel sandstone deposits. Topography was superimposed on this map, using the appropriate section of the Bynum,Montana fifteen minute topographic map enlarged on a Saltzman projector and modified using elevations obtained from the plane table work.

Twenty-two stratigraphic sections were measured during and following the plane table work, using a Jacob's Staff. Sedimentary structures in channel sandstone deposits were also measured and described, and where possible, sandstones were measured for thickness, width, and paleocurrent data. In addition, the geometry of the sedimentary structures was noted, as well as the size, shape, sorting, and mineralogy of the sandstones. During the 1983-84 academic year, petrographic studies were conducted to determine diagenetic histories and classification of limestones and sandstones. Sieve analysis was performed on selected sandstones disaggregated with hydrochloric acid to determine sorting and vertical distribution of grain sizes to supplement petrographic studies. Calcareous rocks suspected to be derived from soil horizons or lacustrine deposits were collected during the field season and were slabbed and examined visually and with x-radiography to detect relict bedding, precipitation fronts, and trace fossil structures. This was done using a medical x-ray unit and 3M Rare Earth film.

RESULTS

The study area is divided into four subfacies based on their lithological and petrologic characteristics. These four subfacies comprise approximately one-fourth of Lorenz's lithofacies (d). These subfacies are:

- the lower subfacies
- the middle subfacies, composed of two laterally equivalent subfacies which are designated the charophytiferous limestone middle subfacies and calcareous mudstone middle subfacies
- the upper subfacies (Figure 7).

Lower Subfacies

The lower subfacies comprises only about one-fourth of the entire section which is exposed at the anticline. Most of it is covered by alluvium or does not crop out due to structural complications but there are indications that it comprises a large part of the section. The main areas where it crops out include the central portion of the anticline and to the north near Fire Ridge (Figure 8 and Plate 1). No base was defined for this unit due to the lack of lower exposures.

In the lower subfacies, there are two distinct sandstone body morphologies. These are termed major and minor sandstone bodies with the major sandstone bodies apparently being derived from the main channel system.

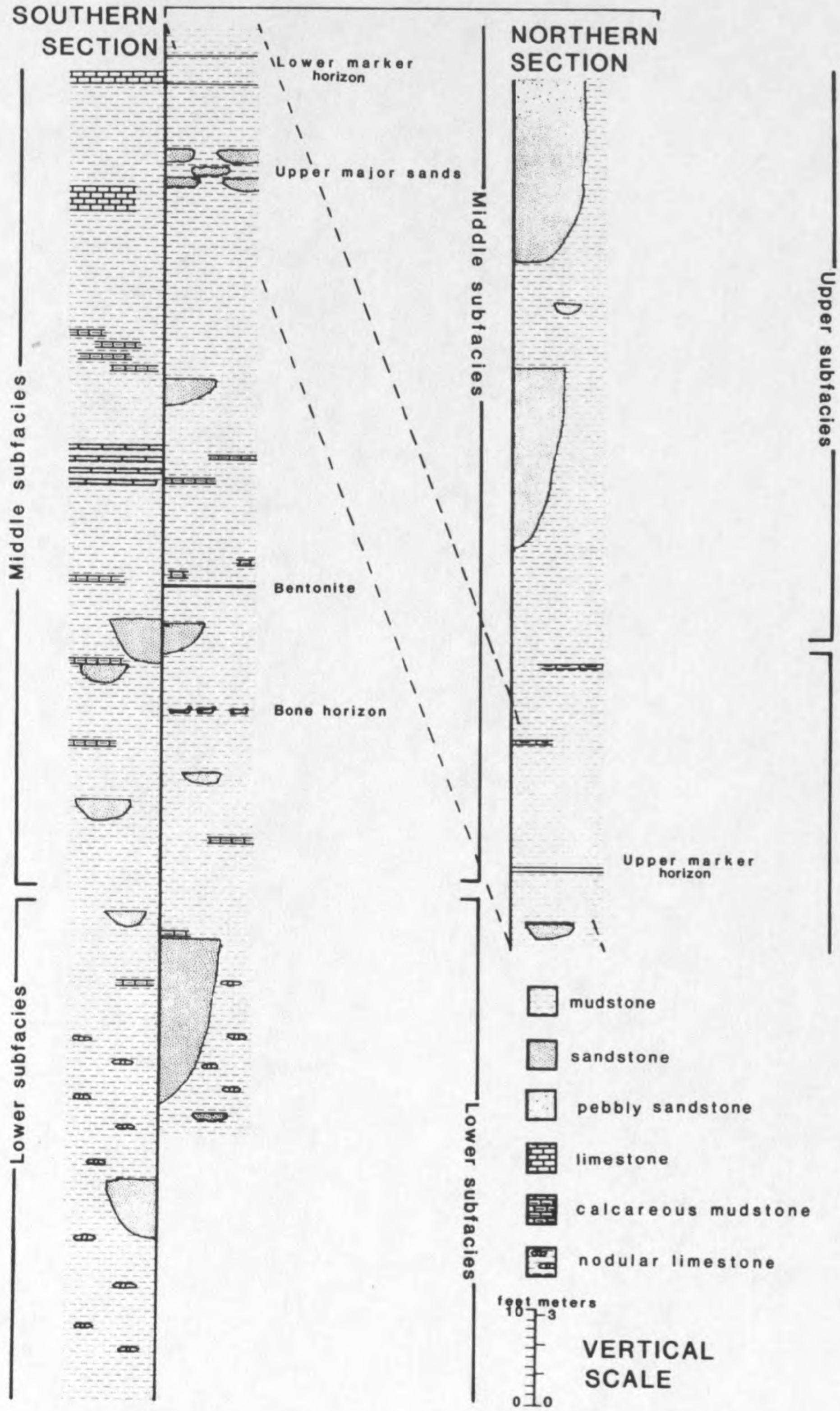

Figure 7. Composite stratigraphic columns for the Willow Creek anticline study area (dashed lines denote continuation of northern section).

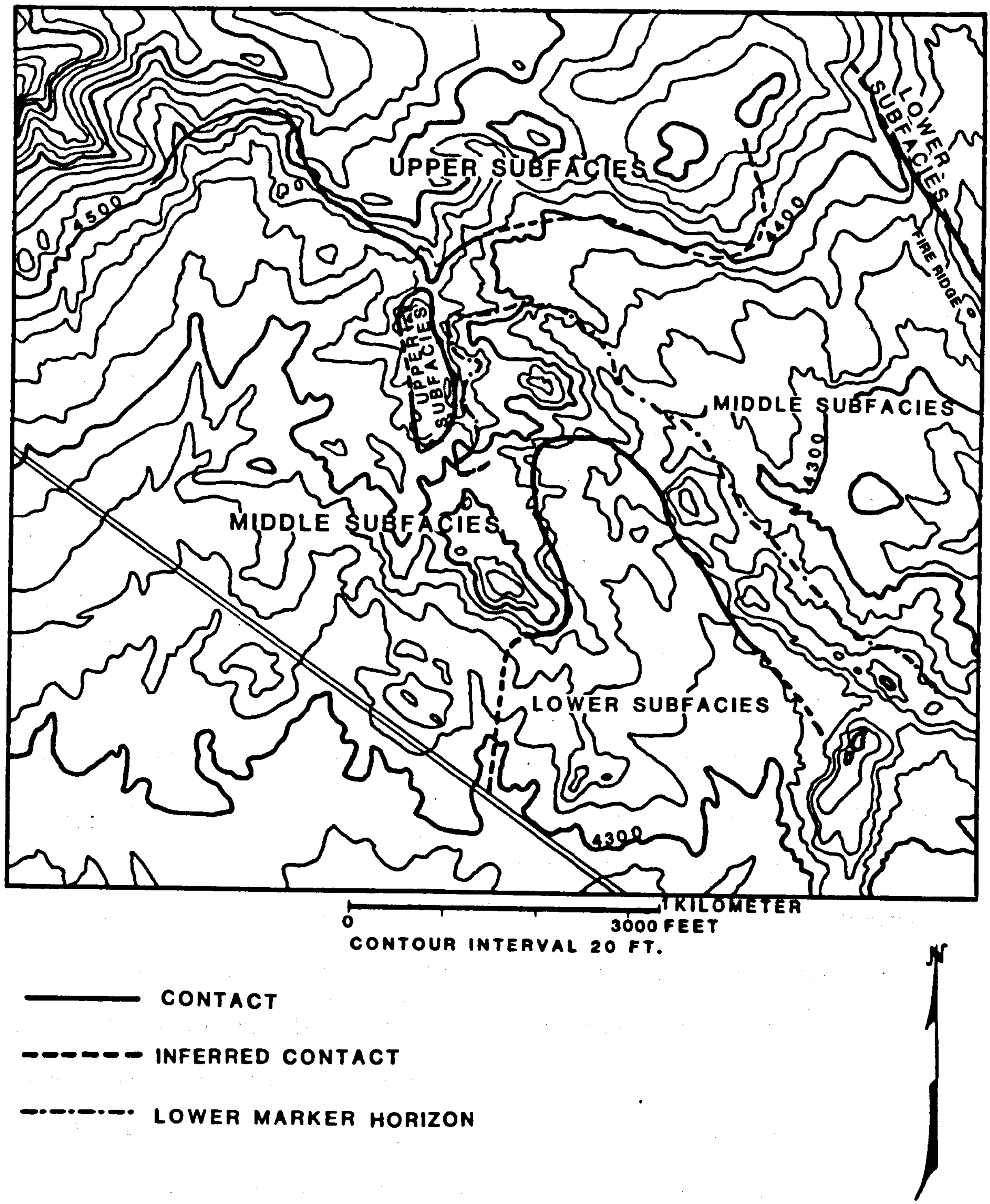

Figure 8. Map of the subfacies outcrops in the study area. No attempt is made to separate the two middle subfacies.

Minor Sandstone Bodies - The minor sandstone bodies are tabular to slightly lenticular, 0.5 to 1.2 meters thick, and up to 43 meters wide. The average width is 15 meters. In most of these sandstone bodies, cross-stratification is impossible to observe due to their extremely friable nature. However, in some sandstones, small-scale trough cross-bedding is visible but diminishes in size, grading into ripple cross-lamination towards the edges and the top of the sandstone bodies. Associated with this decrease in sedimentary structure size is a corresponding decrease in grain size with the top of the sandstone often grading into siltstone or alternating layers of siltstone and very fine-grained sandstones. Sandstone body tops almost always contain burrows and root tubules, some of which have ferric staining and cementation around their perimeters. Sandstone bodies are surrounded by siltstone and mudstone and their bases rest on channels that show evidence of erosion.

The sandstone is gray to gray-green in outcrop and salt and pepper in hand sample. Petrographic study of these sandstones shows 30 to 40 percent calcium carbonate cement and abundant quartz and chert with minor percentages of feldspar and mica. These are classed as chert-arenites and sub-chert-arenites. Grain size is medium to very fine sand and grains range from subangular to angular.

Major Sandstone Bodies - This type of sandstone body is considerably thicker than the minor sandstone bodies (6 to 10.5 meters). Only three outcrops of the major sandstone body morphology occur in the anticline and in no instance is a complete cross-sectional view available due to erosion and structural complications. Measurements taken at several locations along the bases of some of the major sandstone bodies indicate that the sandstone bodies are approximately 30 meters wide. Width-to-thickness ratios are estimated at 3 to 4. All three outcrops occur at the same stratigraphic level and appear either to have been derived from the same channel or branches of the same channel system, based on their morphology and sandstone composition. The major sandstone bodies have abrupt lateral contacts with adjacent red and purple siltstone (Figure 9). There is some minor interfingering along these contacts but it is limited to 1.5 to 3.0 meters in lateral extent. Rounded fist-sized pebbles of siltstone--probably chunks of bank cave that were incorporated into the sandstones before they could be completely disaggregated--occur irregularly throughout the sandstones. The bases of the sandstone bodies are slightly concave and irregular with ripup clasts and a coarser sandstone that contains white to buff rounded clay clasts and tuffaceous volcanic fragments 1 millimeter to 1 centimeter in diameter. The sandstone's friable nature makes it hard to determine the type of cross-bedding, but trough cross-bedding has been observed. Similarly, this friable nature also makes determination of paleocurrent direction impossible.

Major sandstone bodies are composed internally of stacks of fining upwards sequences. The base of any single sequence is composed of medium- to fine-grained sandstone with claystone clasts and tuffaceous volcanic fragments. This base is usually well-cemented with calcium carbonate and weathers into brownish resistant lenses within the sandstone bodies. The top of each sequence is composed of

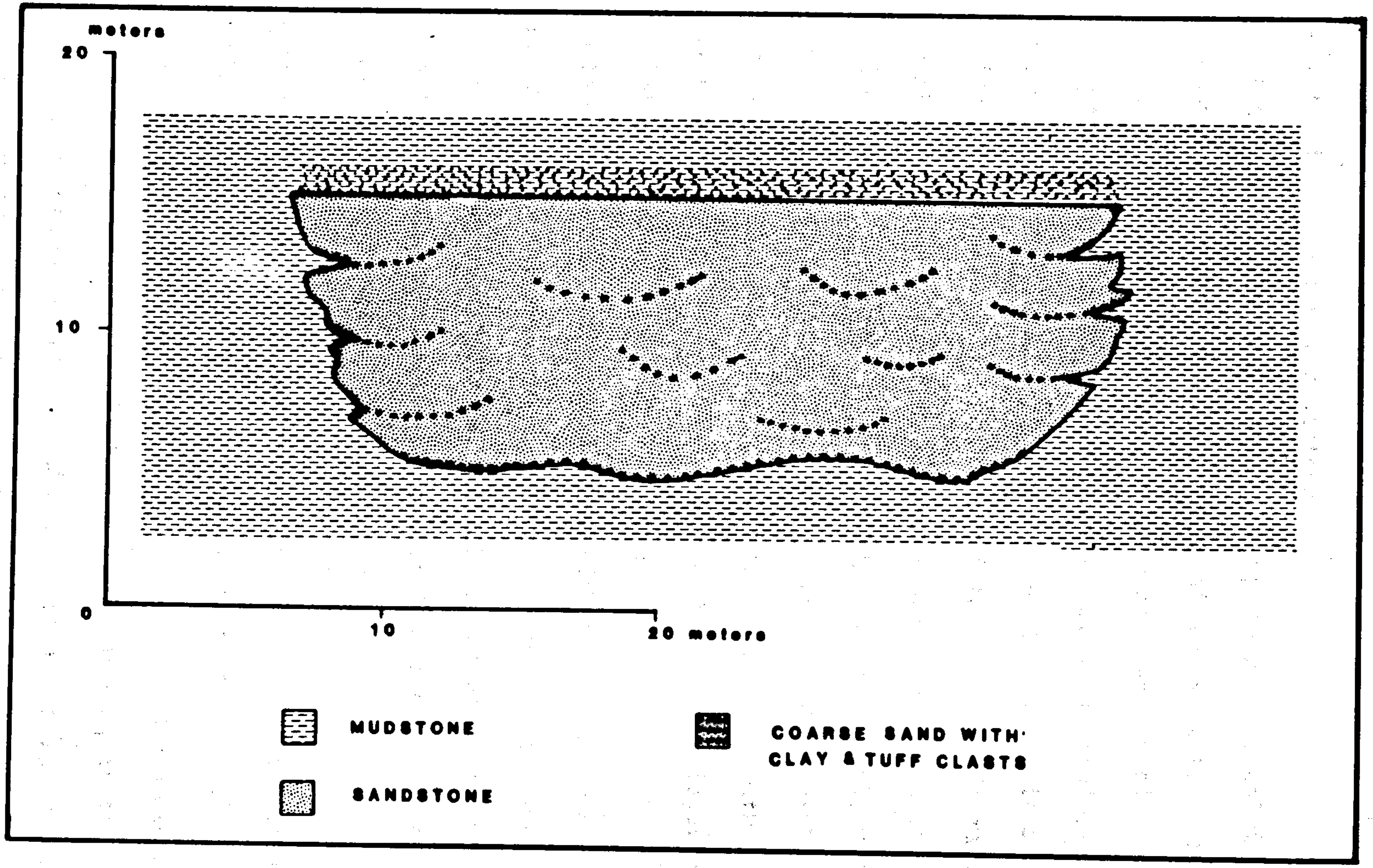

Figure 9. Cross section of typical lower subfacies major sandstone body.

very fine-grained sandstone. In sections at the edge of the sandstone body, the tops grade into siltstone.

Petrographic analysis shows a lower percentage of calcium carbonate cement (49 percent) and a much higher percentage of feldspar than the minor sandstone bodies. These sandstones are classified as feldspathic litharenites. All sandstone grains are angular to subrounded. Of the disaggregated sandstone, 20 percent is silt-size or finer, giving a sand-to-silt ratio of 4. Sand-to-silt ratios, determined from percentages of sandstone in measured sections within the lower subfacies, are much lower, .92, and are probably more representative of the area. The top of these major sandstone bodies is composed of fine to very fine sand which alternates with sandy siltstones in layers 15 to 30 centimeters thick. This layering continues for about 1.5 meters. The sandstone occasionally shows ripple cross-lamination and is riddled with burrows and root tubules. In some instances, ripples in some of the mudstones appear squashed and deformed by the overlying sand, indicating that they were still wet and plastic at the time of the new influx of sand. No desiccation cracks are noted in any of these sediments.

Calcareous Mudstones - The calcareous mudstones in this facies occur as fist-sized nodules in irregular layers that are 5 to 10 centimeters thick and spaced about .3 meters apart. The nodules are pitted and irregular with a rust-colored rough surface. In many instances, the nodules branch down vertically and seem to follow old root traces. When slabbed, these nodules reveal they are composed of smaller nodules 10 to 20 millimeters in diameter. The nodules are almost pure micrite with no silt or sand inclusions within the component nodules. Small inclusions of mudstone occur between nodules. Bone fragments found in this subfacies often have calcareous mudstone nodules growing around them.

Siltstone - Siltstone and mudstone within this subfacies are usually red, orange, purple or yellow and occasionally gray and green. The purple mudstone usually occurs around the edges of channel sandstones. No grain-size analysis was done on any of these fine-grained sediments but almost all have various concentrations of silt or sand-sized material in them. Fifty-two percent of strata encountered in stratigraphic sections measured in the lower subfacies are mudstone. However this may not be representative of the total amount of mudstone in the lower subfacies due to the limited area exposed in the anticline.

The top of this subfacies is located where the calcareous mudstones change from small nodules to thick continuous layers. The major sandstone body morphology changes from thick, laterally confined sandstone bodies to thinner, more laterally extensive sandstone bodies. The siltstone and claystone change in color from red and orange to green and gray. This top is approximately 300 meters below the base of the Horsethief Sandstone.

The carbonate and sandstone morphologies grade upward into the two overlying middle subfacies. These are termed the calcareous mudstone middle subfacies and the charophytiferous limestone middle subfacies. In the transition from the lower to the middle subfacies, the mudstone gradually changes from red and orange to gray and green.

Middle Subfacies

The middle subfacies is divided into two subfacies defined by the presence of either a charophytiferous limestone or calcareous mudstone. The charophytiferous limestone middle subfacies includes thinly laminated mudstones and laterally persistent mudstone beds. The calcareous mudstone middle subfacies is defined as those siltstones containing sandstones and calcareous mudstone layers. Total thickness of the middle subfacies is 40 meters (Figure 7) with the top being approximately 256 meters below the Horsethief Sandstone. The upper contact of the middle subfacies is gradational and is placed at a point 7 meters above a key marker horizon, composed of cemented volcanic ash, which is termed the upper marker horizon.

Calcareous Mudstone Middle Subfacies - This subfacies becomes more predominant in the north part of the study area. However, there is considerable interfingering of both charophytiferous limestone middle subfacies and calcareous mudstone middle subfacies, both north-south and east-west (Plate 2, 3).

Minor Sandstone Bodies - The smaller sandstone lenses are much like those in the lower subfacies, usually 0.6 to 1.2 meters thick and up to 30 meters wide. They average about 15 meters. Bedding in these sandstones is often obscured due to their friable nature but trough cross-bedding is visible in the middle of the sandstone bodies and ripple cross lamination is visible at the top and sides. The top usually grades into siltstone and is always heavily bioturbated with burrows and root traces. These upper areas are usually more resistant and often weather to a brown color. Sandstone bodies are lensoidal in shape and the base is concave upward.

Petrographic studies of these sandstones show they are medium-grained to very fine-grained and angular to subrounded. In most samples, quartz is the primary constituent with varying amounts of chert and feldspar, and minor amounts of mica and heavy minerals. These are classified as sublitharenites and chert-arenites. In some samples, volcanic rock fragments make up the major part of the rock, making these volcanic-arenites. In most cases these sandstones are moderately sorted and are immature to submature.

Major Sandstone Bodies - The second sandstone morphology is thicker and more laterally extensive with high width-to-thickness ratios. There are two stratigraphic locations for these sandstones (lower and upper). The base of the lower sandstones occurs approximately 7.5 to 9 meters above the lower subfacies and about 1.8 meters below a bentonite bed that occurs in the middle subfacies.

These lower sandstone bodies are poorly to moderately indurated and are greenish gray in fresh hand sample and yellowish brown in weathered outcrop. Sandstones are broadly lenticular with relatively indistinct lateral contacts. The top of the sandstone grades up into alternating layers of siltstone and fine sandstone which is riddled with root tubules and burrows. They are fine- to coarse-grained with calcite cement and are composed of abundant volcanic rock fragments with lesser amounts of quartz and chert, making these a volcanic-arenite.

Sedimentary structures are difficult to distinguish but appear to be exclusively trough cross-bedding. The relative lack of observable sedimentary structures make it impossible to collect paleocurrent data for these sandstones. However, work by Hooker (pers. comm.) on bone orientation in a bone horizon located just above these sandstones has determined a paleocurrent orientation of N 40-50 ° E. This probably closely corresponds with the sandstone channel axis orientation.

The upper group of sandstones is located about 15 meters below the top of the middle subfacies. The two major outcrops of this upper sandstone are definitely linked together and form a continuous channel that crosses the study area from west to east.

These sandstone bodies have very large width-to-thickness ratios. The thickness reaches 2.4 meters but averages about 1.8 meters. An exposure of this sandstone on the west side of the study area is almost 200 meters wide while 1.5 kilometers to the southeast, an equivalent outcrop is estimated to be 70 meters wide. The western sandstone body forms one continuous outcrop while the sandstone bodies to the southeast are composed of a series of sandstones which appear to be caused by lateral avulsion. The only sedimentary structure observed was trough cross-bedding. No epsilon cross-stratification was observed in any of these sandstones.

The base of the sandstone bodies rests on pebble lags composed of rounded siltstone clasts averaging 15 millimeters but ranging up to 8 centimeters in diameter. These basal lags occasionally contain isolated dinosaur bones which usually appear to be weathered. Throughout all of the sandstone bodies there is an abundance of rounded mudstone clasts which are presumed to be from bank cave. The lateral contacts show considerable interfingering with adjacent mudstone. The tops are usually abruptly overlaid by siltstone. There is little or no indication of bioturbation at the top or within the sandstone except for some isolated root traces which parallel the top of sandstone.

This upper group is moderately to well indurated and very resistant, forming pronounced ledges in the study area. In hand sample and outcrop, the sandstones are gray-green with a salt and pepper appearance. These sandstones usually fine upwards throughout the entire sandstone body but considerable size variation occurs at any given point. The base ranges from coarse to very fine-grained. The middle is coarse to very fine-grained, and the top is medium to very fine-grained. The sandstones range from volcanic arenites to feldspathic litharenites with abundant volcanic rock fragments. Up to 60 percent of the sandstone may have been silisic volcanic glass. The sandstone has been partially cemented by silica from devitrification of the glass. The devitrification process has also left an abundance of clay in the matrix. There is also some minor calcareous cement. In these sandstones there is an abundance of heavy minerals (mostly magnetite) which are often concentrated at the base of individual beds. Grains are angular to subrounded. Many of the subrounded grains are probably the result of authigenic alteration of formerly angular grains.

Paleocurrent data for these sandstones were obtained by measuring the orientation of axis and limbs of the trough cross-bedding (Figure 10). The results for the western outcrop are V_0 = 38.00 degrees with a consistency ratio of .91 where a ratio of 1 represents perfectly preferred orientation and 0 represents totally random orientations. The results for the eastern outcrop are V_0 = 77.65 degrees and a consistency ratio of .83.

Calcareous Mudstones - The calcareous mudstones in this subfacies are thicker and form more laterally extensive layers than those in the lower subfacies. They range in thickness from 10 centimeters to 1 meter and extend laterally up to several hundreds of meters. Usually they are discontinuous and no single bed can be traced far enough to use it as a marker. The carbonates around nesting sites are more discontinuous than in other areas. They are very limited laterally and seem to occur through a greater vertical area.

Calcareous mudstones are often fractured or jointed due to the folding associated with the area. Where large surfaces of the mudstones are exposed, they form a series of elongate bread loaf-like ridges 1 to 3 meters long with vertical fractures through them, forming "slices" 5 to 10 centimeters thick. The layers are less closely spaced than those in the lower subfacies, varying from 1 to 3 meters, but there is very little consistency in spacing through any given section. These layers are usually the same color as the surrounding clay and mudstone (reddish-brown and gray-green).

Polished slabs of these limey mudstones show rounded clasts of the host mudstone floating in a matrix of very calcareous mudstone.

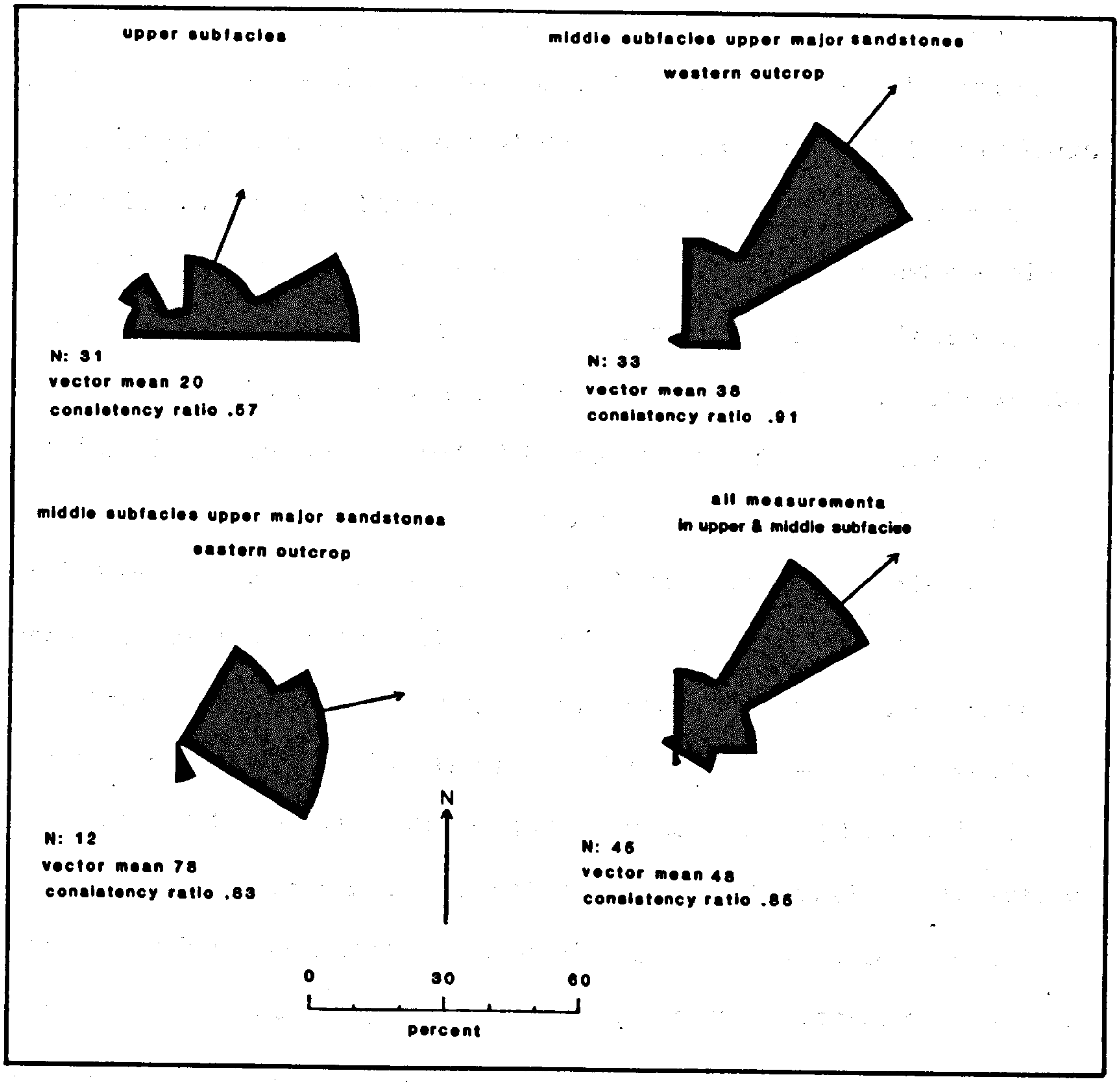

Figure 10. Rose diagrams of paleocurrent data gathered in the study area.