THE MAPPING AND INTERPRETATION OF THE STRUCTURE OF THE NORTHERN SLICK HILLS, SOUTHWEST OKLAHOMA

By

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THE MAPPING AND INTERPRETATION OF THE STRUCTURE OF

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PREFACE

The primary objective of this study is to determine if the structures within the northern Slick Hills evolved as a consequence of a particular structural regime. If such a regime can be identified, it is probable that it has been responsible for the development of many of the structural provinces along the southwest margin of the Anadarko Basin.

The author wishes to express his appreciation to his major adviser, Dr. R. Nowell Donovan, for his constant guidance and encouragement throughout this study. Appreciation is also expressed to Dr. David Sanderson for his initial stimulus, Dr. Carol Simpson for her willingness to help at all stages during the preparation of the manuscript, and to Dr. Wayne Pettyjohn.

I would also like to than Mr. Charlie Oliver (manager of the Kimbell Ranch) and the Dietrich family for permission to use their lands for access to the field area, and for their friendly hospitality. Thanks are also due to Mr. Woods, Mr. Sims, Mrs. Tully, and the other landowners for permission to work on their property.

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CHAPTER I

INTRODUCTION

Statement of Purpose

This thesis describes and interprets the structural geology of the northern part of the Slick Hills, in the Wichita Mountains, southwest Oklahoma. It forms part of an ongoing study of the Slick Hills supervised by Dr. Nowell Donovan, of Oklahoma State University, under the auspices of the Oklahoma Geological Survey. A synthesis of this work will make up part of a new map being produced by the Survey.

Location of the Area

The Wichita Mountains are situated in Caddo, Comanche, and Kiowa Counties, southwest Oklahoma (Figure 1). Two principal geological units can be recognized. To the south is the Wichita igneous complex, representing a rare exposure of basement within the mid-continent (Gilbert, 1982). To the north, separated by the Meers Fault, is the Lower Palaeozoic sedimentary succession of the Frontal Wichitas (Harlton, 1962). These Cambro-Ordovician rocks are mostly carbonates and form the Slick (or Limestone) Hills. They extend from T4N R13W to T5N R14W, paralleling the trend of the Meers Fault. The hills reach heights of over 2000 feet above sea level, with an average relief of approximately 900 feet. They represent an Upper Palaeozoic landscape exhumed from beneath a cover of Permian conglomerates.

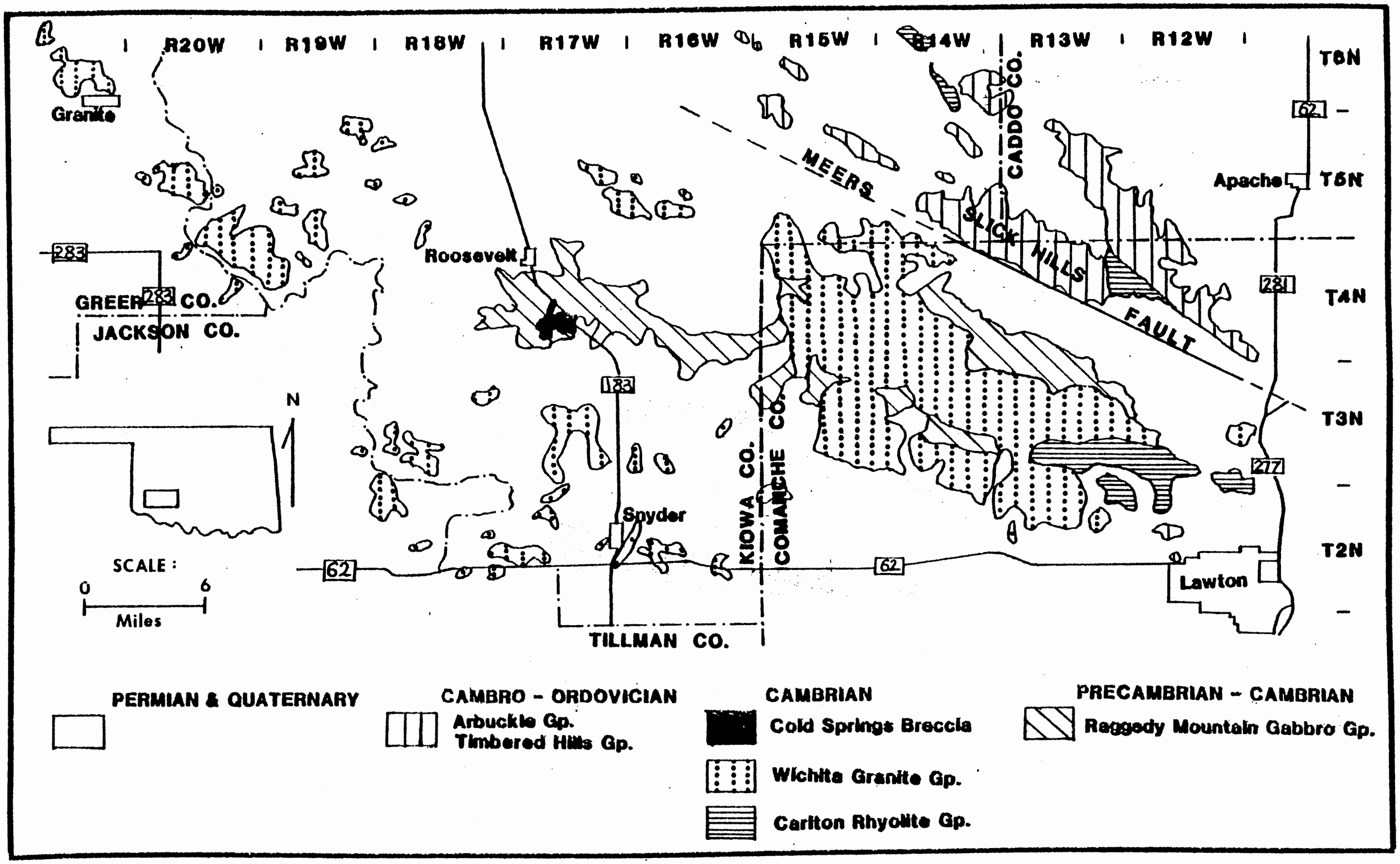


Figure 1. Geologic Map of the Wichita Mountains, Southwest Oklahoma (after Gilbert, 1982, Figure 2)

Procedure

This thesis was completed in two stages. The first involved field mapping which was conducted during July and August 1982, and on weekends throughout the subsequent Fall and Spring semesters. The second stage involved analysis and interpretation of the data that was accumulated during the mapping.

Due to the great areal extent (approximately 30 square miles) of the Slick Hills, the work was divided equally between myself to the north, and Weldon Beauchamp (see Beauchamp, 1983) to the south. The boundary between our areas was an arbitrary line drawn northwest-southeast through the center of the Slick Hills, approximately half a mile southeast of the conspicuous 2000-foot ridge which forms the drainage divide in the area.

During the field work, every effort was made to collect as much pertinent data as possible. This was subject to physical limitations, such as the size of the area involved and the occasional lack or ambiguity of outcrops. On the whole, however, exposure in the area is excellent, varying from 20-50% rock. As a result, the approach used was one of evenly spaced transects along predetermined bearings, taking readings at regular intervals ranging from 30-90 yards, as the structure warranted. This method was augmented with a greater density of readings in areas of complexity. The generally homoclinal attitudes associated with the major folds meant that this was seldom necessary.

All readings are given in terms of dip and dip direction (azimuth). For example, a bed recorded as dipping 15/315 is dipping northwest at 15 degrees.

Due to the large number of folds mapped and their variance in size, a systemized nomenclature has been developed. This scheme is given in detail in Chapter IV but is briefly introduced here.

All the major structural features are named, for example, the Oliver syncline, Stumbling Bear shear zone, Meers fault. Many of these names were adopted by previous workers, but several are being introduced into the literature for the first time. Smaller folds are given initials and numbers indicating the fold's position in relation to a nearby major (named) fold. For example, KAss3 would refer to the third fold south of the Kimbell anticline, and would identify it as a syncline, whereas KAsa3 would indicate that the fold was an anticline.

Regional Setting

A consistent geological style is found throughout southwestern Oklahoma (Figure 2). The essential elements of this style are: (a) a Cambrian/Pre-Cambrian igneous and metamorphic basement; (b) a thick sequence of Lower Palaeozoic carbonates deposited in a basin (aulacogen) trending northwest-southeast; (c) a relative hiatus in Silurian and Devonian times; (d) pronounced Pennsylvanian and Permian sedimentation in rapidly subsiding intercratonic basins. Considerable complementary uplift and a great deal of faulting and related folding accompanied this subsidence.

Hoffman et al. (1974) placed this sequence of events in a plate tectonic framework, suggesting that an early trough formed as a result of an extensional episode during which the continental crust rifted, causing southern Oklahoma to split from the N. American craton. However, the rifting aborted and was followed by a period of subsidence (within an aulacogen setting), during which a thick sedimentary pile accumulated in Lower Palaeozoic times. In Pennsylvanian time, closure of successfully rifted arms to the east formed the Ouachita Mountains. This closure

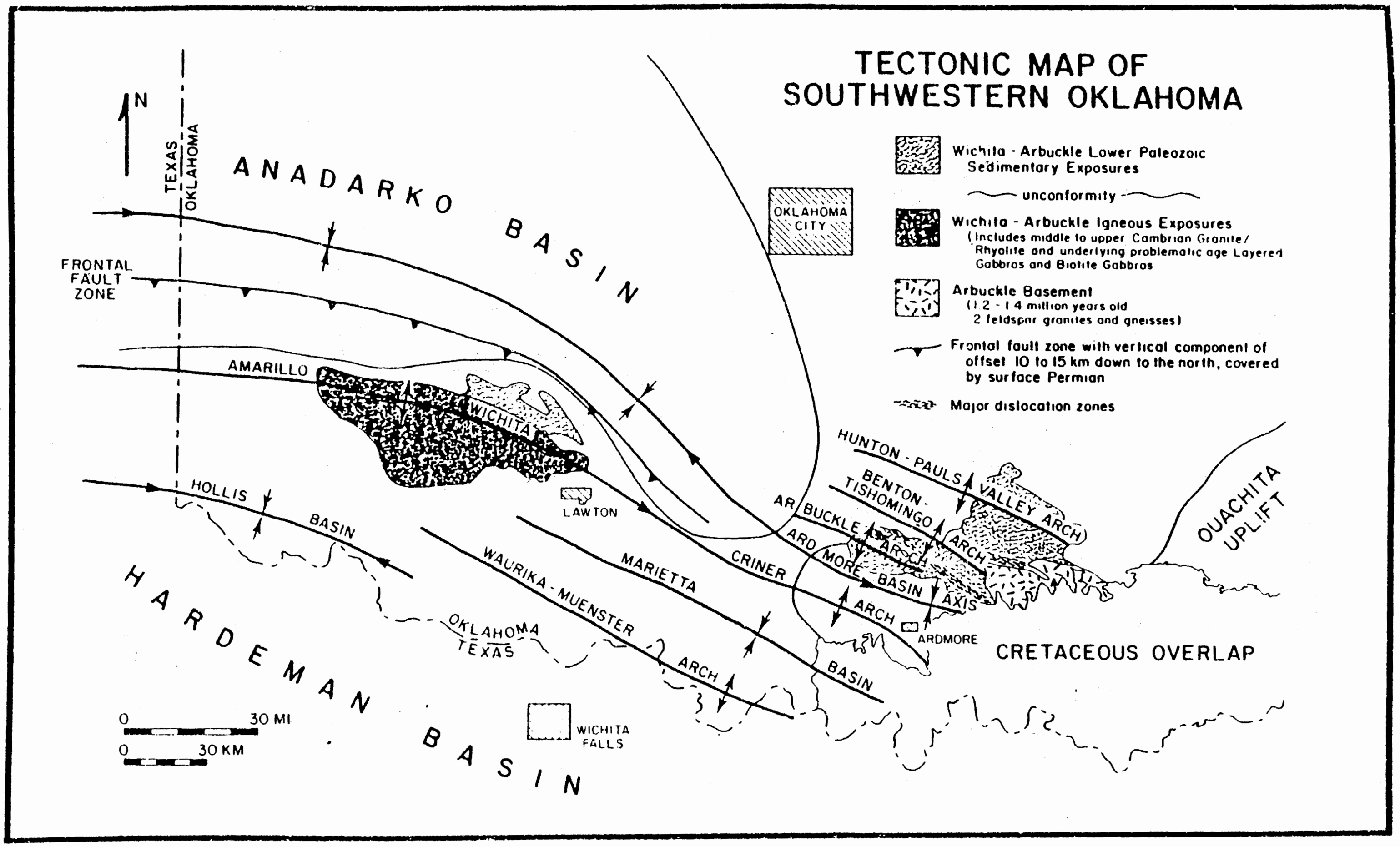


Figure 2. Tectonic Map of Southwest Oklahoma (Powell et al, 1980, Figure 1)

apparently triggered uplift and basin formation along lines of weakness established during the rifting phase.

In a more specific setting, the tectonic history of the Wichita Mountains uplift is closely associated with that of the Anadarko basin (Figure 2). The Anadarko basin is highly asymmetric, with a steep and highly faulted southern margin. This margin constitutes the Frontal Wichita's fault zone to the north of the Wichita uplift; one of the components of movement of the fault zone is a downthrow of six-nine miles to the north (Powell et al. 1980). The Slick Hills are located in one of the more intensely deformed parts of the Frontal Wichita's fault zone.

CHAPTER II

PREVIOUS WORK

Previous work in this area of the Frontal Wichita's fault zone is related to two areas of interest. The first is the structure of the area; the second, a combination of the Lower Palaeozoic stratigraphy and sedimentology as exposed in the Slick Hills. In essence, workers in both areas of interest sought to relate the geology to that of the better known and understood Arbuckle uplift to the east (Figure 2).

An early study by Decker (1939) established the general characteristics of the Arbuckle Limestone Group, dividing it into lower, middle, and upper units and recognizing the presence of siliceous, shaley, and dolomitic zones.

Harlton (1951) named and mapped both the Lawtonka graben and Blue Creek Canyon horst to the north of the Wichita Mountains. He accounted for the structure by invoking a complex series of normal faults with a general northwest-southeast trend. Dominant faults were the Blue Creek Canyon, Thomas, Stoney Point, and Lawtonka faults. He subdivided the rocks of the Arbuckle Group on the basis of silica content. This stratigraphic differentiation went unchallenged until reconnaissence mapping of part of the Slick Hills by Barthelman (1968) and Brookby (1969), who redefined many boundaries using a combination of faunal zones and lithological criteria. This revision is accepted here as the stratigraphic basis for mapping.

Riggs (1957) proposed that the Wichita Mountains arose as a geanticlinal welt in response to a gravity sag phenomenon caused by the subsidence of the Anadarko basin. He suggested that the faults along the basin's southern boundary were high angle reverse in style at the surface, but steepened to normal at depth. Riggs (1957) also pointed out two prominent lineaments in southern Oklahoma, the first trending east-west originating in Post-Morrovian times, and the second aligned northwest-southeast, being initiated in Hoxbar times.

In a review of his earlier work, Harlton (1963) renamed the Thomas fault as the Meers Valley (Meers) fault and suggested that this, plus the Blue Creek Canyon and Mountain View faults represented the main structural control in the area. In a still later work, Harlton (1972) attributed the origin of these major faults to a tensional episode in the Lower Palaeozoic associated with the opening of the Lawtonka graben.

Harlton's (1951, 1962, 1972) interpretations, which invoke essentially vertical movements, were at variance with the left-lateral transcurrent model which was developed for the faults of a similar trend in the Arbuckle uplift. For example, Tanner (1967) interpreted the displacement of facies variations in the Simpson Group to be the result of up to 40 miles of left-lateral transcurrent movement on the Washita Valley fault during the Lower Pennsylvanian. Similarly in later work, Booth (1981) described additional structural patterns observed in the Arbuckle and noted that these concurred with the left-lateral transcurrence model.

Donovan (1980) described an unconformity between rocks of Cambrian age, the Timbered Hills Group, and the Carlton Rhyolite in Blue Creek Canyon. He pointed out that the lower member of the Timbered Hill Group, the Reagan Sandstone, is overlapped by the Honeycreek Limestone. Schultz et al. (1982) identified this transgression as being equivalent to others recognized within the Lower Palaeozoic throughout North America. As seen in Blue Creek Canyon, this unconformity had previously (Harlton, 1951) been interpreted as the surface expression of a (normal) Blue Creek Canyon fault.

Subsequently, Donovan and Babaei (1980) and Donovan (1982) located the trace of this fault a short distance to the west, and described its anomalous north-south trend, comparing it to the northwest-southeast alignment of the Meers and Mountain View faults (Figure 3). They interpreted the fault as high angle reverse, thrusting Cambrian rocks over Ordovician to the west. They proposed that the fold axes within the Blue Creek Canyon area had been rotated to parallel the fault, and suggested that the period of compression which resulted in the Blue Creek Canyon fault may also have generated left-lateral transcurrent movements along the major northwest-southeast faults. Donovan (1982) also described some of the fold patterns and styles developed within the area.

Additional work in the same area by Donovan et al. (1982) gave evidence for left-lateral transcurrent movements along the major faults bounding the Slick Hills. The evidence is in the form of slickensides, tension gashes, and en echelon folds. Where anomalous north-south fault trends occurred (as in Blue Creek Canyon itself) they were seen to involve high angle reverse, rather than transcurrent, movement. Shear zones were described which paralleled the fault trends and exhibited phacoidal textures. These workers attributed the formation of folds to progressive nucleation under rotational strain, and they suggested that folds which are more oblique to the regional trend formed later.

Brewer (1982) described a deep, subsurface COCORP seismic study

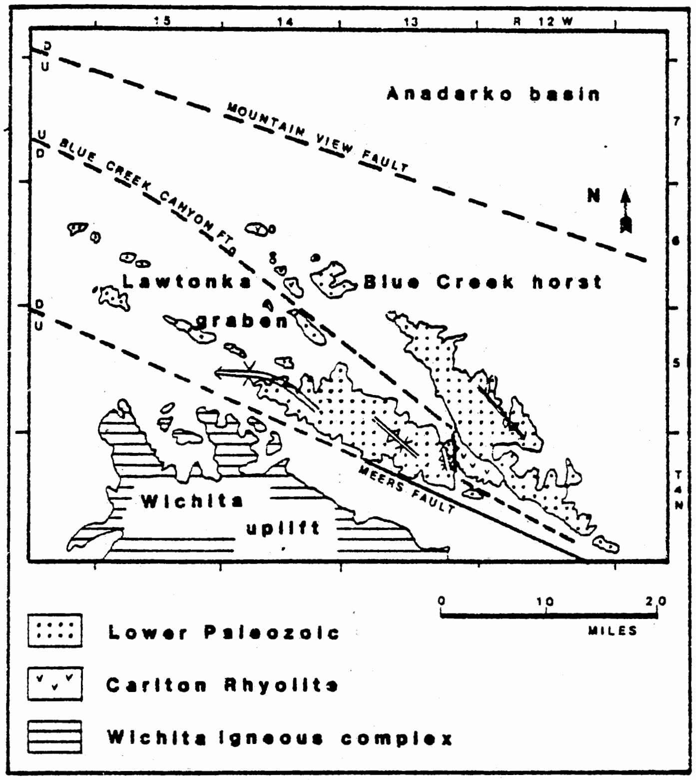


Figure 3. Simplified Geologic Map of the Slick Hills Showing Principal Structural Elements (Donovan 1982, Figure 46). Note the "horst" and "graben" terminology, first adopted by Harlton (1951) is not strictly correct as the bounding faults are not normal

across southwest Oklahoma, which showed the Wichita uplift to be thrust over the southern margin of the Anadarko basin. The Mountain View fault, which represents the northern boundary of the Frontal Wichita's fault zone, was traced south-southwest with a dip of 30-40 degress, to a depth of 20-24 miles. The Meers fault was considered to have an equivalent orientation. This pattern clearly differs from that proposed by Harlton (1951, 1963, 1972) and Riggs (1957), but supports the tectonic model put forward by Hoffman et al. (1974). Brewer (1982) regarded it as indicative of a significant phase of crustal shortening during Pennsylvanian (Atokan) time. He also proposed that later transcrurrent movements may have occurred along previously formed faults due to a second phase of deformation during Virgilian-Missourian time, or that they may be accounted for in a single phase of deformation during which oblique slip occurred with components of both thrusting and transcurrent movements.

Apart from the previously cited work done in the Blue Creek Canyon by Donovan and others, there has been little detailed work done on the structure of the remainder of the Slick Hills. Barthelman (1968) and Brookby (1969) undertook reconnaissance mapping for the Oklahoma Geological Survey, but interpreted their data according to the model suggested by Harlton (1951, 1963).

CHAPTER III

REVIEW OF TRANSCURRENT TECTONIC THEORY

Introduction

Recent work by Donovan et al. (1982) has established that left-lateral (sinistral) shear movement played a dominant role in the structural evolution of the Frontal Wichita's fault zone. This chapter reviews the literature related to this theme and prepares a theoretical background against which the data collected during this study can be analyzed.

Shear zones, as defined by Ramsay (1980) are areas of high deformation which are often localized in narrow, sub-parallel-sided zones. Where a clear discontinuity exists between the sides of the zone, and where the shear zone walls show little evidence of strain, it is termed a fault or brittle shear zone. As has been outlined previously, the Frontal Wichita's fault zone is a relatively narrow, northwest-southeast trending zone which, in the area of study, is delineated by the Meers and Mountain View faults (Figure 3). Between the bounding faults there is ample evidence of intense deformation. If the Slick Hills are representative of the Frontal Wichita fault zone as a whole, then the zone, on a grand scale, falls within the bounds of Ramsay's (1980) definition.

Features Typical of a Strike-Slip Environment

Wilcox et al. (1973) defined transcurrent or wrench faults as high angle strike-slip faults of great linear extent, forming in response to horizontal shear couples within the earth's crust. It is widely acknowledged that their associated structures are best explained as originating as a consequence of heterogenous simple shear (Ramsay, 1980) between two rigid blocks (Moore, 1979)(Figure 4).

The directions of maximum compression and extension parallel the minor and major strain ellipse axes respectively, and neither of these directions is parallel with or normal to the principal shear direction (Wilcox et al., 1973). This oblique resolution of stresses results in en echelon structures and a linear, persistent zone of deformation (Harding and Lowell, 1979).

A transcurrent fault zone develops in three principal stages which are closely related in time. The initial stage is marked by the development of an en echelon series of doubly-plunging folds of similar size and orientation. For true, simple shear the angle between the axes of these folds and the fault zone itself will always be less than 45 degrees. Wilcox et al. (1973), using clay models, found the angle more closely approximated 30 degrees. The folds will always be synthetic to the sense of strike-slip component; i.e., a left-lateral strike-slip component will produce left-handed folds (Figure 5).

It should be emphasized that the en echelon folds form in response to the stress field which later causes the formation of the major strike-slip fault--they are not a direct consequence of the transcurrent movement itself. Both share a common deformational genesis (Harding, 1974). With an increasing strike-slip component the axes of the folds may become rotated, decreasing the angle they make with the fault zone.

The second stage in the development of a transcurrent fault system

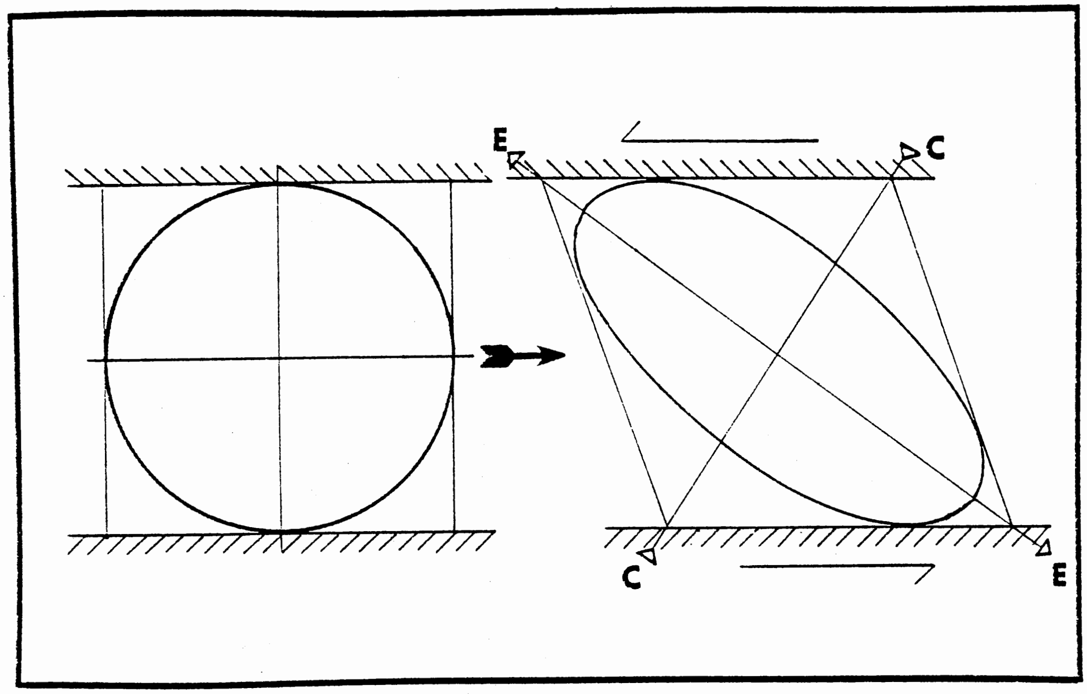


Figure 4. Strain Ellipse Formed by Simple Shear on an Initially Undeformed Circle Situated Between two Rigid Blocks; (C) Maximum Compression; (E) Maximum Extension

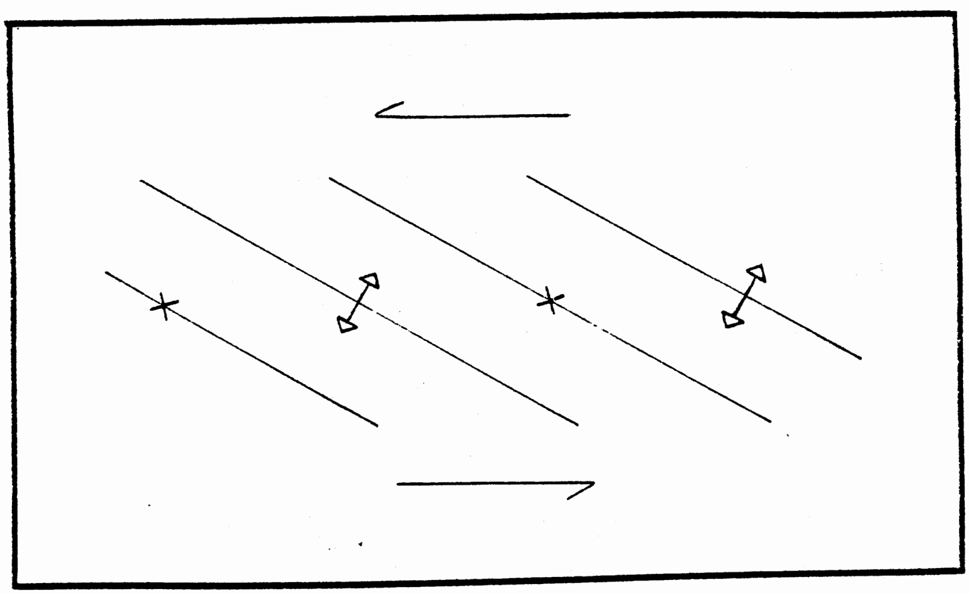


Figure 5. Left-handed Folds Generated in a Left-lateral Stress Field

is marked by the appearance of a conjugate set of fractures which initiate as strike-slip faults (Wilcox et al., 1973). They have predictable orientations being aligned at 10-30 degrees (synthetic) and 70-90 degrees (antithetic) to the fault zone, respectively. The former have the same sense of movement as the strike-slip component, whereas the latter have the opposite sense (Wilcox et al., 1973). Tchalenko (1970) termed these features Riedel and conjugate Ridel shears, respectively, and correlated their development with the period of maximum resistance to shear during the evolution of the fault zone. Moore (1979) saw the conjugate sets originating simultaneously at several locations within the proto-fault zone, accompanied by the initiation of the en echelon folds. With continued deformation, the block between the synthetic and antithetic faults is driven inwards, in the direction of maximum compression, thus forcing the conjugate sets further apart (Wilcox et al., 1973)(Figure 6).

With the further rotation of these conjugate fault sets, the movement along them will be concentrated along the synthetic elements (which will virtually parallel the strike-slip component's direction). The antithetic faults, however, are aligned nearly normal to the trace of the fault zone. As a result, any movement which occurs on these antithetic faults will be in a vertical plane, and may produce high angle reverse faults.

If deformation continues, the final stage in transcurrent fault development occurs. The strain is expressed as movement along already formed structures or as the development of newly formed synthetic faults aligned at -30 degrees to the fault zone boundary. These later faults are equivalent to Tchalenko's (1970) P-shears. These may interconnect

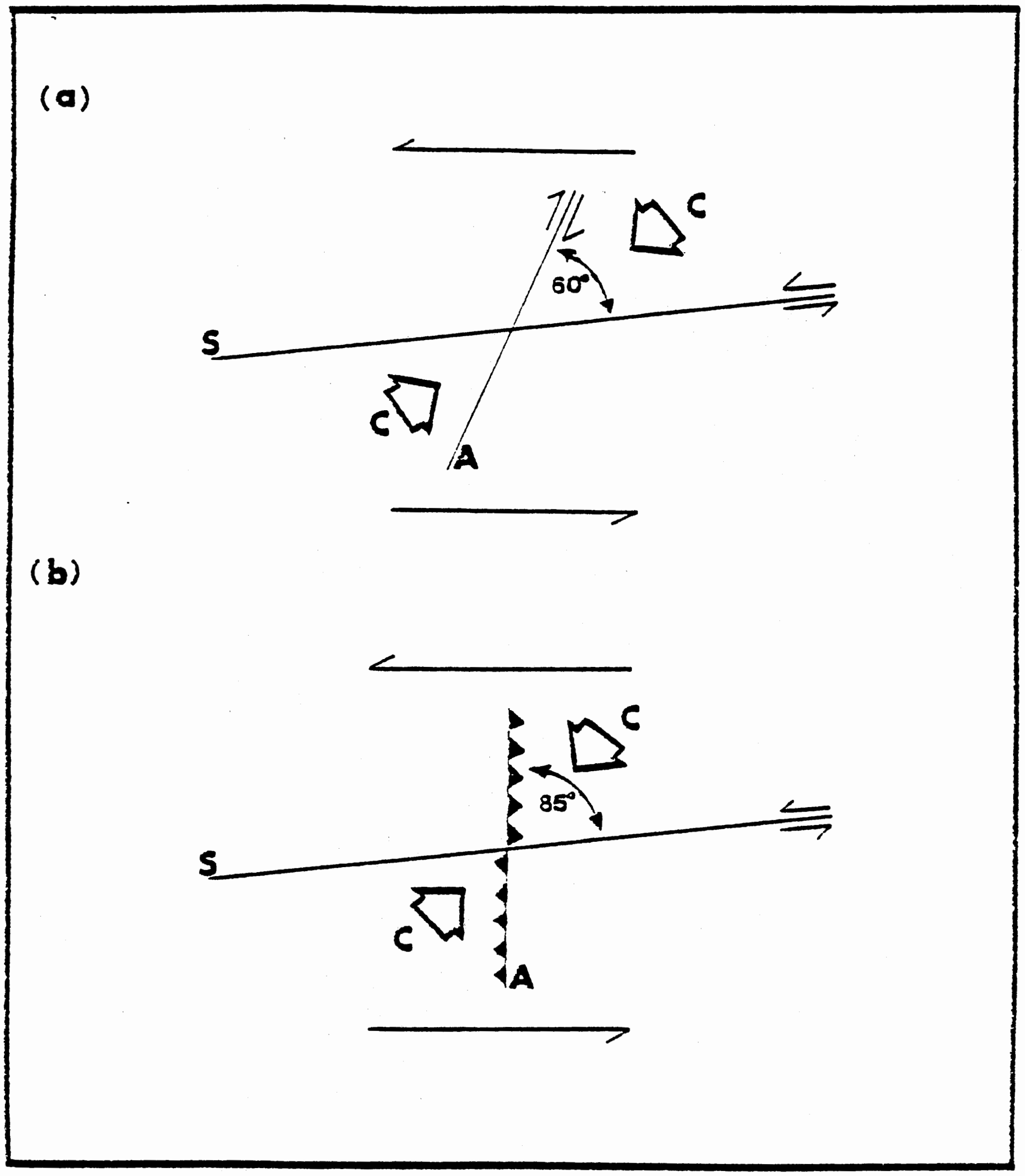


Figure 6. Rotation of Synthetic and Antithetic Faults Within a Left Lateral Stress Field; (a) Initial Arrangement; (b) After Rotation; (C) Compression; (S) Synthetic Faults; (A) Antithetic Faults

with the already present synthetic faults to form a network of small faults enclosing a series of phaocidal blocks. This leads to the propagation of a through-going transcurrent fault parallel to the principal strike-slip direction (Wilcox et al., 1973). Any subsequent movement will be concentrated along this major fault.

In addition to the features mentioned above, tension joints or normal faults may parallel the short axis of the strain ellipse, crossing the fold axes at right angles (Wilcox et al., 1973).

In profile view, wrench faults may exhibit a characteristic flower-structure (Figure 7), expressed as an upward spreading fault zone whose elements usually have reverse separations (Harding and Lowell, 1979). If the spreading fault system is asymmetrical, it remains in a half-flower structure (Lowell, 1972). At the surface, these structures appear as thrusts similar to those recognized by Allen (1965) in association with the Alpine fault in New Zealand. Development of a flower structure will be enhanced by a component of convergence accompanying the strike-slip movement.

Moody and Hill (1956) give several lines of evidence for the recognition of transcurrent faults in the field such as steep fault planes, sub-horizontal slickensides, offsets in structures and lithofacies (Tanner, 1967), as well as the presence of the structures dealt with above.

Compressional Modification of the Strike-Slip Environment (Transpression)

When opposed blocks do not move absolutely parallel with one another but converge, the compressional structures within the transcurrent fault zone become enhanced. Folds, and antithetic and synthetic

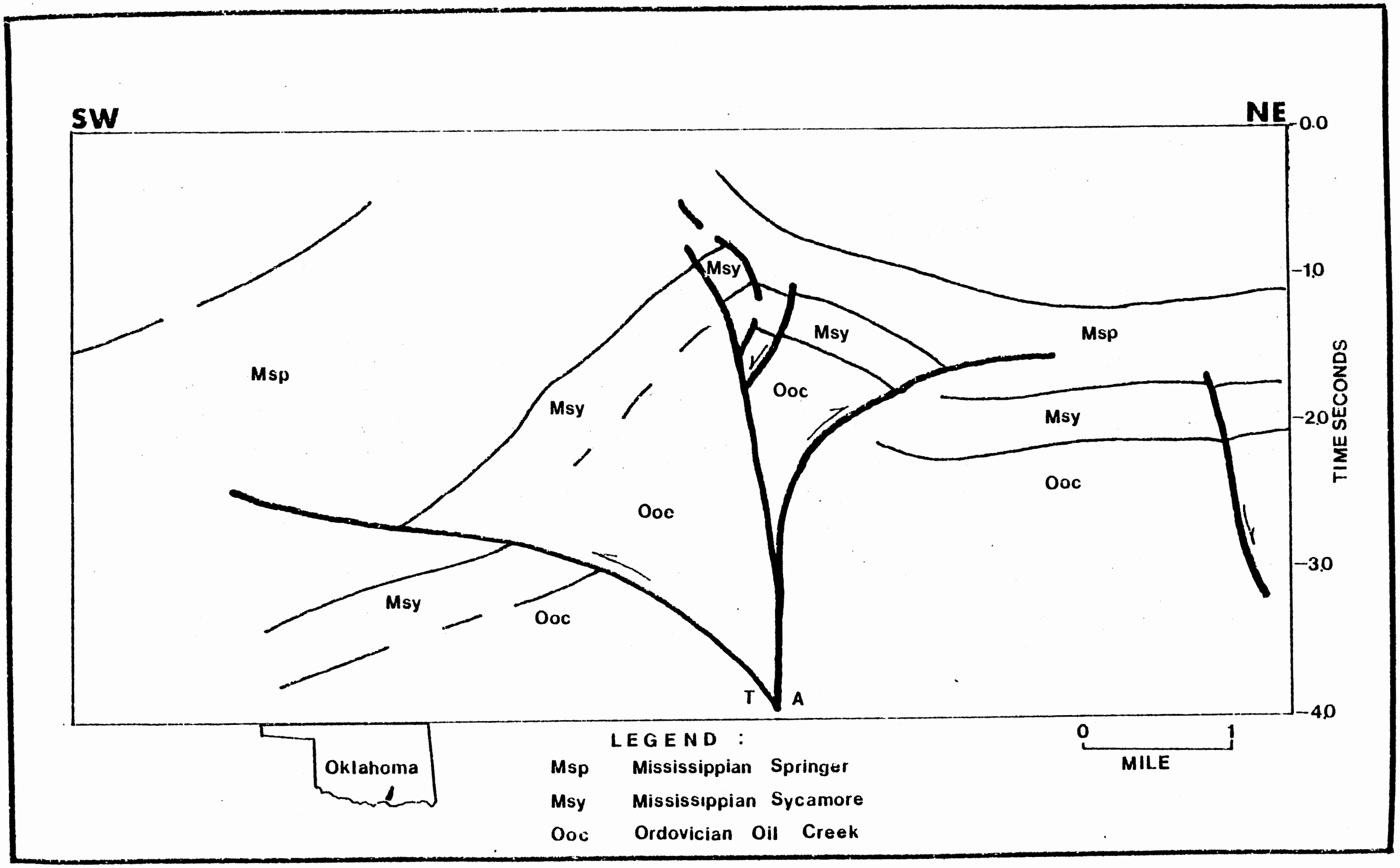


Figure 7. Flower Structure Geometry Interpreted From a Seismic Line Across the Arkoma Basin, S. Oklahoma (after Harding and Lowell, 1979, Figure 6); (A) Displacement Away From Viewer; (T) Displacement Toward Viewer

faults become further developed while higher angle reverse faults and thrusts may occur. Harland (1971) termed this development transpression.

A transpressive environment may develop in two ways. The first was adopted by Harland (1971) when he postulated three possible sets of component movements with a plate translation direction oblique to the mobile zone (Figure 8). Figure 8a represents the intitial situation, and 8b, c and d represent the structures which could result from oblique compression.

Garfunkel (1966) pointed out that fault traces may be treated as space curves on the surface of the (spherical)earth. The only such curves to move past each other without either colliding or moving away from one another are those on small and great circles. Hence, it is likely that elements of a transcurrent fault complex will converge or diverge at some point along its length to create both compressional and extensional features along its length. Thus, the second way in which transpressive environment can develop is when anomalous bends will cause convergence or divergence, resulting in transpression and transtension components, respectively, within the transcurrent system. If the trace of an initial through going transcurrent fault is irregular--as would occur with a combination of Tchalenko's (1970) Riedel and P-shears--movement would result in alternating zones of local transpression and transtension (Harland, 1971)(Figure 9).

Eventually, there will be a smoothing out of the trace as transpressive areas thrust and fold, and transtensile areas are infilled with sediments or igneous material. Sylvester and Smith (1976) used the presence of folds, reverse faults and thrusts to indicate convergence at a transcurrent zone bend. They identified major strike-slip faults as having low angle thrust segments at the surface, and proposed that this occurred

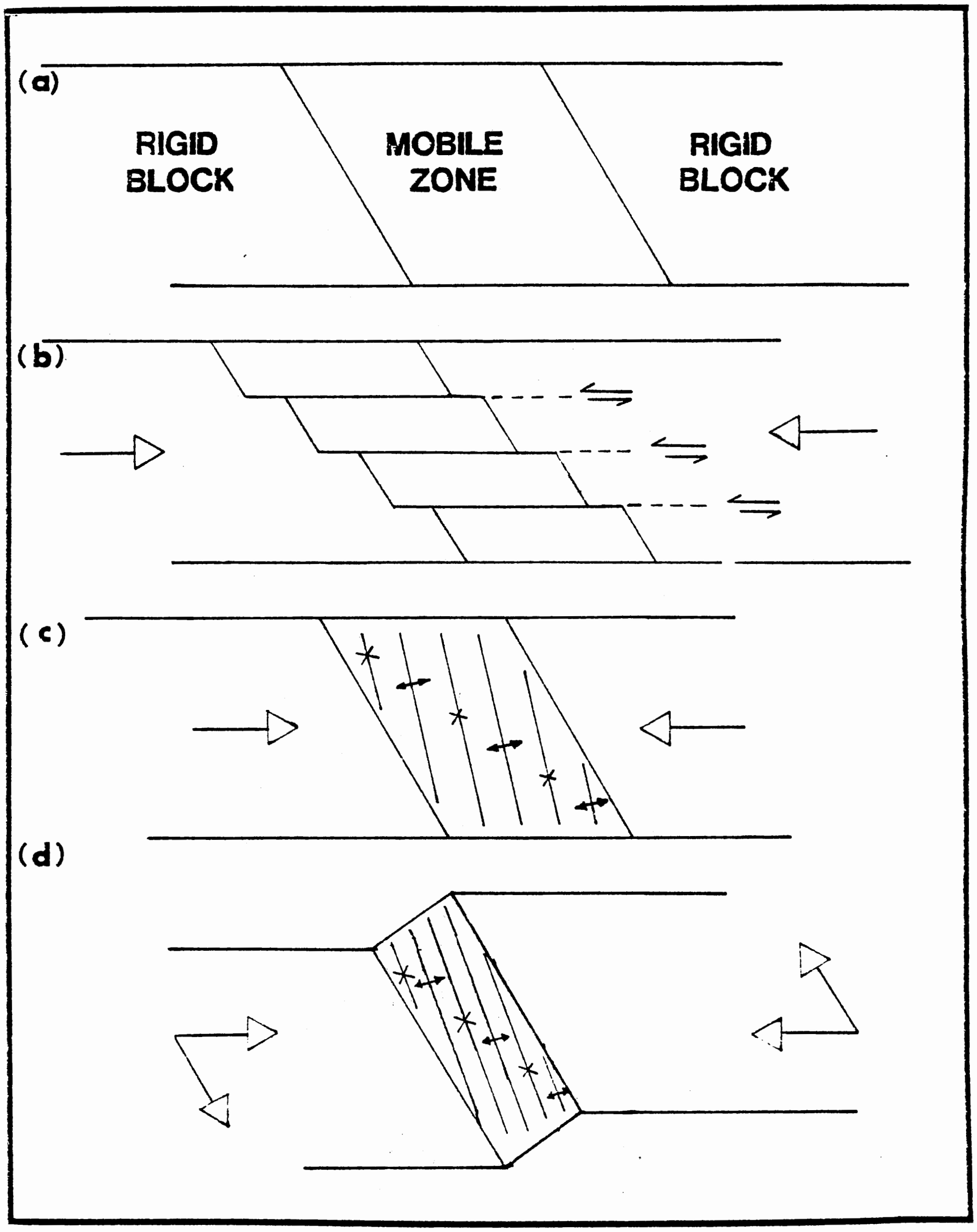


Figure 8. Development of Transpressive Environments (after Harland, 1971, Figure 2); (a) Initial Situation; (b) Compression, With Strike Slip Parallel to Translation Direction; (c) Simple Transpression With Folding Oblique to Mobile Zone Boundary; (d) Transpression With Transcurrent Component Dominant

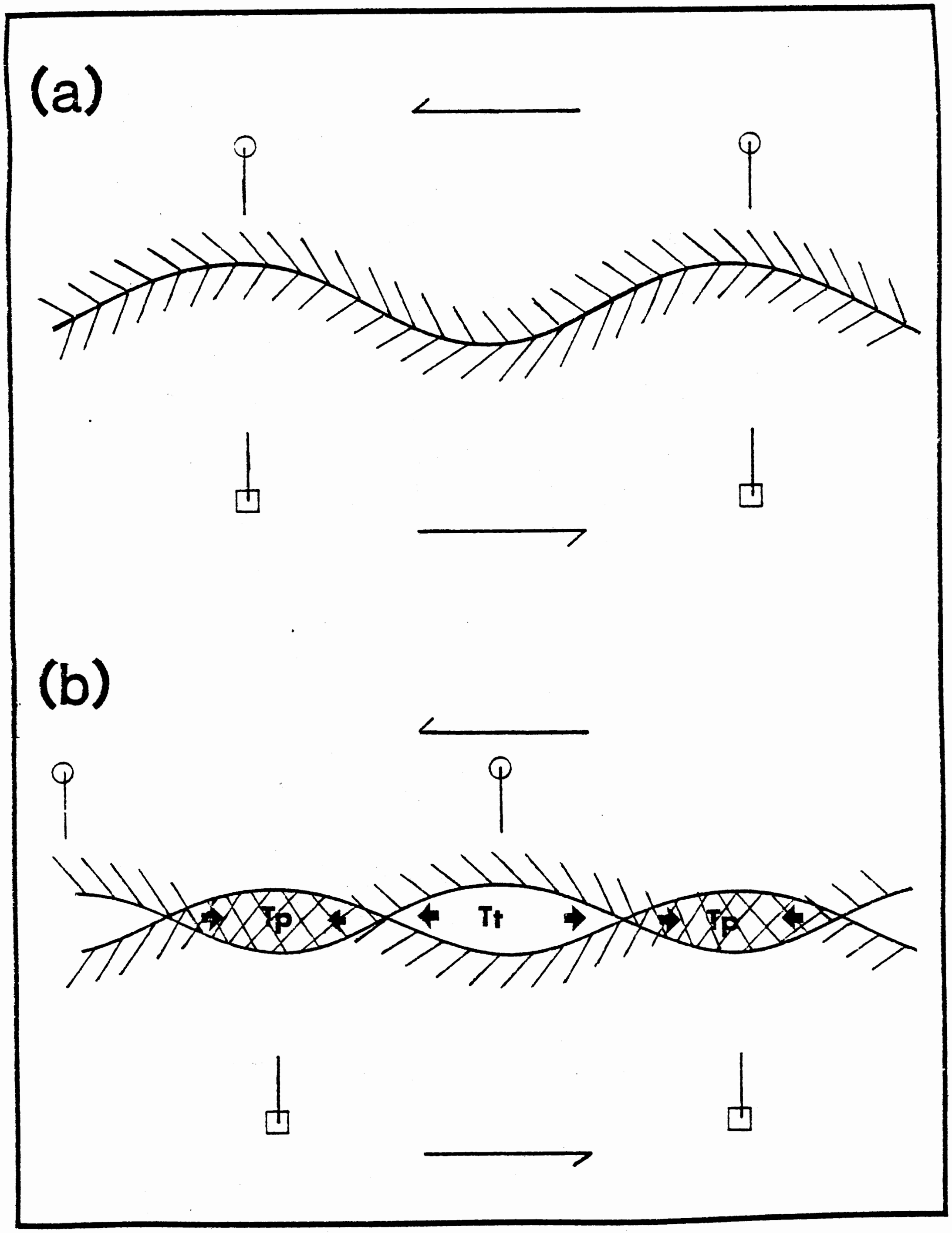


Figure 9. Development of Transpression and Transtension Regimes Along an Irregular Transcurrent Fault (after Harland (1971, Figure 4); (a) Initial Irregular Fault Trace; (b) Development of Transpressive and Transtensile Environments Following Sinistral Movement; (Tp) Transpression; (Tr) Transtension

as a consequence of initial transcurrent movement followed by compression (Figure 10), thus producing an overall transpressive regime with half-flower structures evident on either margin of the shear zone (Figure 11a).

Lowell (1972) identified flower structures in the Spitsbergen Fracture zone and described the mechanism of their formation. When one block moves with convergent strike slip towards another, a space problem is created with the easiest direction of relief for the stressed material being upwards. This creates a welt with down-tapering wedges and upthrust margins (Figure 11b). In this model of deformation, the faulting will follow an initial period of folding (Lowell, 1972).

Summary: A Comparison of Transcurrent and Transpressive Regimes

The transpression model modifies the basic transcurrent fault model by increasing the component of compression and thus initiating thrusts and high angle reverse faults as well as rotating folds, normal faults and Riedel shear sets. The angle the folds make with respect to the boundary of the shear zone decreases, whereas there is an increase in the angles the normal faults and Riedel shear sets make (Figure 12). Also, the shear zone itself becomes narrower, and the folds tighter.

Theoretically, the problem of differentiating between transpressive and normal transcurrent fault regimes would not appear too difficult, but it must be noted that in the field we see only the end result and have no control model of either type to compare it with. Furthermore, as Garfunkel (1966) states, "the study of geometrical models can be expected to apply to nature, at least qualitatively": however, one must

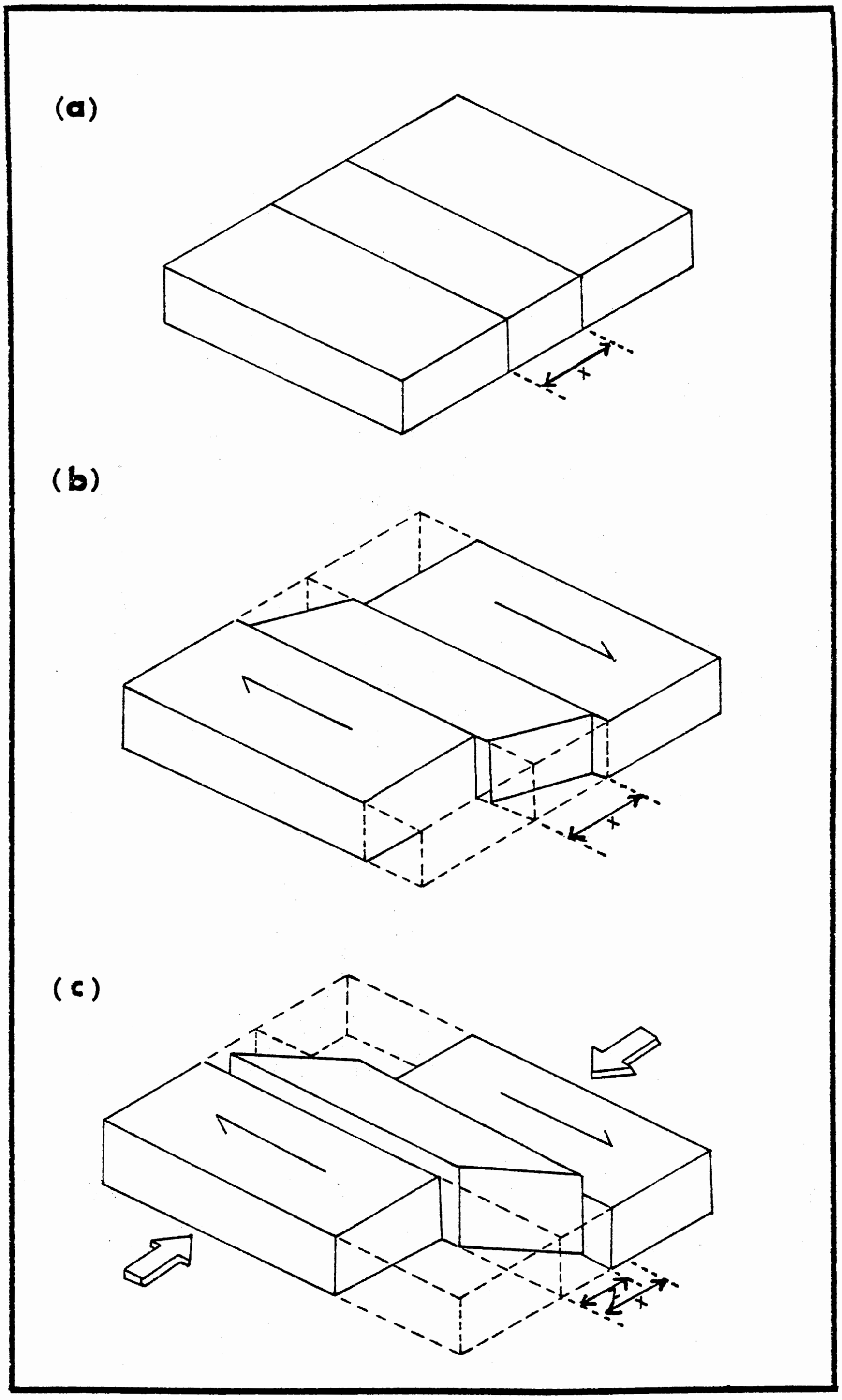


Figure 10. Conceptual Model of Basement Deformation (after Sylvester and Smith, 1976, Figure 21); (a) Non-rigid Block, Bounded by Rigid Blocks; (b) Simple Shear Resulting From Transcurrence; (c) Uplift and Shearing of Non-Rigid Block due to Transpression

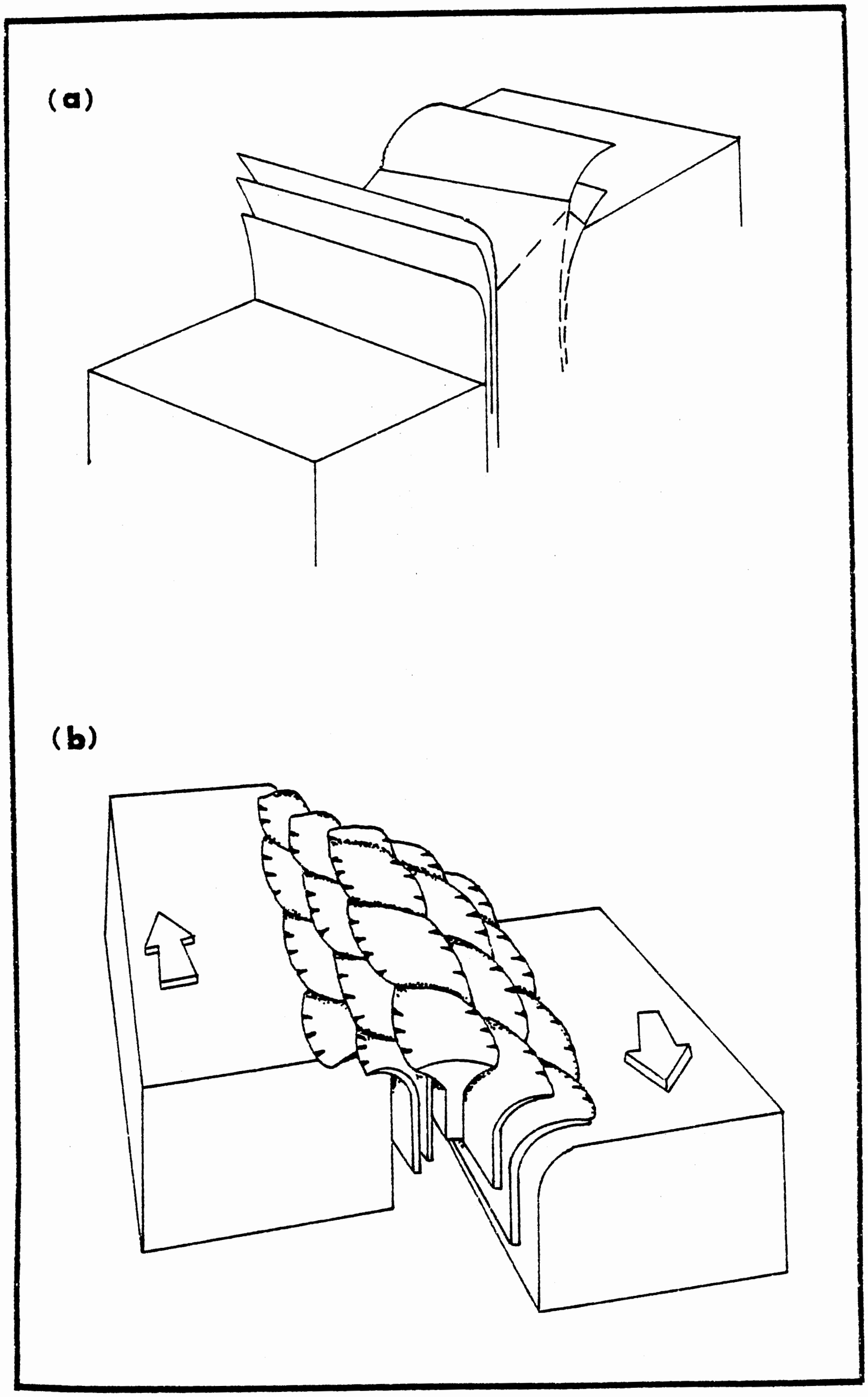


Figure 11. Flower Structures Within a Transpressive Regime; (a) Half-flower Structures on Either Margin of a Deformed Central Block (after Sylvester and Smith, 1976, Figure 6); (b) Upthrust Bounded Welt due to Transpression (after Lowell, 1972, Figure 9)

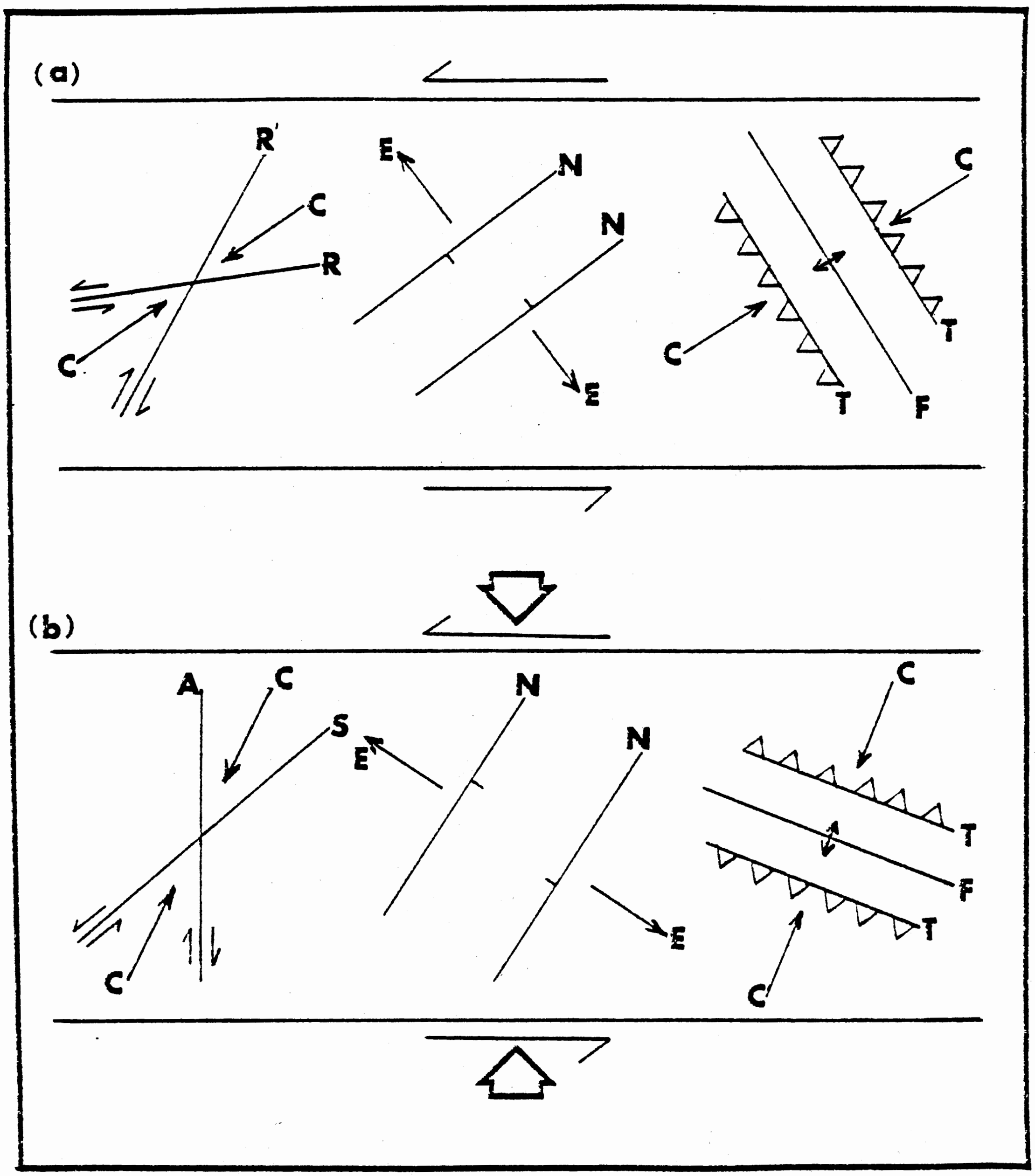


Figure 12. Reorientation of Structures Created by (a) Transcurrence; (b) After Compression (after Sanderson and Marchini [in press]); C, Compression; T, Thrusts; F, Folds; E, Extension; N, Normal Faults; R, Riedel Shears; R' Conjugate Riedel Shears; A, Antithetic Faults; S, Synthetic Faults

mindful that the rheological and physical properties of the rocks involved, and the strain path the structures evolved along will play a part in distorting the quantitative aspects of any proposed model.

CHAPTER IV

ANALYSIS OF DATA

Introduction

An understanding of the stratigraphy of an area is important when attempting any form of structural analysis, as it will often bring to light points which otherwise might have gone undetected. This is certainly the case in the Slick Hills. Therefore, before dealing with the structural aspects of the area, a brief review of the stratigraphic column is presented.

Geologic Succession

Carlton Rhyolite Group

The Middle Cambrian Carlton Rhyolite Group is exposed in the Blue Creek Canyon area and comprises lava flows and tuffaceous sandstones. In addition, a pebbly conglomerate occurs between two of the flows (Donovan, 1982)(Figure 13).

Timbered Hills Group

The Upper Cambrian Timbered Hills Group overlies the Carlton Rhyolite Group on an unconformity surface which shows considerable relief. The lower formation of the Timbered Hills Group, the Reagan Sandstone, is onlapped by the upper Honey Creek Formation from north to south within

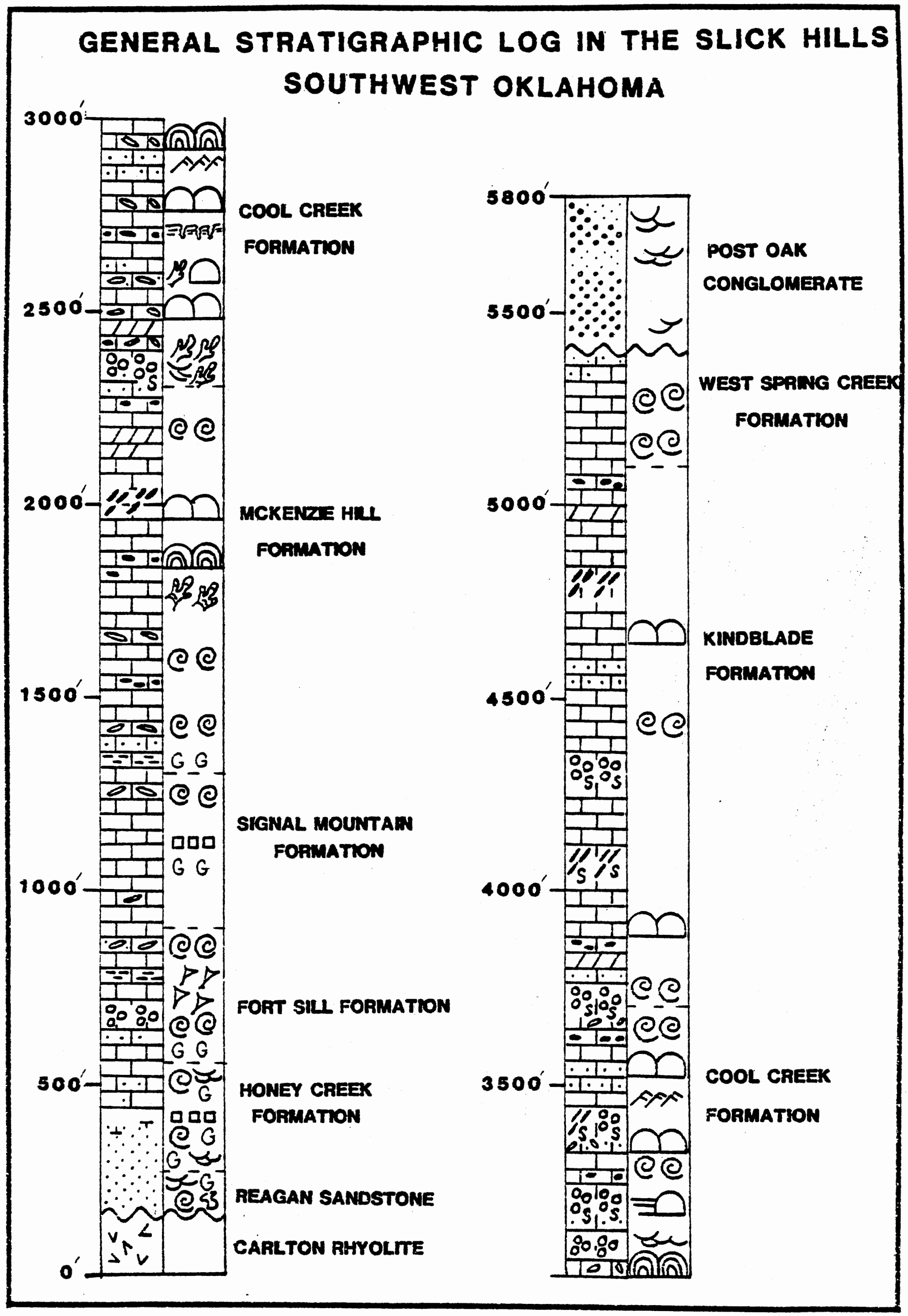
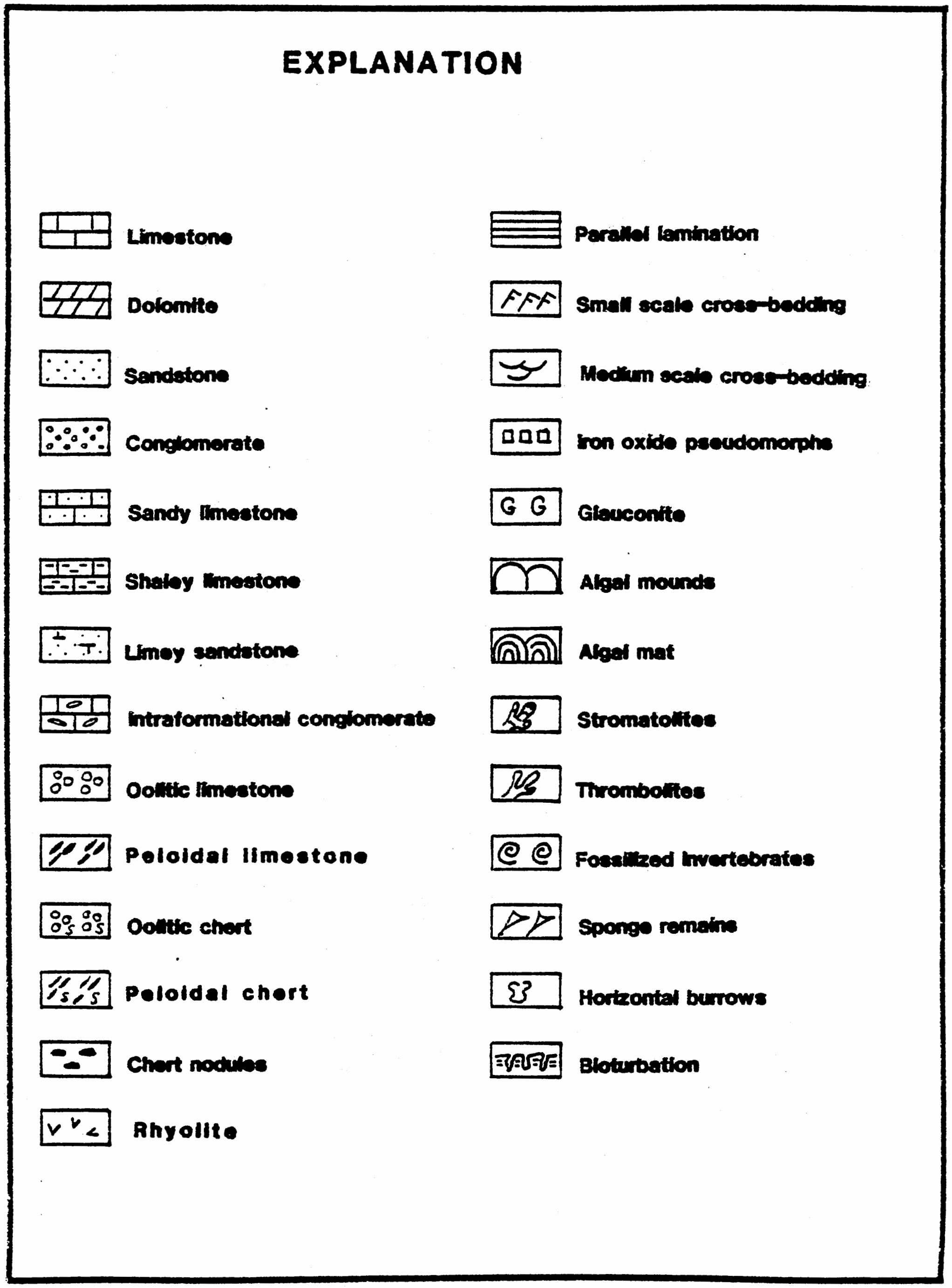


Figure 13. General Stratigraphic Log (Ragland, 1983)



Legend for Stratigraphic Log (Ragland, 1983)

Figure 13 (Continued)

Blue Creek Canyon (Donovan, 1982). The principal facies within the Reagan Sandstone is a glauconitic, fine grained, quartzose sandstone. Upsection the Reagan has a gradational boundary with the more carbonate rich Honey Creek Formation. Within this latter formation, three clastic facies developed which were subsequently cemented by sparite. The most well developed facies among these is a bioclastic sandstone composed principally of predominantly pelmatozoan shell fragments (Donovan, 1982) (Figure 13).

Arbuckle Group

The Arbuckle Group is made up of several formations of carbonate rocks found throughout the Slick Hills. The Cambrian Fort Sill Formation (Figure 13) represents the lowest component of the group and can be divided into three members. The uppermost member, a massive bedded limestone, acts as a good marker horizon in the field as units below and above it are more easily weathered and form weak ground.

As a result of this, there is a clear and distinctive mapping boundary with the overlying Signal Mountain Formation, a thinly bedded limestone with calcereous mudstones and shales (Donovan, 1982)(Figure 13). Brookby (1969) placed the Cambro-Ordovician boundary 400 feet from the base of this formation in a sequence to the northeast. However, Donovan (1982) considered this thickness as suspect within the Blue Creek Canyon area, due to possible tectonic thinning caused by movement along fissile shale horizons.

The lowermost entirely Ordovician element within the Arbuckle Group is the McKenzie Hill Formation (Figure 13). It comprises a series of well bedded carbonates, mostly mudstones. The top part of the formation is characterized by numerous chert nodule horizons. This is the first widespread occurrence of chert in the Arbuckle Group, although minor amounts are encountered within the upper Fort Sill Formation. The limestones of the upper McKenzie Hill Formation have resisted erosion and form a conspicuous ridge easily traceable in the field and on air photographs.

The overlying Cool Creek Formation (Figure 13) is over 1400 feet thick (Ragland, 1983, personal communication) and its base represents a good marker horizon, characterized by the first appearance in the section of quartz sand which persists sporadically throughout the section. The formation contains a variety of sedimentary structures, and many forms of stromatolites can be recognized.

The uppermost two components of the Arbuckle Group, the Kindblade and the West Spring Creek Formations, were taken together as one mapable unit by Harlton (1963). The Kindblade-Cool Creek boundary is an unsatisfactory field mapping horizon, as it is marked by the first appearance of the silicified gastropod opercula, genus Ceratopia (Ragland, 1983). The Kindblade Formation makes up most of the field area to the northwest of Blue Creek Canyon, with the laminated basal member of the West Spring Creek Formation outcropping only in the most northerly part of the area. Barthelman (1968) noted that this basal member contained individual beds extremely rich in quartz sand. Both formations are characterized by the presence of extensive bodies of dolomite, some several hundreds of feet thick. Dolomite is less common in the lower Arbuckle Group. These dolomites weather to a distinctive brown colour and form less prominent relief than the well bedded, finely crystalline carbonates which make up the larger part of these formations. Harlton (1963) has estimated a combined thickness of 2300 feet for the Kindblade and West Spring Creek Formations.

Hennessey Group

The only representative of the Permian Hennessey Group encountered in the study was the Post Oak Conglomerate (Figure 13). This lies unconformably against the thick carbonate succession. It is a polymictic conglomerate made up of cobble sized fragments of predominantly limestones in the field area.

Structural Geology

Three principal types of structures are represented in the northern Slick Hills and adjacent areas; these are folds, faults, and shear zones. The character and distribution of these features within the area of study can be used to give an insight into the development of the area.

Folds

As mentioned in Chapter I, a systemized nomenclature has been developed to describe and locate folds. The folds are classified as first, second, or third order, depending upon their scale. If their axial trace is longer than 1500 yards they are termed first order; if the trace is between 600-1500 yards they are second order, and if it is less than 600 yards they are third order folds. In addition, any first, second, or third order fold may exhibit minor (parasitic) folds on its limbs.

The axial trace was used to rank the folds in preference to the amplitude method defined by Donovan (1982) as it was often impossible to see the same bed on both an anticline's crest and in its adjacent syncline's trough.

All first, and some significant second, order folds were named;

otherwise the folds were given a series of initials. The first two initials signify a named fold it is close to; the third initial indicates its orientation (north, south, east, or west) relative to the named fold. The fourth initial defines it as an anticline or syncline, while the succeeding number denotes its position relative to the named fold (Figure 14). All of the folds which have been named or initialed in this manner are set down (Table I) together with their location (township, range, section number), trend (plunge/azimuth for significant folds) and order. Folds are listed in alphabetical order and are located on the map (Plate 1). Each fold is also given an arbitrary number which is used to refer to plots in later figures. Where an * appears by the number, a stereographic plot of the fold is included, under that number, in the Appendix or as a text figure. The larger folds are generally arranged en echelon trending northwest-southeast (Figure 15). They are commonly parallel and show a range of profiles varying from symmetric to moderately overturned (but not recumbent); i.e., axial plane dips vary from 45-90 degrees. The parallel geometry of the folds means that fold profiles vary consistently (Figure 16). Consequently, the same fold may vary from open and symmetric to tight and asymmetric. In areas of tightness, disharmony has been resolved by the development of minor folds. The folds' sense of parallelism results in their disappearance both up and down section.

An example of the constraints of parallel geometry is provided by the Kimbell anticline (Figure 16). This fold is generated from the northwest limb of the Paradox anticline (Figure 17) in section 11 and, upsection, has an asymmetric to overturned fold profile in southeast section three; to the northwest the profile broadens from overturned through asymmetric until, in northeast section four, the fold is open with limb dips of less

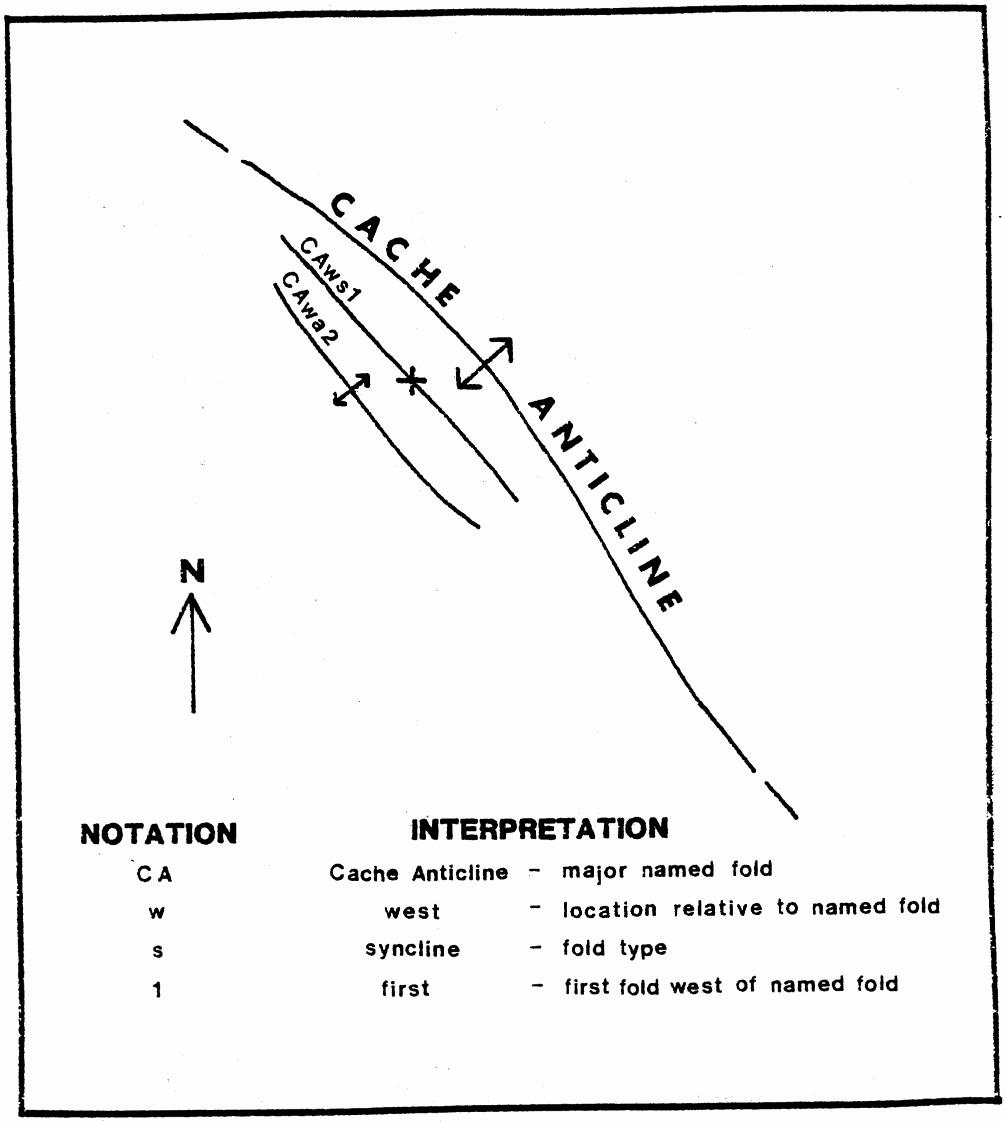


Figure 14. Explanation of Procedure Adopted to Initialize Folds (example taken from the southwest quarter of section 30, T5N, R13W)

TABLE I

CATALOGUE OF FOLDS

Fold Number	Fold Name	Order	Trend	T (N)	R (W)	Section(s)
1*	Blue Creek Canyon Syncline	1	28/332	4	13	2,11
2*	Bullrun Anticline	1	20/320	5	13	23,24,25
3	BAws1	3	336	5	14	24
4	BAwa2	2	348	5	14	23,24
5	BAws3	3	319	5	14	25
6	BAwa4	3	318	5	14	25
7	BAws5	3	324	5	14	25
8	BAwa6	3	320	5	14	25
9	BAws7	3	323	5	14	25
10	BAwa8	3	332	5	14	25,26
11*	BAws9	2	7/320	5	14	23
12*	BAwa10	2	8/318	5	14	23
13*	BAwa11	3	10/152	5	14	23
14*	Bullrun Syncline	1	12/320	5	14	24
15*	BSna1	3	8/319	5	14	25
16*	BSns2	3	6/313	5	4	25
17*	BSsa1	3	16/330	5	14	25
	BSss2	3	16/330	5	14	25
18*	Cache Anticline (N.)	1	6/312	5	13	19,24,30
19*	Cache Anticline (S.)	1	6/140	5	13	29,30,32
20*	Cache Syncline	2	4/314	5	14	24
21	CAes1	3	318	5	13	32
22*	CAea2	2	4/339	5	13	32
23	CAws1	3	7/132	5	13	30
24	CAwa2	3	0/130	5	13	30
25*	Dietrich Anticline (N.)	1	10/146	5	14	24
26*	Dietrich Anticline (S.Z.)	1	17/156	5	14	24,25
27*	Dietrich Anticline (S.)	1	6/305	5	13	30
28*	DAsa1	3	13/290	5	13	30
29	DAss2	3	314	5	13	30
30	DAsa3	3	312	5	13	30
31*	Dietrich Syncline (N.)	1	20/143	5	14	24
32*	Dietrich Syncline (S.)	1	8/156	5	14	24,25
33*	DSea1	3	14/128	5	14	24
34*	Kimbell Anticline (N.)	1	5/305	4	13	4
35*	Kimbell Anticline (S.)	1	4/307	4	13	3,10
36*	Kimbell Syncline	2	15/320	4	13	3,11
37*	Marshall Anticline (N.)	2	25/318	5	14	25
38*	Marshall Anticline (S.)	2	20/300	5	14	25
39*	MAns1	3	320	5	14	30
40	MAws1	2	337	5	14	24,25
41	MAwa2	2	348	5	14	24,25
42*	Oliver Syncline (N.)	1	3/137	5	13	31,32
43*	OSna1	3	6/135	5	13	31

TABLE I (continued)

Fold Number	Fold Name	Order	Trend	T (N)	R (W)	Section(s)
44	OSns2	3	6/140	5	13	31
45	OSna3	3	305	5	13	31
46	OSns4	3	305	5	13	31
47*	OSna5	3	0/307	5	13	31
48*	OSns6	3	8/311	5	13	31
49*	Oliver Syncline (S.)	1	2/327	4	13	5
50*	Paradox Anticline (N.)	1	18/325	4	13	2,11
51*	Paradox Anticline (S.)	1	30/323	4	13	11
52	PAss1	3	302	4	13	2,3
53	PAsa2	3	300	4	13	2,3
54*	Ridge Anticline (N.)	1	2/303	5	13	32,33
55*	Ridge Anticline (S.)	1	4/152	4	13	4,5
56	RAss1	3	303	4	13	5
	RAsa2	3	303	4	13	5
57	Ridge Syncline	2	4/326	4,5	13	4,33
58*	Saddle Mountain Syncline	1	6/312	5	14	22,26
59*	Sims Syncline	2	14/318	5	14	24
60	SSna1	3	320	5	14	24
61	SSsa1	3	322	5	14	24
62	SSss2	3	325	5	14	24
63	SSsa3	3	328	5	14	24
64	SSss4	3	338	5	14	24
65*	Valentine Syncline	2	18/319	4	13	14
66*	Valentine Syncline (S.Z.)	2	35/307	4	13	11
67	VSwa1	3	340	4	13	14
68	VSws2	3	329	4	13	14
69*	VSwa3	3	27/332	4	13	14
70	VSwa4	3	316	4	13	14
71	VSws5	3	307	4	13	14
72*	VSwa6	3	35/320	4	13	14
73*	VSws7	3	34/318	4	13	14

(N.) = North (S.Z.) = Shear Zone
(S.) = South (W.) = West

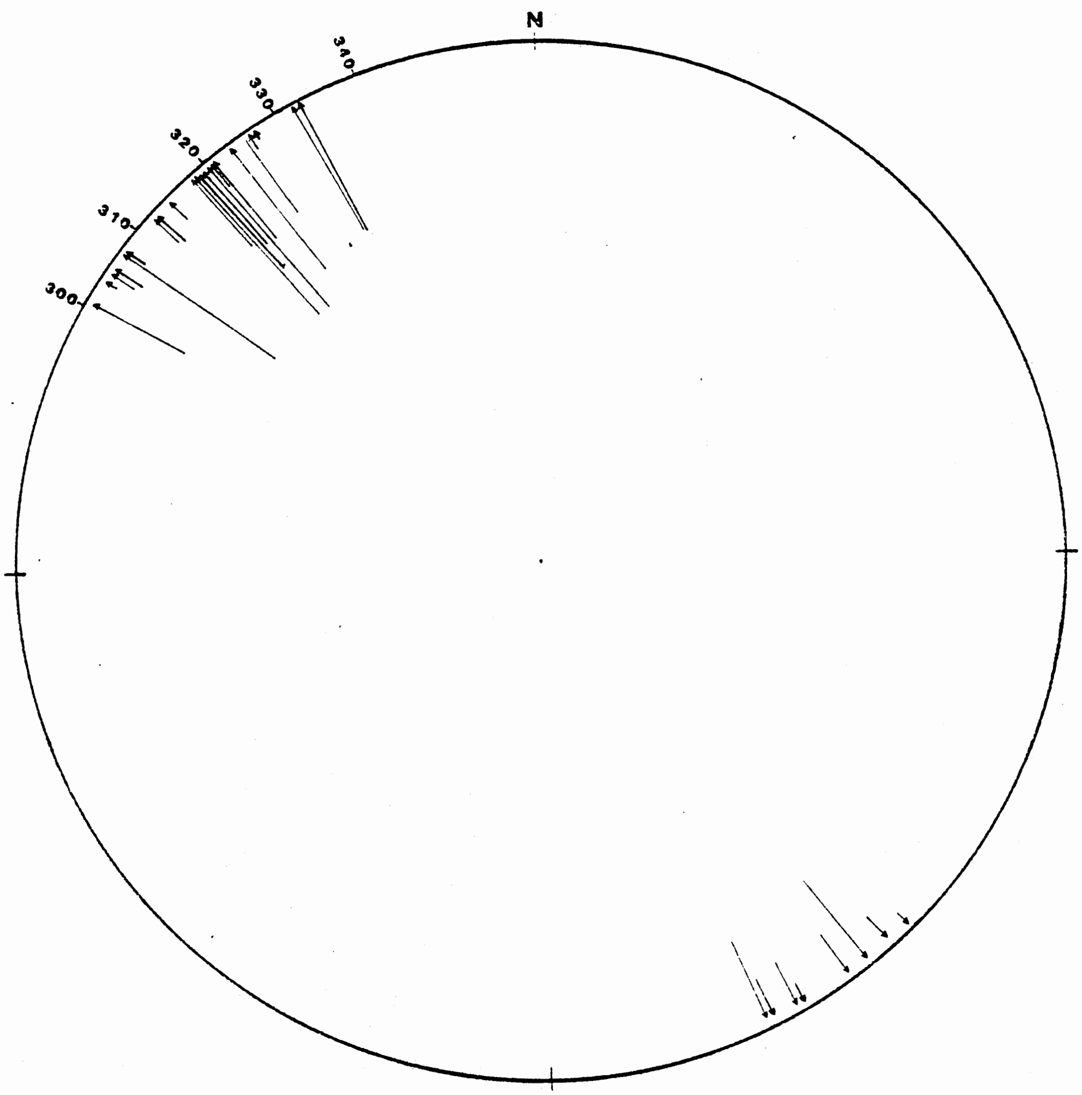


Figure 15. Stereogram of Plunge and Azimuth Values of Major Folds

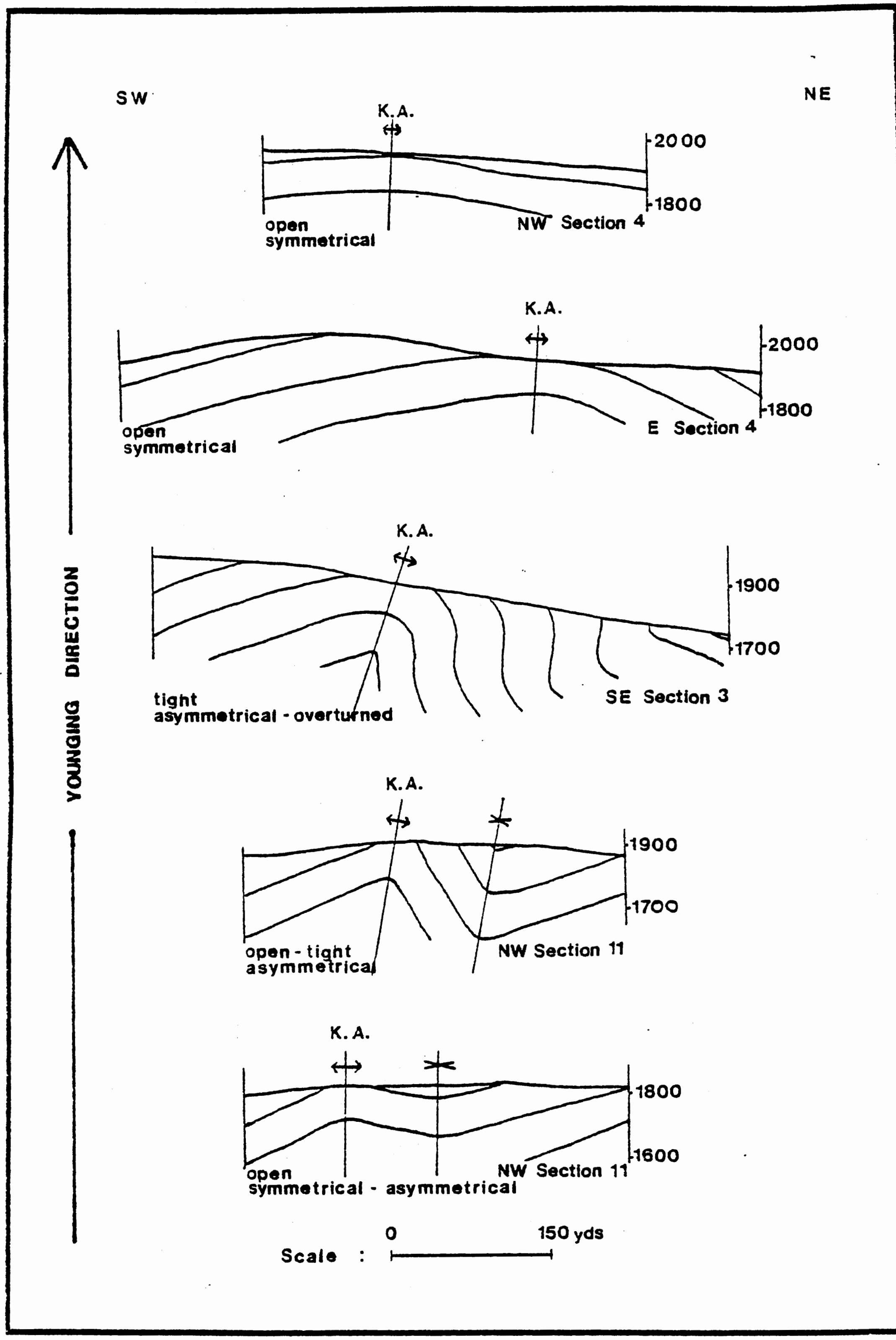


Figure 16. Variations in Fold Profile (using the Kimbell anticline [K.A.] as an example)

Figure 17. Generation of Kimbell Anticline From Paradox Anticline, northwest quarter of section 11, T4N, R13W

Figure 18. Saddle Mountain Syncline, northwest quarter of section 11, T5N, R14W

than 10 degrees. As a result of this, the fold hinge becomes increasingly difficult to locate accurately toward the northeast.

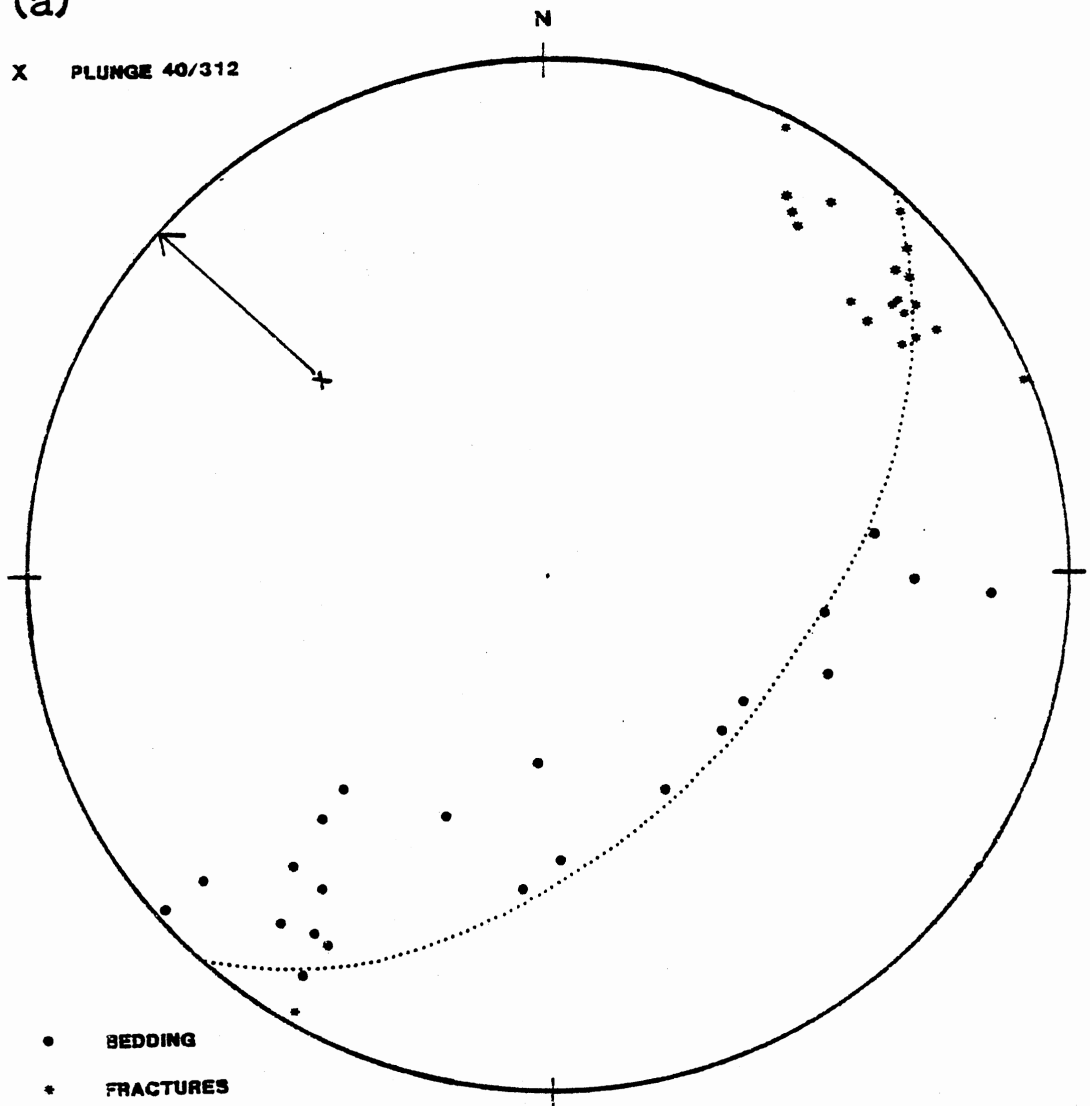
Donovan (1982) estimated the amplitude of the largest of the first order folds, in the Blue Creek Canyon area, to be up to 3000 feet. However, it is difficult to estimate the equivalent fold wavelength due to the en echelon nature of the folds and the presence of shear zones in many areas between what otherwise would have been considered complementary folds.

The only major fold which shows neither overturning nor a marked asymmetry is the Saddle Mountain syncline (Figure 18). This open, first order fold controls the outcrop pattern in the northwest of the area, west of sections 23 and 26, T5N, R14W.

The first and second order folds all exhibit a characteristic sense of vergence to the northeast, i.e., the anticlines all have a steeply dipping northeast limb and, consequently, the synclines have a steep southwest limb. Third order and minor folds verge toward higher order anticline hinges and away from syncline troughs. Variations of these patterns exist in sections 30, 31, and 32, T5N, R13W, where the beds have been contorted into anomalous fold styles. Such variations are attributable to the effects of a shear zone rather than the mechanism of folding which is prevalent throughout most of the area.

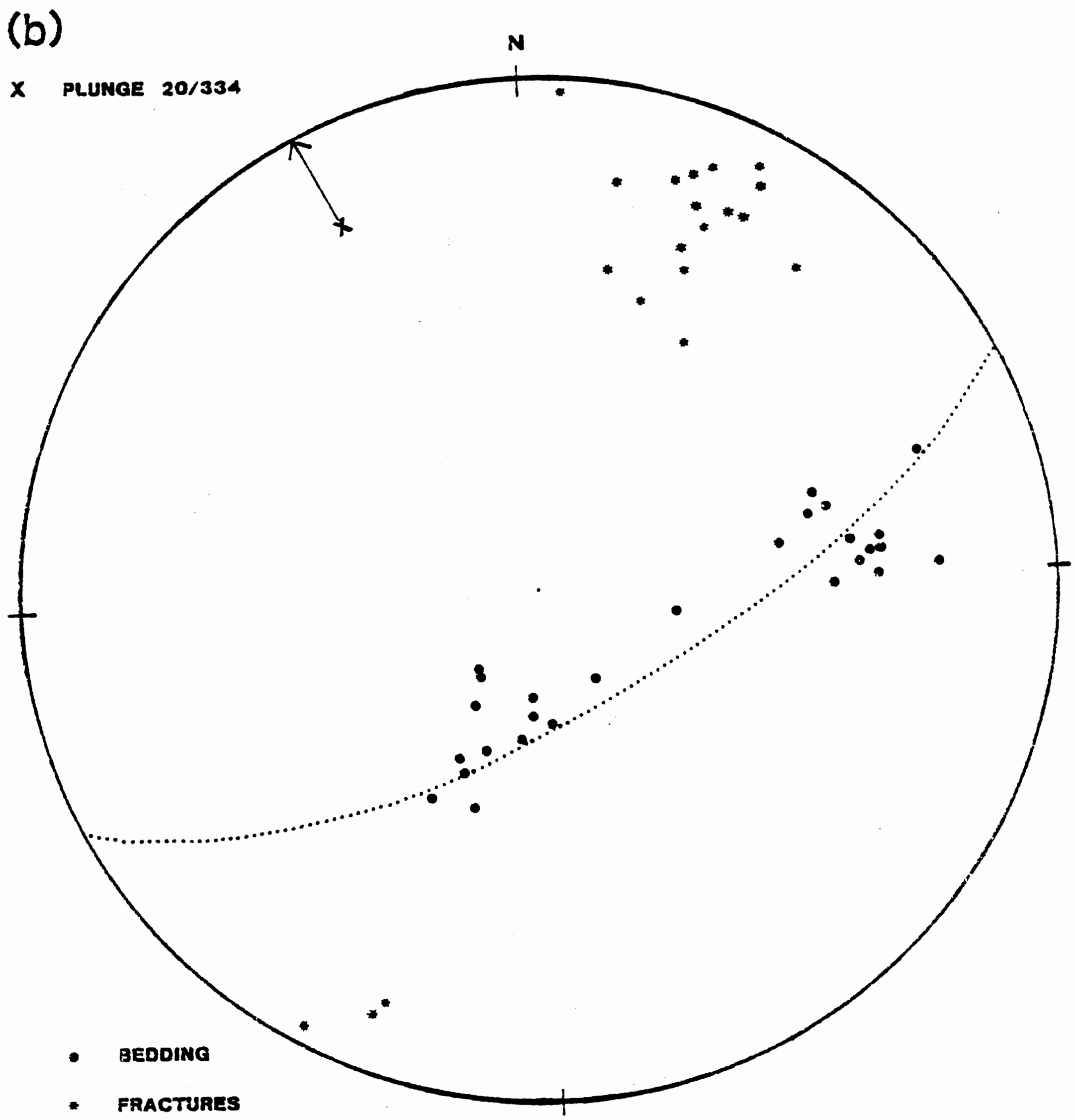
Some folds within the field area exhibit fracture patterns (Figure 19) in, or adjacent to, their fold hinges. These fractures are developed in single beds and do not extend laterally for more than 10 yards. Some of these fractures may represent axial planar fracture cleavage (Figures 19a, 19c), while others may be related to nearby fault complexes or localized stresses within the fold axes (Figure 19b)and are not axial planar.

(a)



(a) Stereogram of Fractures in Axis of Paradox Anticline

Figure 19. Fracture Patterns in the Blue Creek Canyon Area, Central Section 11, T4N, R13W



(b) Stereogram of Fractures Near Axis of Blue Creek Canyon Syncline

Figure 19 (Continued)

(c) Axial Planar Cleavage in Minor Fold Hinge

Figure 19 (Continued)

Faults

Within the field area, two major fault complexes are recognized; the Blue Creek Canyon fault complex (Figures 20, 21) in sections 2 and 11, T4N, R13W , and the Bullrun fault complex in section 25, T5N, R14W.

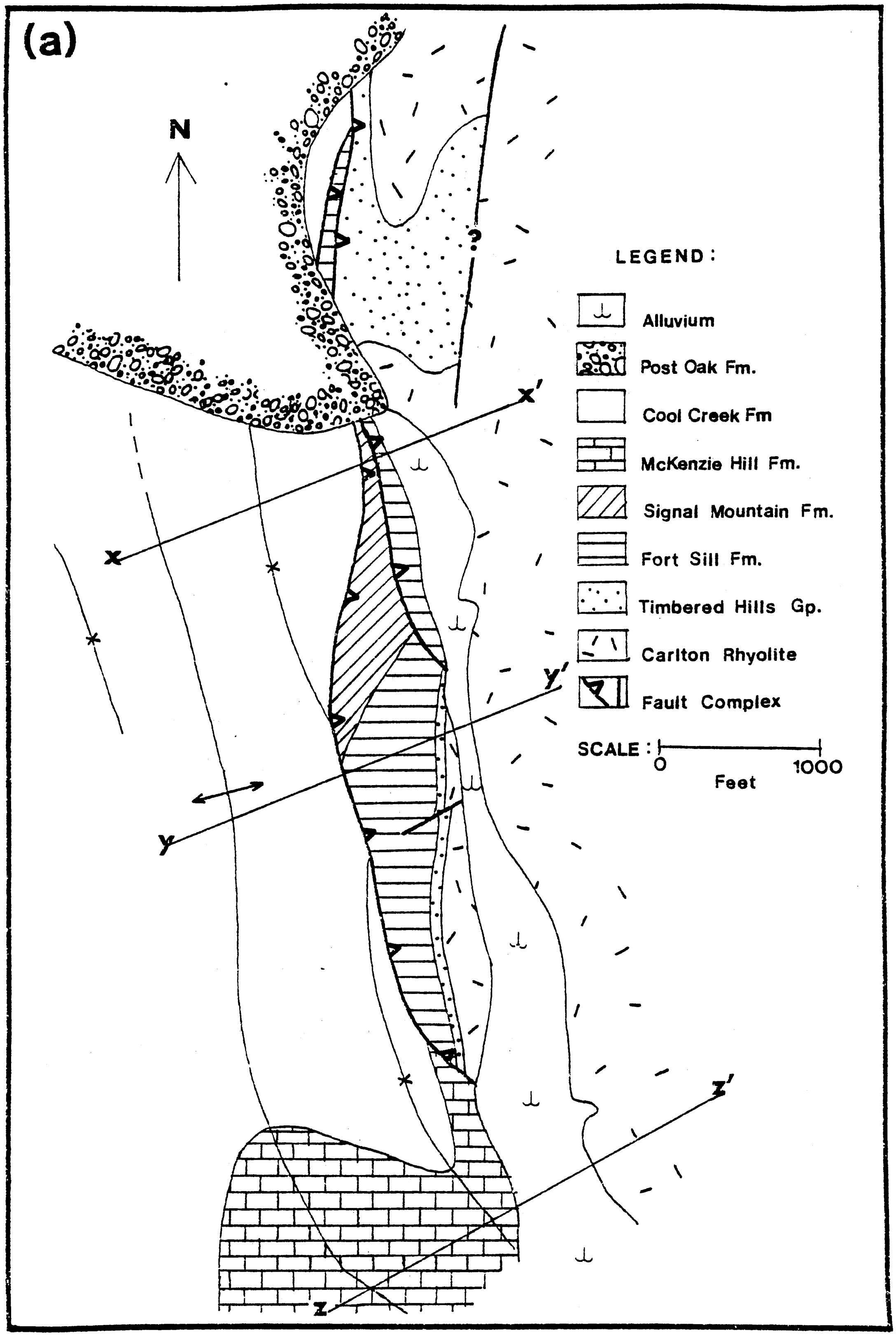
The major fault within the Blue Creek Canyon complex brings the Carlton Rhyolite, Timbered Hills Group, Fort Sill, and Signal Mountain Formation against Ordovician rocks to the west. The fault plane dips steeply east at 45-90 degrees (Donovan, 1982), requiring the fault to be high angle reverse in style. The fault trends approximately northwest-southeast and was estimated by Donovan (1982) to have a stratigraphic throw of 1800-2400 feet. He recorded the fault plane dip as increasing, and the stratigraphic throw as decreasing northward (Figure 21).

The fault cuts the trace of the Blue Creek Canyon syncline in central section 11, T4N, R13W, and adjacent to the fault plane, the eastern limb of the fold is overturned.

In southern half of section 2, T4N, R13W, another member of the fault complex of similar style converges with the principal Blue Creek Canyon fault. To the north they are both overlain by Permian Post Oak conglomerate, with the fault trace exposed again in a small inlier in central section 2. To the south, the trace disappears beneath alluvium in section 11 (Figure 21a).

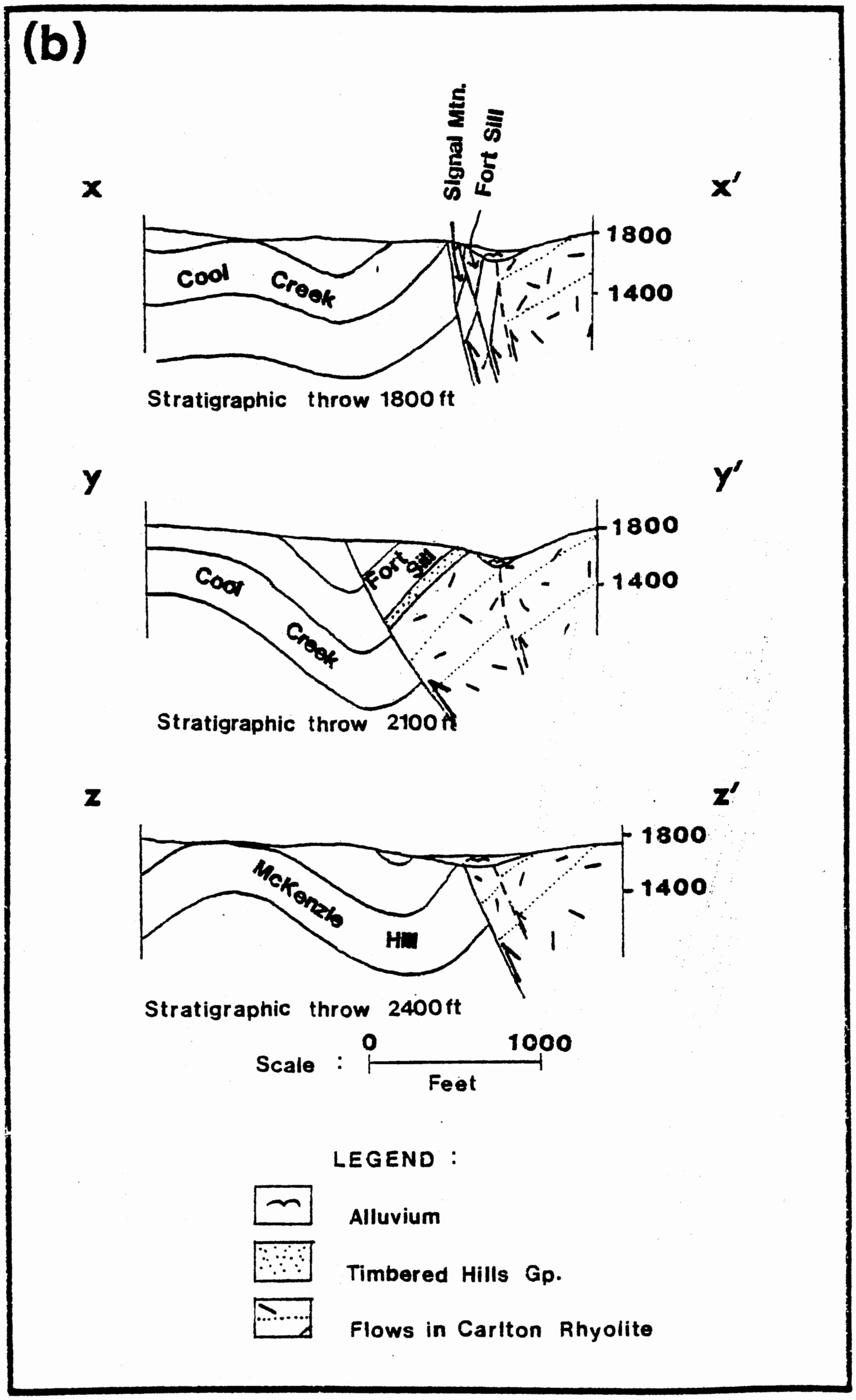
A minor member of the Blue Creek Canyon fault complex cuts the northern trace of the Blue Creek Canyon syncline in the northern half of Section 11 (Figure 22). The fault appears to be a bedding plane slip feature; the offset of the fold axial plane (which dips to the east-

Figure 20. Blue Creek Canyon Fault (viewed from the southern half of section 11, T4N, R13W)



(a) Geologic map after Donovan, 1982, Figure 154)

Figure 21. Geology of Blue Creek Canyon Area



(b) Geologic Cross-sections (after Donovan, 1982, Figure 155). See Figure 21a for Lines of Sections

Figure 21 (Continued)

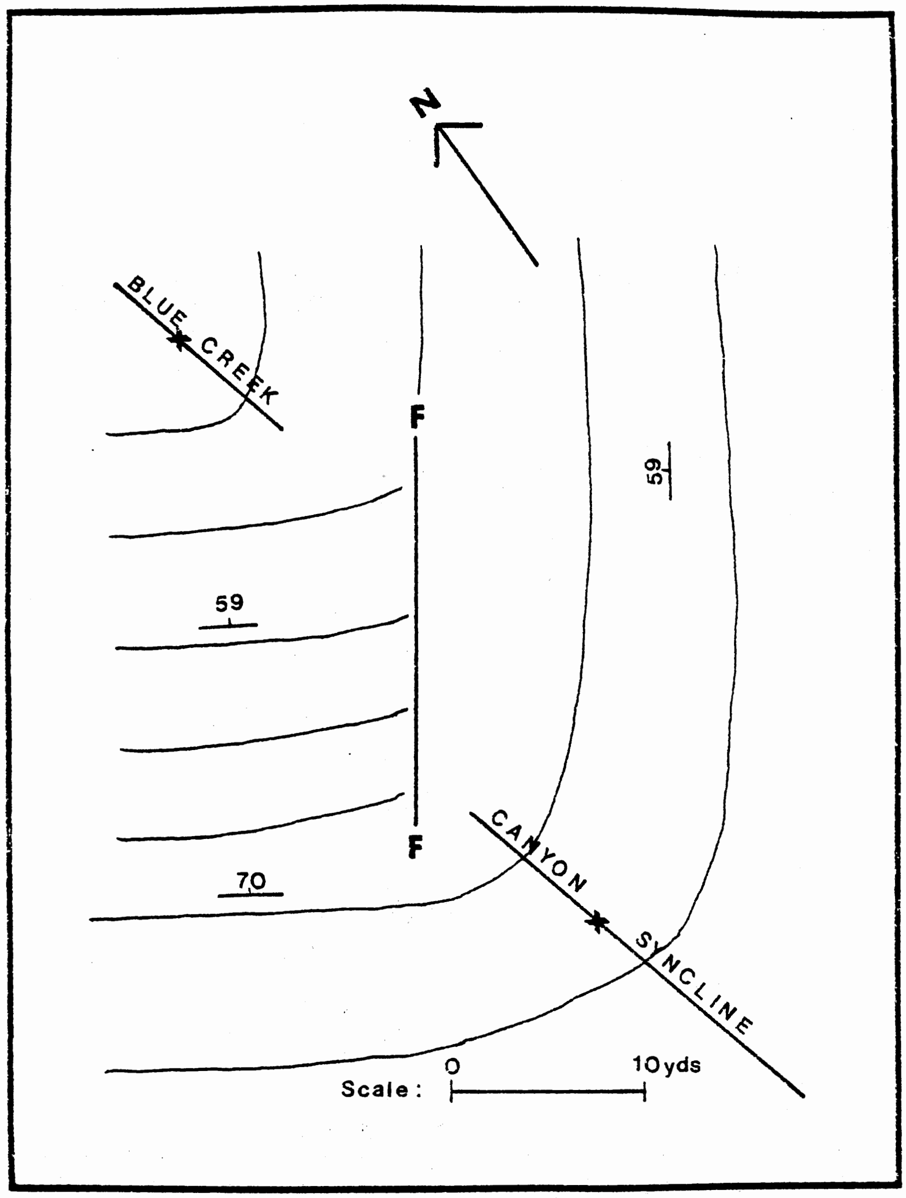


Figure 22. Minor Member of Blue Creek Canyon Fault Complex (offsetting the axis of the Blue Creek Canyon syncline, northern half of section 11, T14N, R13W)

southeast suggests it is a high angle reverse fault.

The Bullrun fault complex is so named because of its location on the northeastern limb of the Bullrun syncline. The faults cannot be traced for any significant distance beyond this fold's axis. The sense of movement on the faults was high angle reverse with a transport direction toward the northeast. The faults are conspicuous because they repeated the Cool Creek-McKenzie Hill Formation boundary, represented by a sequence of oolitic and sandy beds. The actual throw on the faults is difficult to gauge, due to the lack of marker beds within the McKenzie-Hill Formation.

Where the faults are seen in cross-section view in valley sides, they have a 40-50 degree dip to the southeast (Figure 23). They often truncate synclinal autliers of the Cool Creek Formation, for example, in the southeast quarter of section 25, T5N, R14W (Figure 24). These synclines may exhibit axial planar fracture cleavage. The faults were terminated either where the beds became reorientated (as they changed strike into fold hinges) or in fold pairs aligned parallel to the fault trend (Figure 25). In addition, associated minor folds are found in both the hanging wall and footwall blocks.

Elsewhere in the area, faults are not common. Where they do occur, they are minor features with stratigraphic throws of less than 20 feet. They are normal faults aligned approximately perpendicular to the fold axes and may be on either limb of the fold.

Shear Zones

Two intense zones of shearing are recognized in the field area. The Stumbling Bear shear zone extends north from section 14, T4N, R13W

Figure 23. Reverse Faults on the Northeast Limb of the Bullrun Syncline (F faults)

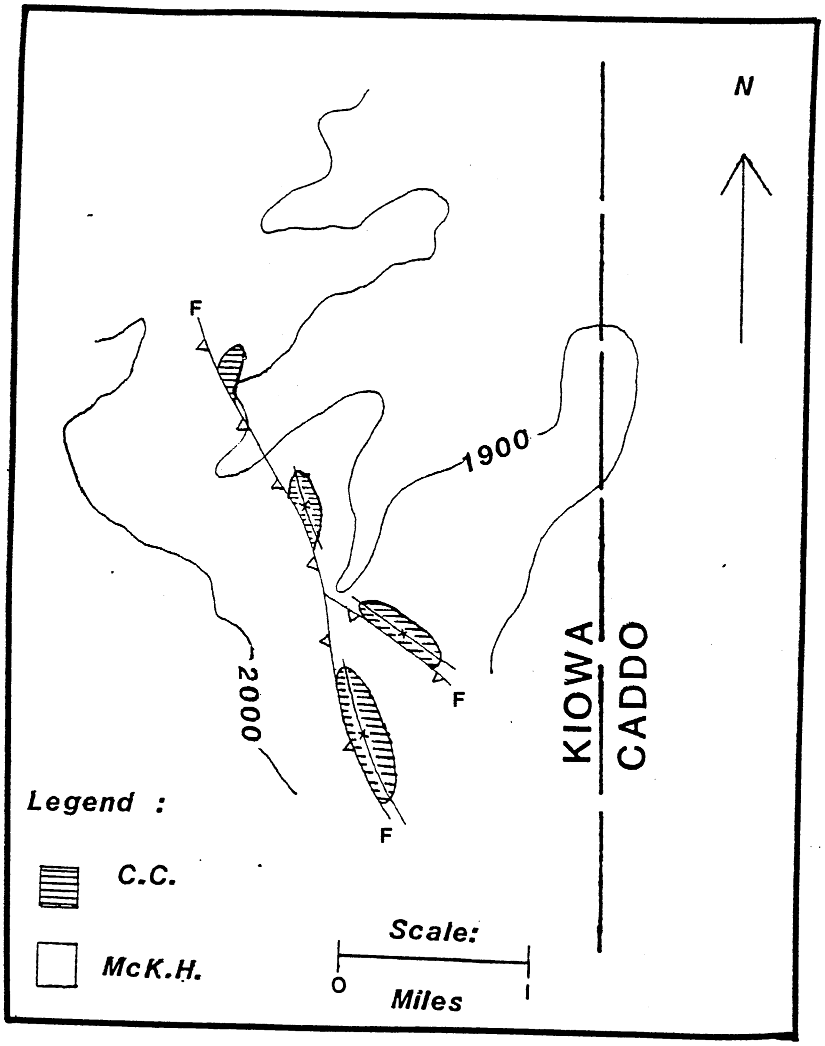


Figure 24. Reverse Faults Repeating the Cool Creek-McKenzie Hill Formation Contact (southwest quarter section 25, T5N, R14W; F, faults, McK. H., McKenzie-Hill Formation; C. C., Cool Creek Formation)

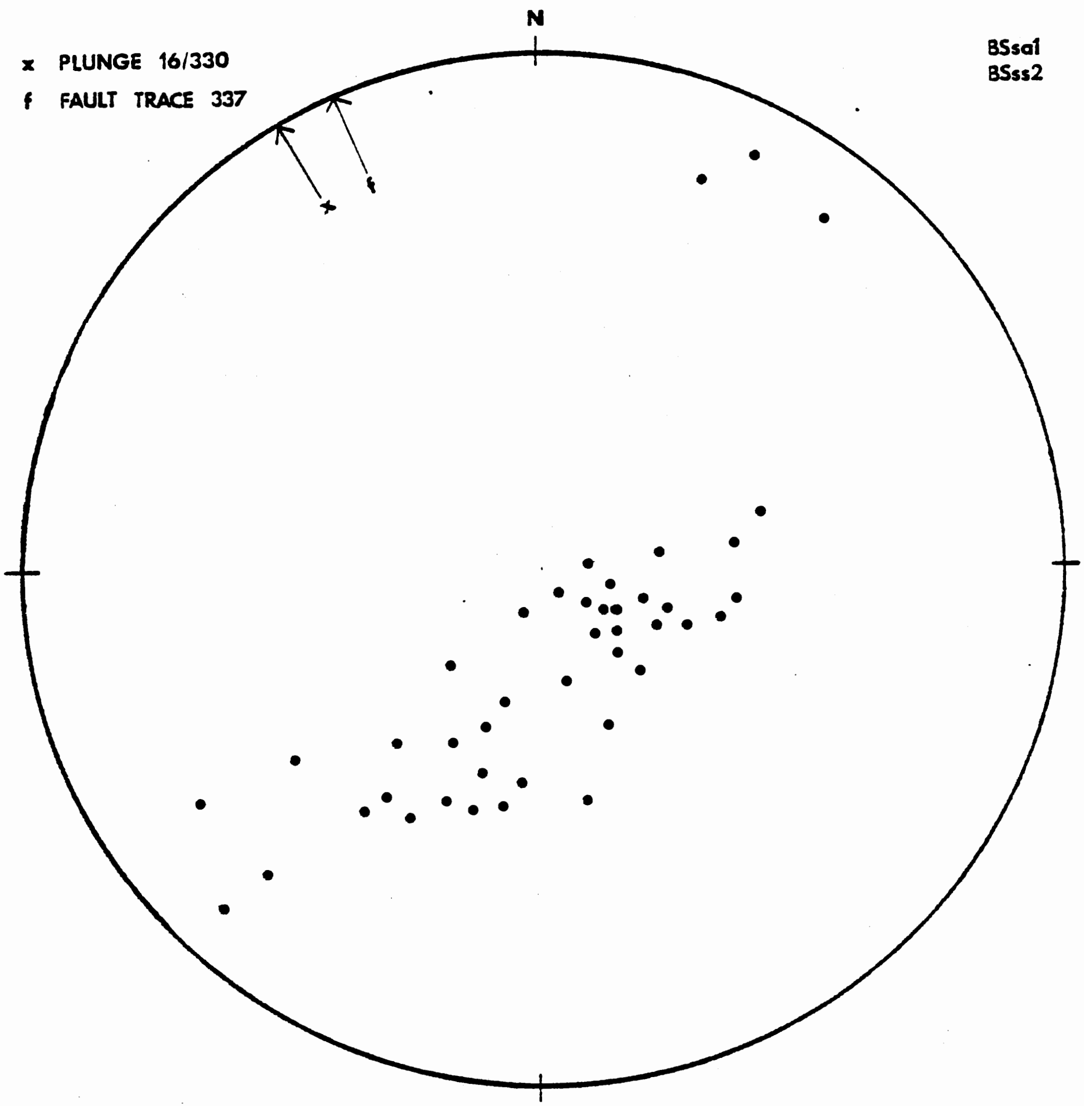


Figure 25. Stereogram of a Fold Pair at the Termination of a Fault in the Bullrun Fault Complex (southeast quarter section 25, T5N, R14W)

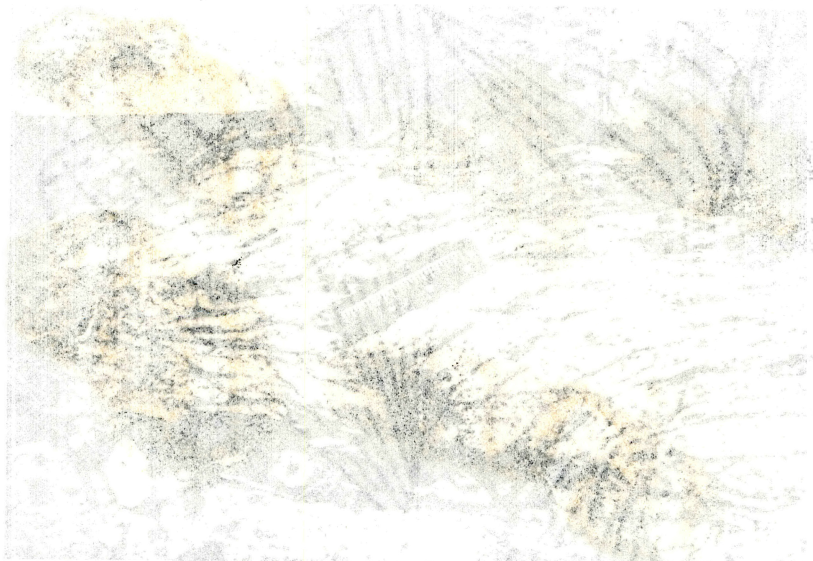
section 11, where it lessens in intensity and gradually assumes a northwest trend which can be traced to section 30, T5N, R13W. The Dietrich shear zone trends northwest from northeast quarter section 25, T5N, R14W, into section 24, where it is less well developed and, as a result, less easily recognized.

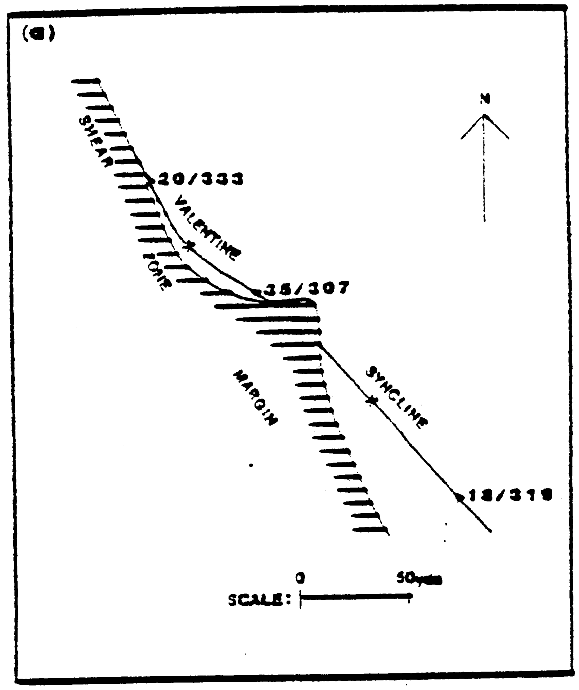
Within both shear zones, bedding has been variably deformed. With intense shearing, bedding is obliterated and a strong shear fabric is developed (Figure 26). The most extreme shearing is observable in the Stumbling Bear shear zone in southwest quarter section 11. Here, bedding has no continuity except on the zone margins. Within the zone it is impossible to trace individual beds for more than a few feet. Individual folds, such as the Valentine syncline, can be traced into the shear zone margin where their axes have been reorintated and their plunges steepened (Figure 27).

To the north, the shear fabric within the Stumbling Bear shear zone becomes less intense. Individual segments of bedding become more obvious but they have much steeper dips and different orientations than the adjacent unaffected outcrops. In northeast quarter section 10, T4N, R13W, where the shear zone becomes orientated northwest, the zone is approximately 200 yards wide and the dip of the beds within it become steepened by up to 50 degrees. Minor folds are common and have led to local overturning of beds. These minor folds may have a sense of vergence to the southwest, which is opposite to the vergence of the major folds, as well as to the northeast. The minor folds can rarely be traced for more than 30 yards, and their axes are sub-parallel to the trend of the shear zone boundary (300-305).

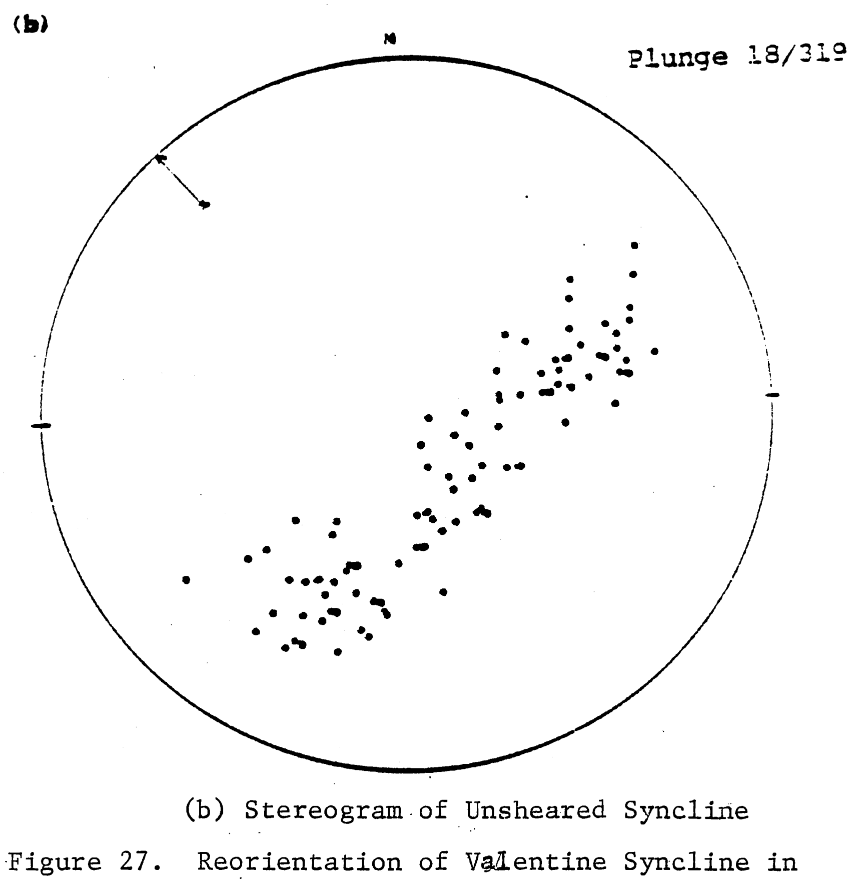
In sections 5, T4N, R13W and 32, T5N, R13W, the shear zone becomes

Figure 26. Strongly Developed Shear Fabric in Stumbling Bear Shear Zone (note sigmoids produced by left-lateral shearing, west half, section 11, T4N, R13W)



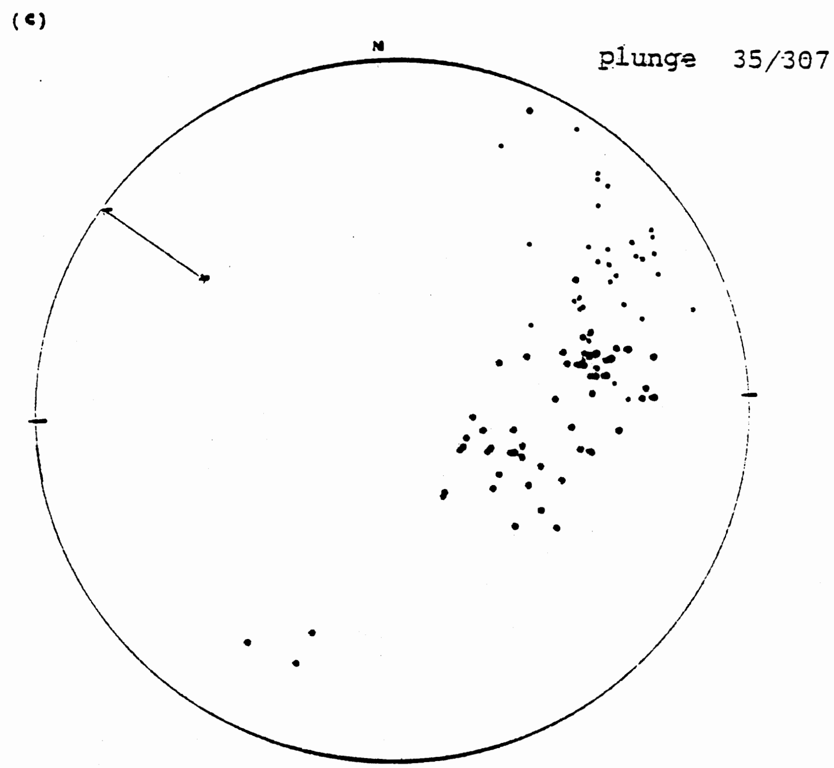


(a) Geologic Sketch Map

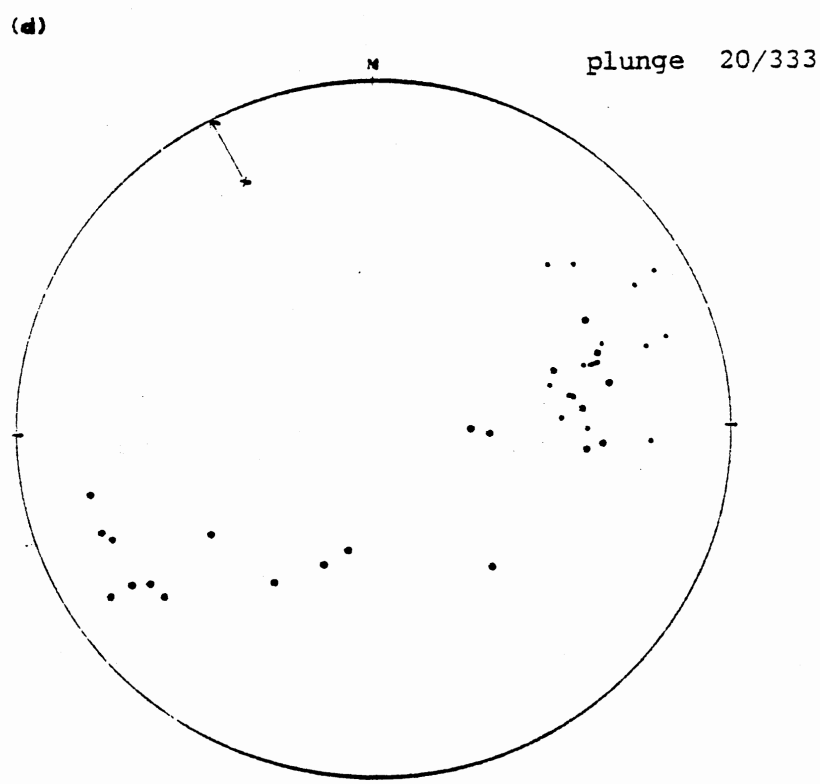


(b) Stereogram of Unsheared Syncline

Figure 27. Reorientation of Valentine Syncline in Margin of the Stumbling Bear Shear Zone (southwest quarter section 11, T4N, R13W)



(c) Stereogram of Sheared Syncline



(d) Stereogram of Sheared Syncline

Figure 27 (Continued)

more difficult to define, as the rocks are dolomitized and therefore have weathered more easily, resulting in poor exposures. To the northwest, the Stumbling Bear shear zone is bordered on the southwest by the area of anomalous folds (sections 30, 31 and 32, T5N, R13W, mentioned above.

As well as affecting the attitude of the beds, the shear zones may also cause unusual stratigraphic relationships. For example, in Blue Creek Canyon, as a consequence of the relatively steeply plunging folds, the succession adjacent to the shear zone dips west and youngs to both the west and north (Plate 1). The shear zone is therefore bordered on its eastern side by Ordovician formations. To the west of the shear zone, the Cambrian Signal Mountain Formation is locally present, also with a westerly dip. The juxtaposition of Ordovician against Cambrian formations requires the removal of over 2000 feet of stratigraphic section within the intervening shear zone. To the north and northwest, the stratigraphic throw remains just as significant with the Kindblade and McKenzie-Hill Formations adjacent to one another.

The southeastern end of the Dietrich shear zone is located within section 25, T5N, R14W, and is aligned with the Stumbling Bear shear zone. At its southeastern end, the Dietrich shear zone is less than 50 yards wide. To the northwest, bedding to the southwest of the shear zone is less discernible where the shear zone obliquely truncates some second order folds. The shearing within the zone is more confined to the southeast and places Cool Creek Formation of the syncline MAns1 against the Kindblade Formation of the adjacent Dietrich anticline.

The Dietrich shear zone trends obliquely (316) to the axes of the folds (330), and where a fold approaches the zone, it becomes sheared. For example, the gently dipping southeast limb of the Dietrich anticline is steepened considerably into the shear zone. The dips increase from

46 to 80 degrees toward the shear zone, and the plunge steepens to 17/156. To the northwest, the effect of the Dietrich shear zone lessens. Bedding is contorted into minor folds or is preserved within phacoidal blocks bounded by small scale shear zones less than 20 feet across. In central section 24, T5N, R14W, the Cool Creek-McKenzie Hill Formations are offset in a left-lateral sense by two sub-parallel minor shear zones. Between this point and the Permian cover to the northwest, the effects of the shear zone are once again obscured by dolomitization.

Structural Domains

Within the field area, four distinct structural domains can be recognized (Figure 28) by the character and distribution of the structures they contain. An understanding of the arrangement of these domains, and their relationships to regional structures will give an insight into the structural evolution of the Slick Hills.

The domains are principally delineated on the orientation, plunge, and intensity of their folds. When the plunge and azimuth readings of the major folds are plotted on a stereogram (Figure 15), the values can be seen to fall into three principal clusters. The two clusters in the northwest quadrant are centered around the 305 and 320 azimuths. The 305 cluster is, with few exceptions, made up of folds located within what shall be termed the Kimbell domain. The 320 cluster is made up of folds within either the Dietrich or Blue Creek Canyon domains. The folds of the latter can be differentiated from those of the former by their steeper plunges. The Woods domain is represented only by the Saddle Mountain syncline, which plots between the 305 and 320 clusters.

The third cluster of points, recording folds plunging to the southeast, is a consequence of the fact that en echelon folds are cylindrical and hence may be doubly plunging. The points in the southeast quadrant represent the southeast closure of such folds that also close to the northwest and are, therefore, also represented by points in the northwest quadrant (hence, the same fold may appear more than once in Table I). However, it is noteworthy that in the Blue Creek Canyon domain, all folds plunge to the north-northwest.

Blue Creek Canyon Domain

The Blue Creek Canyon structural domain is delineated to the east and west by the Blue Creek Canyon fault and the Stumbling Bear shear zone, respectively, and to the north and south by the Post Oak Formation (Figure 28).

The domain is marked by the presence of 330 trending folds (Figure 29; Table I), which are slightly oblique to the aforementioned fault and shear zone. The folds plunge north-northwest at angles up to 30 degrees, exposing a greater amount of stratigraphic section than the more gently plunging folds found elsewhere in the field area. In section 14, T4N, R13W, the southern termination of the shear zone occurs in a complex area where the shear, the Blue Creek Canyon fault, the Oliver and Valentine synclines and the Meers fault converge. In section 11, to the north, beds adjacent to the Blue Creek Canyon fault plane are overturned and some fold hinges exhibit cleavage.

Cross-sections a-a' through e-e' (Figure 30; Plate 1) demonstrate the relationships of the principal structures within this domain.

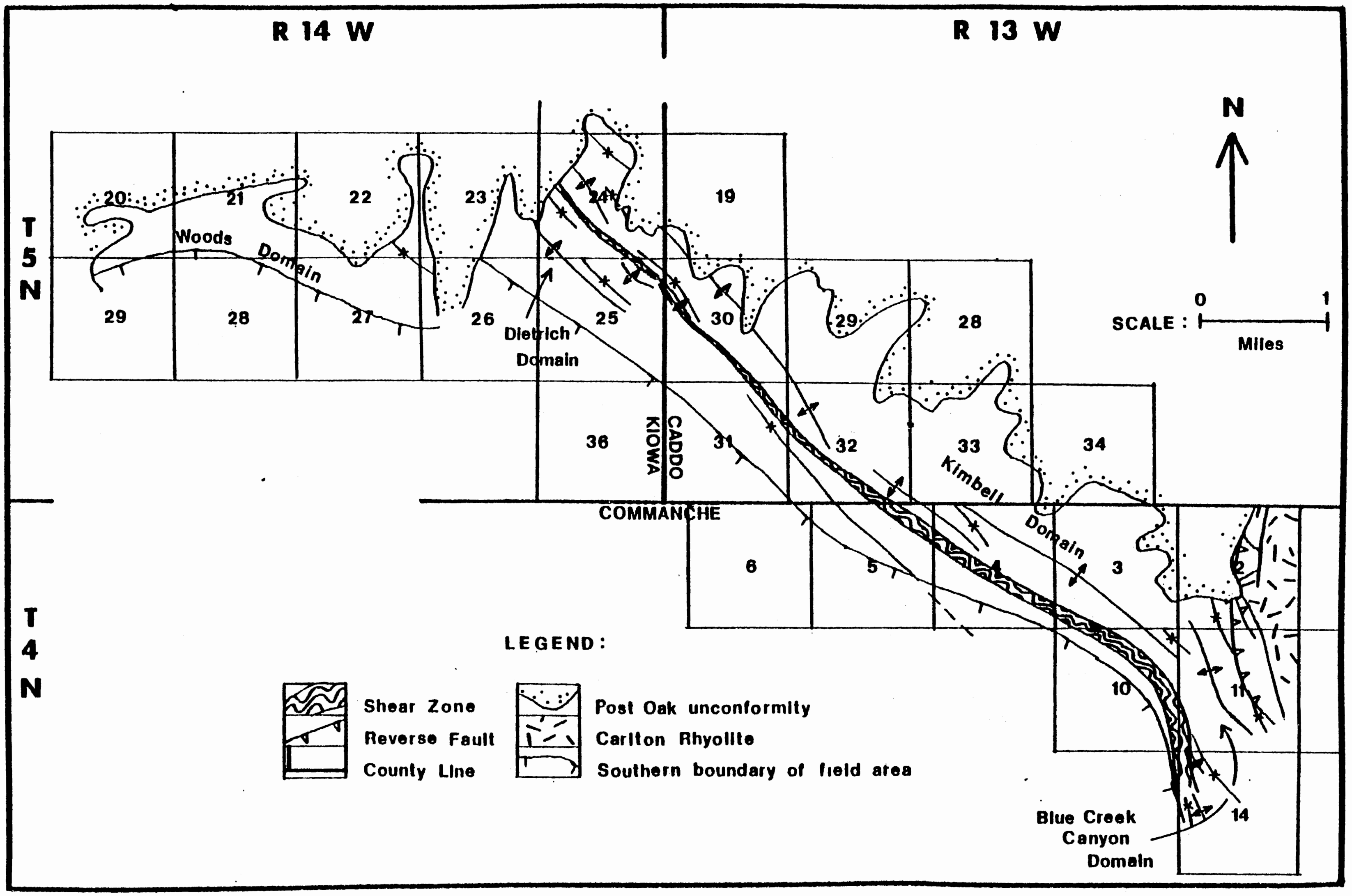


Figure 28. Geologic Sketchmap Showing Location of Structural Domains Within the Field Area

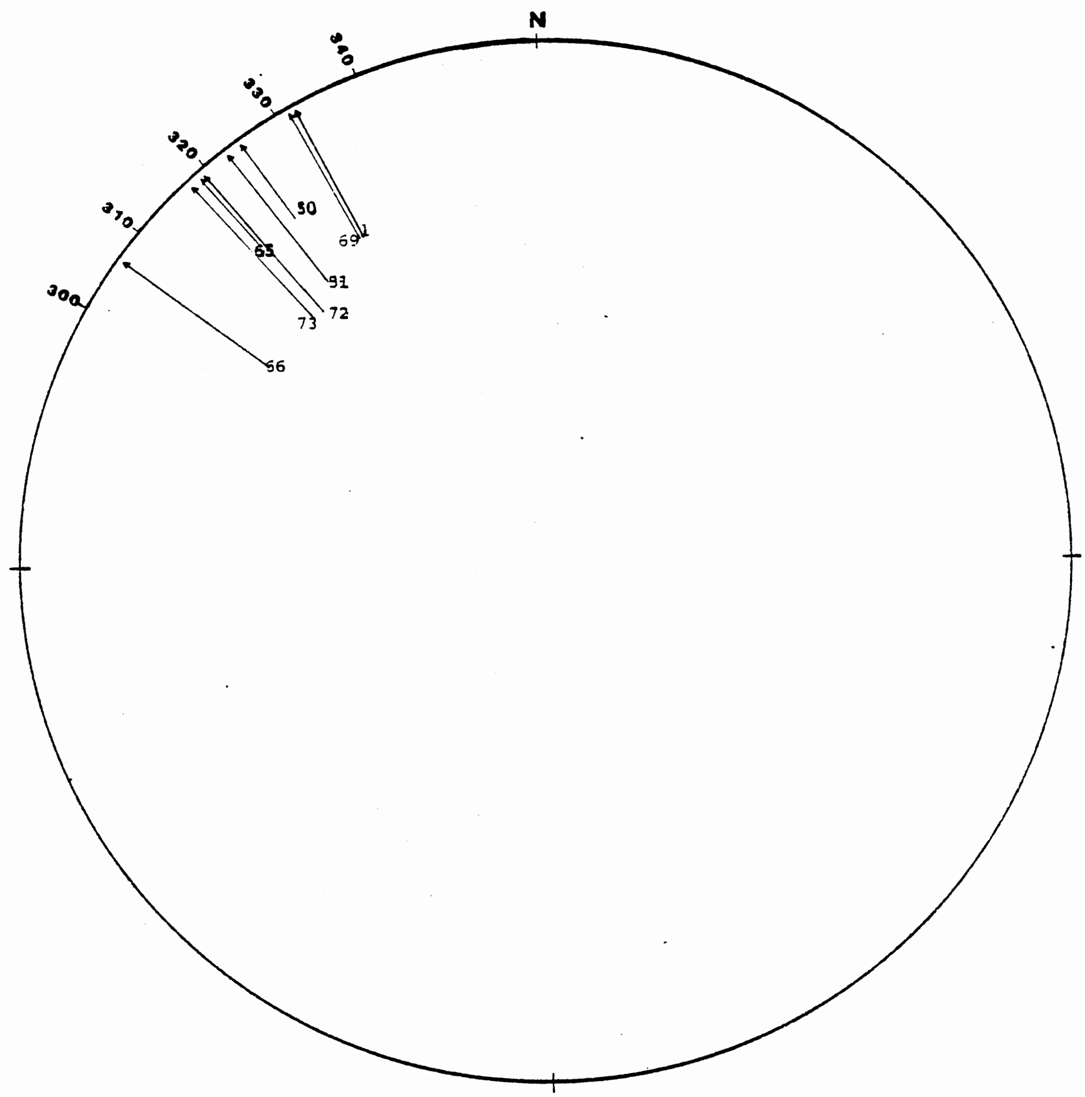


Figure 29. Stereogram of Plunge and Azimuth Values of Folds in the Blue Creek Canyon Domain

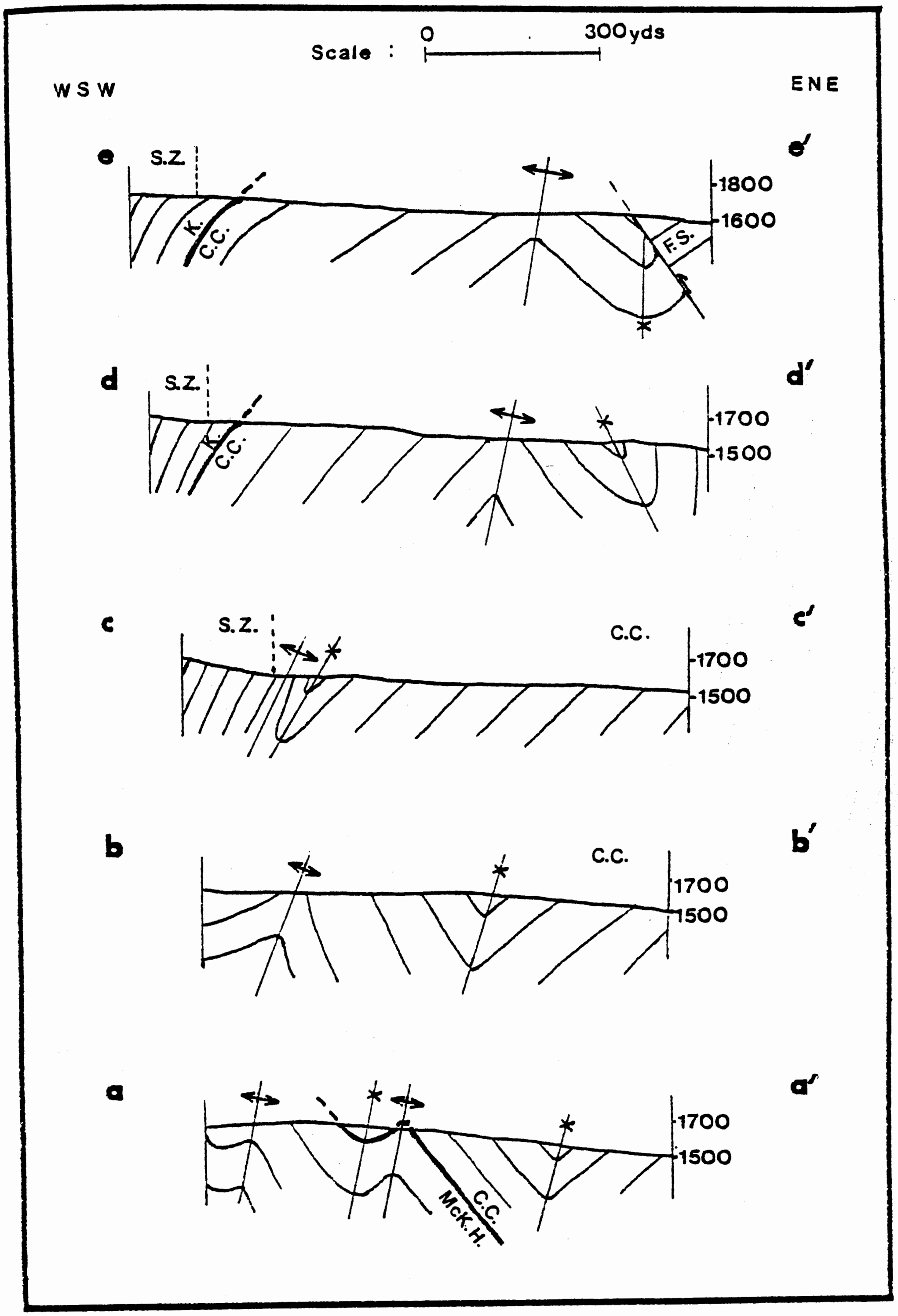


Figure 30. Geologic Sections Across the Blue Creek Canyon Domain (McK. H., McKenzie Hill Fm.; C. C., Cool Creek Fm.; K., Kindblade Fm.; S. Z., shear zone)

Kimbell Domain

The Kimbell structural domain extends from the northeastern boundary of the Blue Creek Canyon domain northeast to the Kiowa-Caddo County line. This is the largest domain, and its main feature is a series of en echelon, first order folds trending ca.305 (Figure 28; Table I; Figure 31). To the northeast it is bounded by the Post Oak Formation unconformity, while to the southwest the Stumbling Bear shear zone and the Oliver syncline represent the boundary.

Cross-sections f-f' through j-j' (Figure 32; Plate 1) demonstrate the domain's structural relationships.

Dietrich Domain

The Dietrich structual domain is bounded to the east by the Kiowa-Caddo County line; to the north and west by the Permian unconformity; to the south by the Tully disturbed zone from within section 25, T5N, R14W, into section 26 (Figure 28). Within the confines of these boundaries there is the highest density of folds in the Slick Hills, in addition to the Dietrich shear zone which is aligned with the Stumbling Bear shear zone to the southeast and the Bullrun fault complex.

The plunge and azimuth of the folds more closely resemble those of the Blue Creek Canyon domain (Figure 33, Table I) than the adjacent Kimbel domain. Some of the folds are aligned en echelon.

Cross-sections k-k' through o-o' (Figure 34; Plate 1) demonstrate the structural relationships within the Dietrich domain.

Woods Domain

The Woods structural domain extends west from its boundary with the

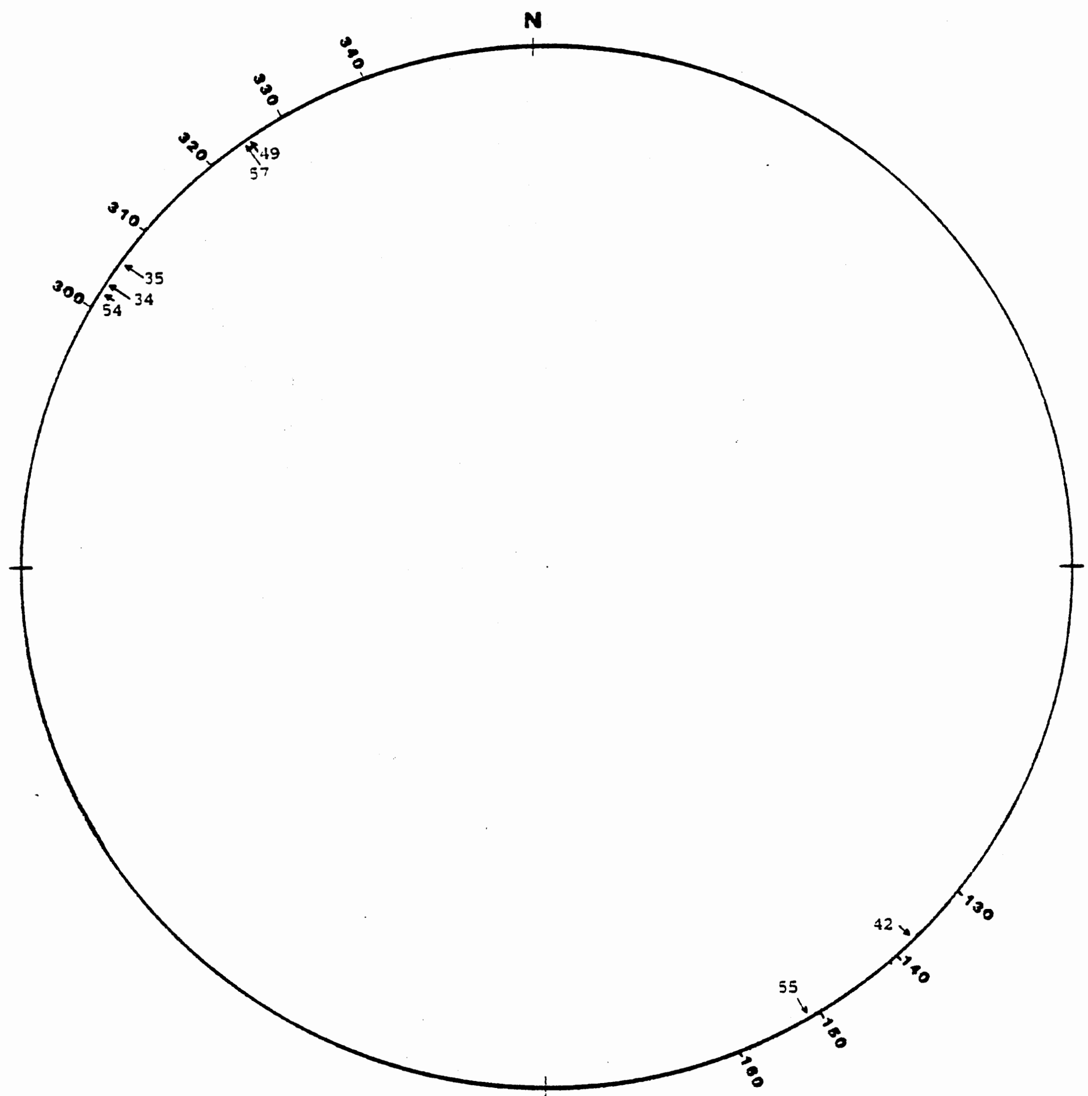


Figure 31. Stereogram of Plunge and Azimuth Values of Folds in the Kimbell Domain

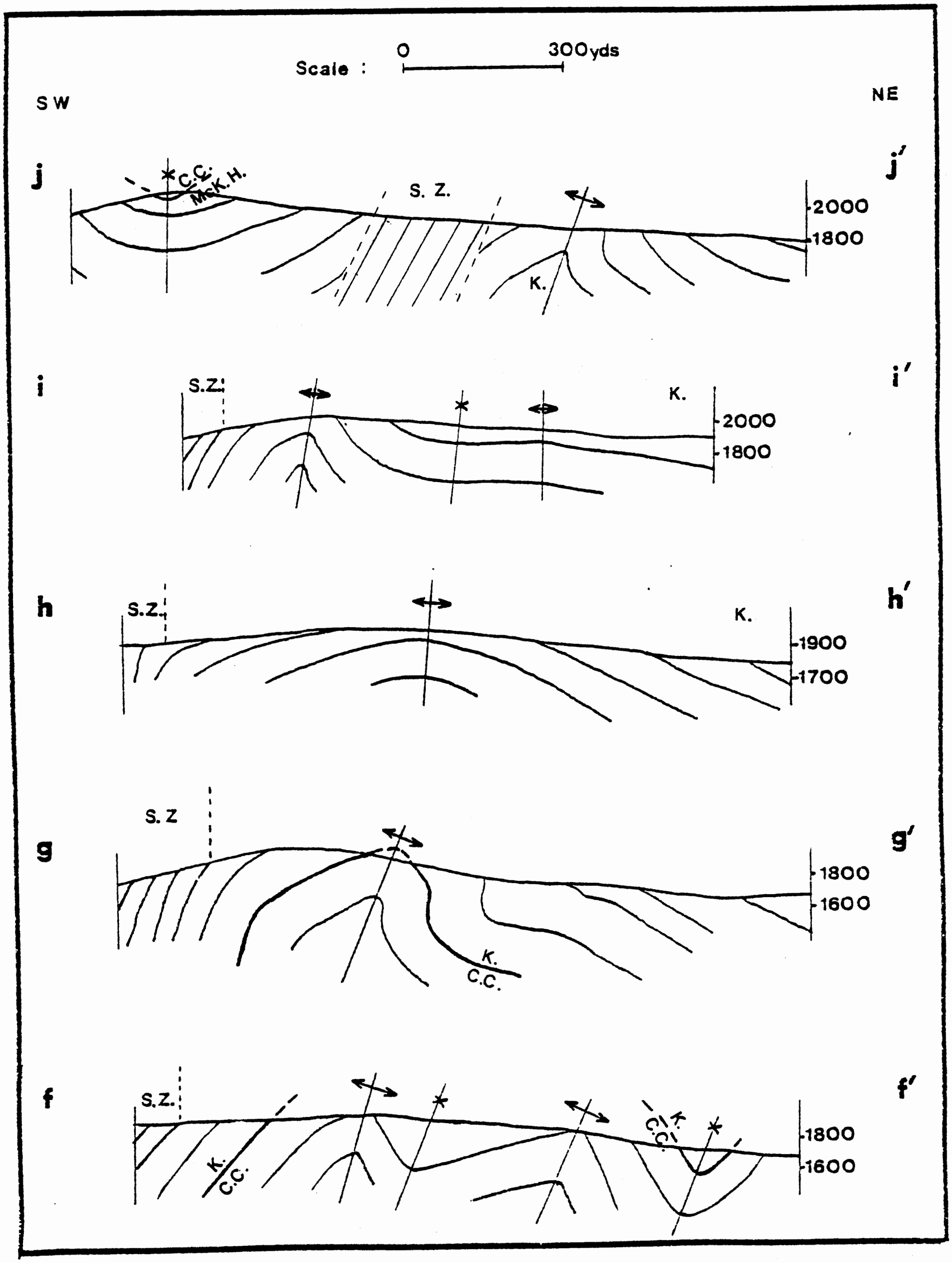


Figure 32. Geologic Sections Across the Kimbell Domain (McK. H., McKenzie Hill Fm.; C. C., Cool Creek Fm.; S. Z., shear zone; K., Kindblade Fm.)

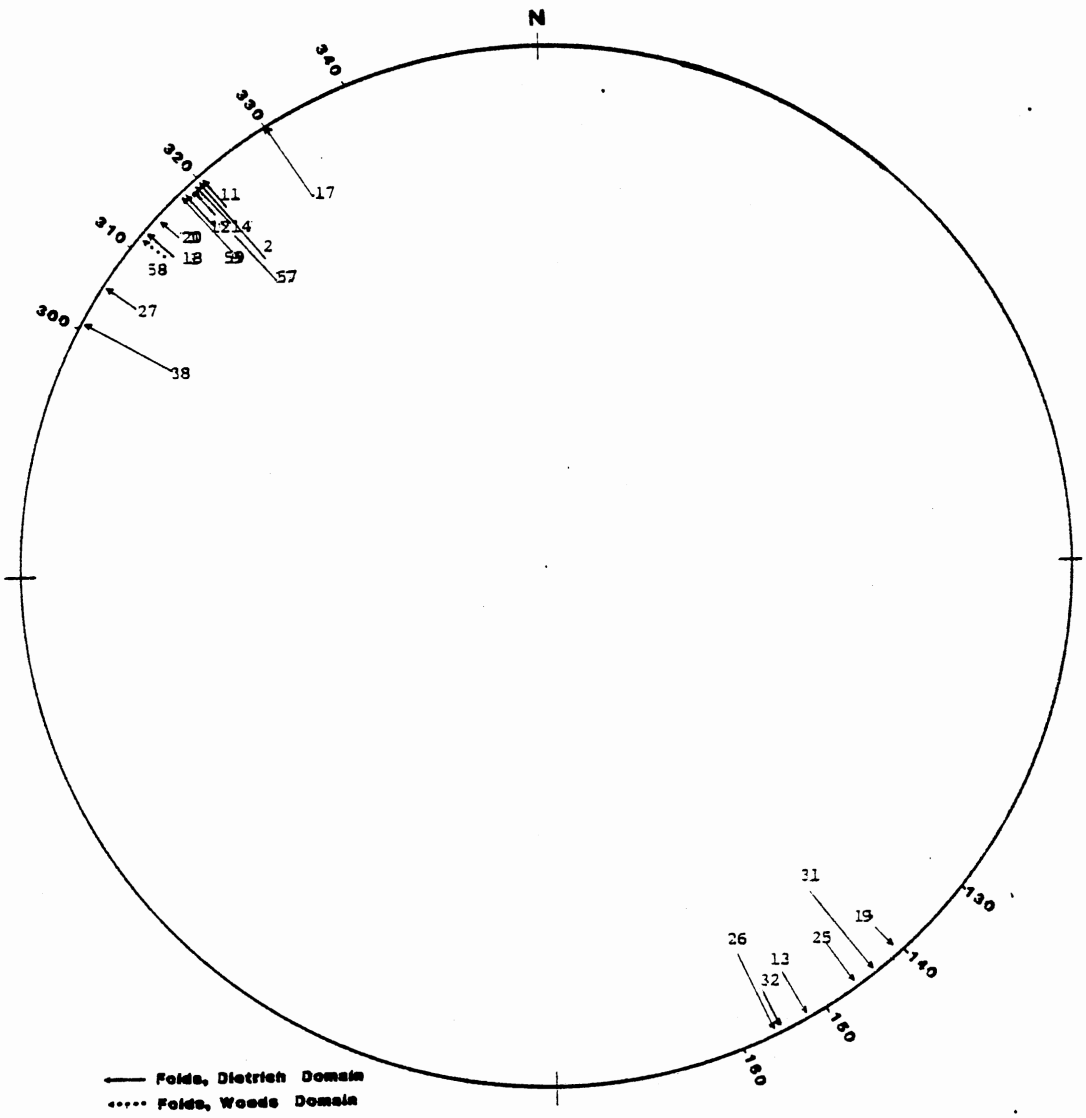


Figure 33. Stereogram of Plunge and Azimuth Values of Folds in the Dietrich and Woods Domains

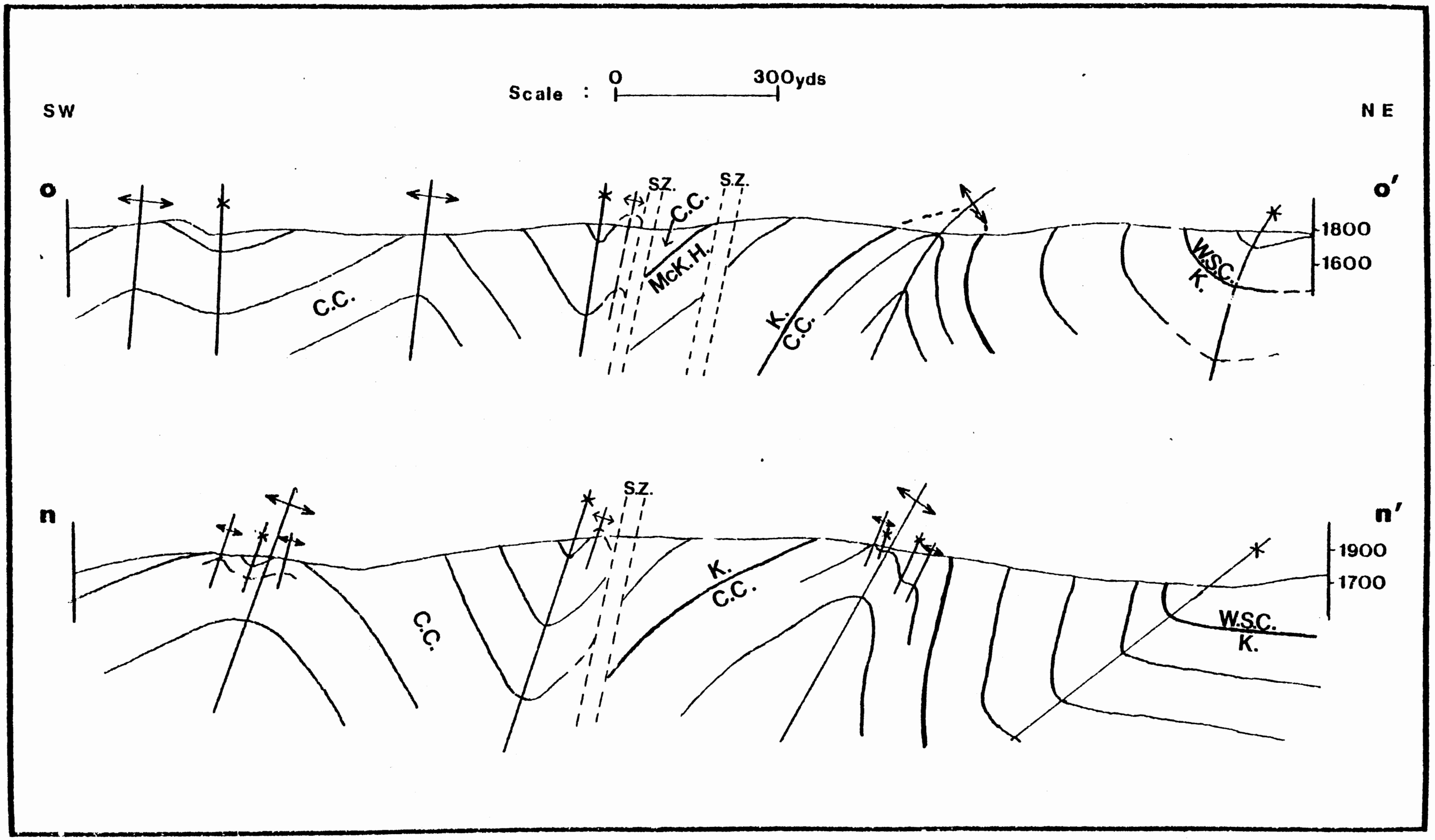
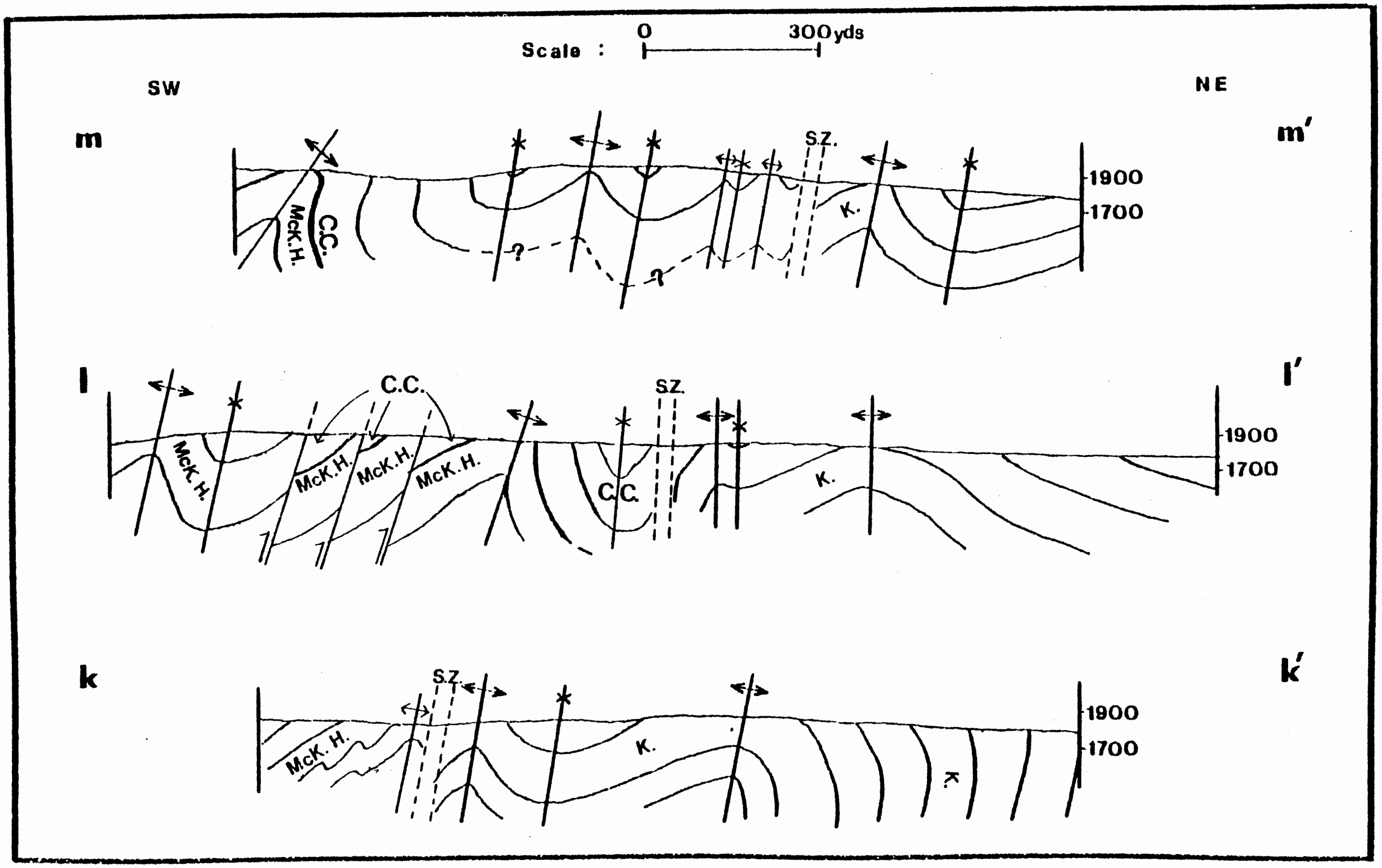


Figure 34. Geologic Sections Across the Dietrich Domain
(see continuation for explantion of symbols)



McK. H.; McKenzie Hill Fm.; C. C., Cool Creek Fm.; K., Kindblade Fm.; W.S.C., West Spring Creek Fm.; S. Z., Shear Zone

Figure 34 (Continued)

Dietrich domain in sections 23 and 26 to the western edge of the field area, marked by the Post Oak Formation unconformity, in section 20, T5N, R14W. Its southern boundary in the prominent 2000' ridge which trends east-northeast in section 27, T5N, R14W, and its norther boundary is the Post Oak Fromation (Figure 28).

Except for the first order Saddle Mountain syncline (Figure 33; Table I), this domain is characterized by homoclinal beds. The major syncline has a trend which falls between the trend of folds in the Kimbell and Dietrich domains.

Cross-sections p-p' and q-q' (Figure 35; Plate 1) demonstrate the structural relationship within the Woods domain.

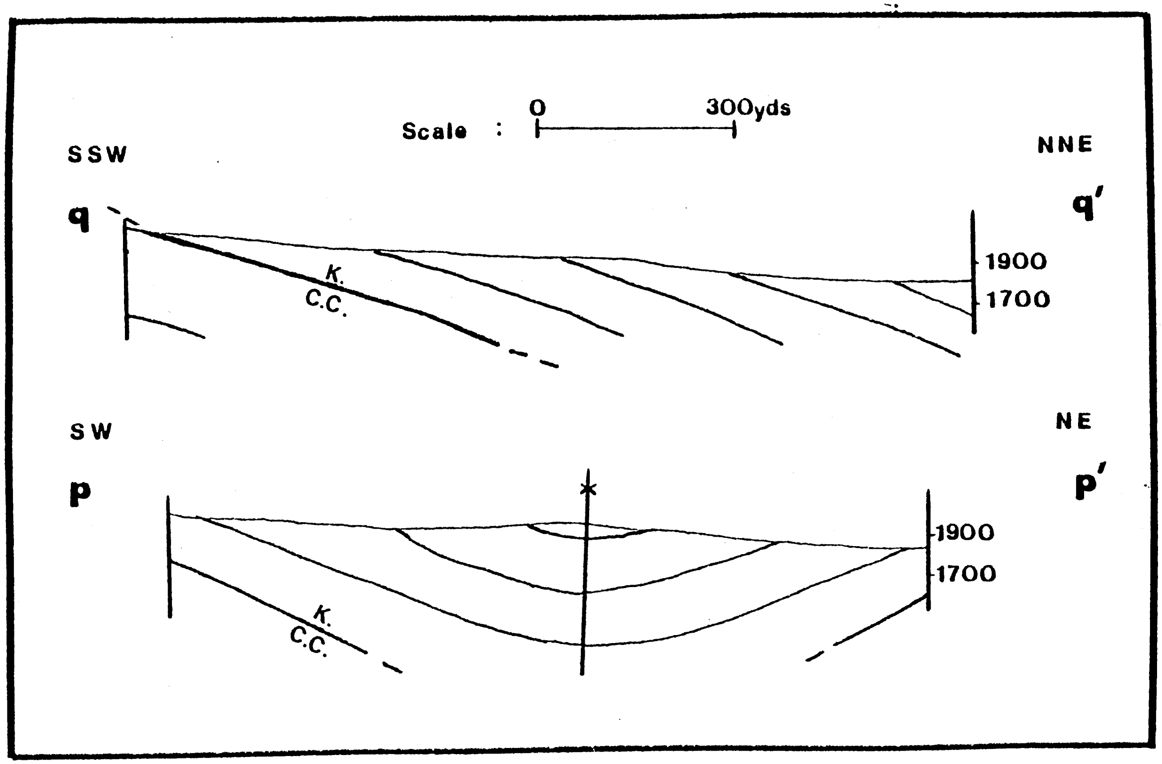


Figure 35. Geologic Sections Across the Woods Domain (C. C., Cool Creek Fm.; K., Kindblade Fm.)

CHAPTER V

INTERPRETATION OF DATA

Introduction

This chapter interprets the data presented and analyzed in the previous chapters, with each structural domain being dealt with separately.

The parallel fold geometry and the asymmetric-overturned nature of the folds (with one major exception) are consistent throughout the field area. The former occurs as a consequence of the anistropy of the succession, while the latter reflects on asymmetric stress component orientated from the southwest. Variations in other characteristics, such as plunge and azimuth, may be attributed to local features specific to individual domains, for example, the Blue Creek Canyon fault complex, or may be due to a more widely recognized feature, for example, the Stumbling Bear shear zone.

The folds must have preceded the development of the fault complexes and shear zones, as they are affected by both. There is no evidence for more than one episode of folding, nor is there any indication as to whether the fault complexes or the shear zones developed first.

Structural Domains

Blue Creek Canyon Domain

Within this domain, all of the folds plunge relatively steeply (18 degrees or more) toward ca.320. There is a sub-parallelism between the fold axes and the trends of the Blue Creek Canyon fault complex and Stumbling Bear shear zone. This suggests that the folds have been influenced by a combination of the effects of these latter structures. The generation of the Kimbell anticline from the Paradox anticline (Figure 17) suggests that the folds in the Blue Creek Canyon domain were coeval with those of the Kimbell Domain.

The fault complex overturned the northeast limb of the Blue Creek Canyon syncline (Figure 21b) and may also have encouraged the occasional development of a cleavage in the axes of adjacent folds, for example, the Paradox anticline (Figure 19a).

Donovan (1982) suggested the fault complex represented a dextral stepover between the Meers and Blue Creek Canyon (s.l.) faults (Figure 3) of the Frontal Wichita fault system. Such an arrangement is typical of en echelon transcurrent faults. The presence of a transcurrent component within the Frontal Wichita's fault system is further implied by the anastamosing pattern of faults (Figure 36), often recognized in the incipient stages of transcurrent fault evolution. These faults were mapped by Harlton (1963) but he wrongly attributed them to a tensile regime. This network pattern closely resembles that obtained by the intersection of Tchalenko's (1970) Riedels, conjugate Riedels, and P-shears. The folds within the Blue Creek Canyon domain are best explained as having been generated in a compressional stress field which gave rise to the high angle, reverse fault complex.

The most intense shearing in the field area is recognized in the Stumbling Bear shear zone, section 10, T4N, R13W, as the shear zone reoriented folds (Figure 27) it must post-date them. The trend of the

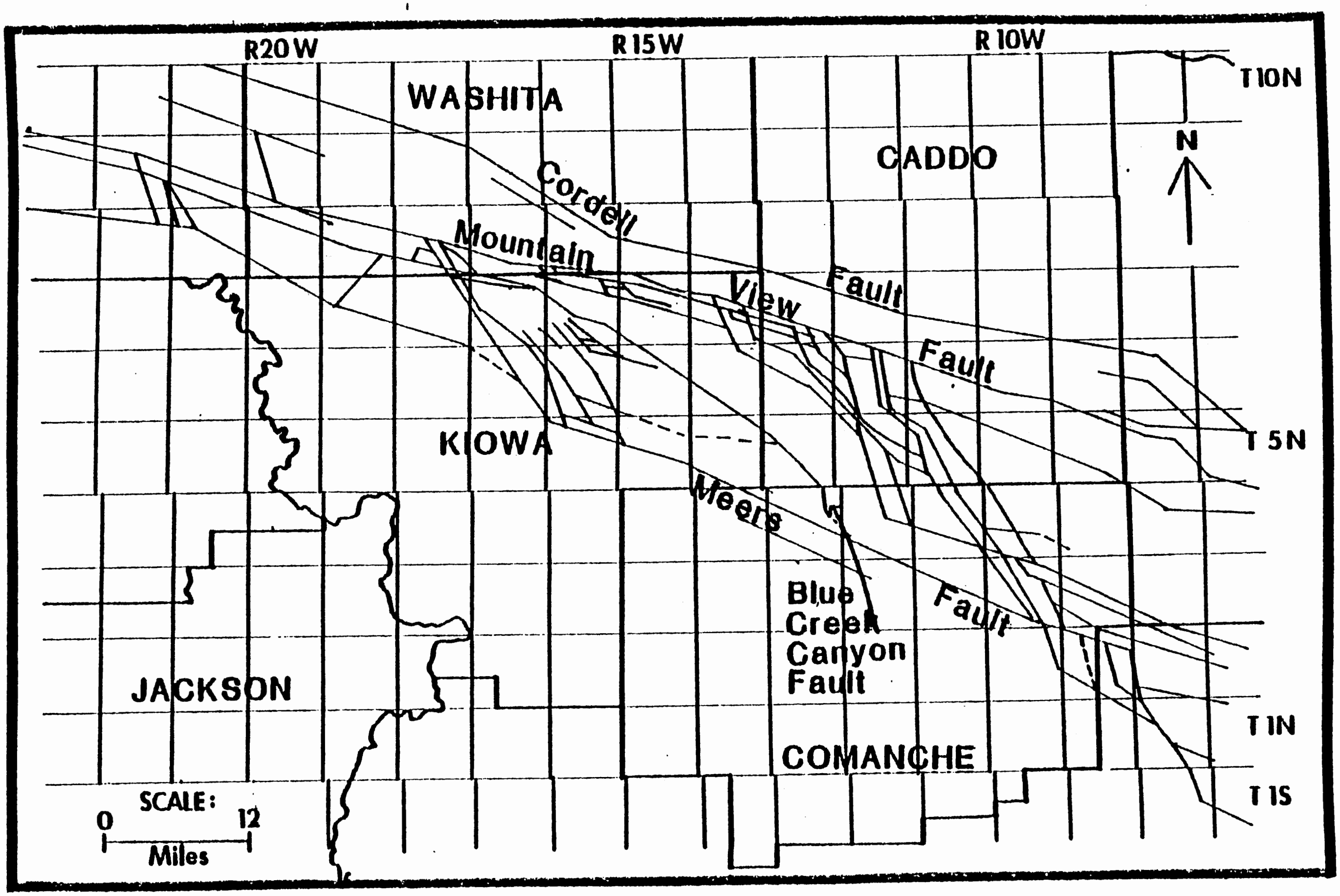


Figure 36. Anastamosing Pattern of Frontal Wichita Fault System (after Harlton, 1963, Figure 1)

shear zone is sub-parallel to strike of bedding along the zone margins. It is noteworthy that the shear zone terminated where its eastern half was aligned normal to strike, in the hinge area of a pair of third order folds, section 14, T4N, R13W (Figure 37).

This association suggests that the folds acted as indirect influences on the geometry of the shear zone. The vergence of minor folds and the overturning of major folds on the margins of and within the shear zone is toward the northeast. Taken in conjunction with the juxtaposition of the Cool Creek and Signal Mountain Formations, to the northeast and southwest, respectively, this indicates that the shear zone operated as a major zone of displacement. It is proposed that the steep-overturned limb of the Valentine syncline was sheared out, perhaps by the mechanism of bedding plane slip with a high angle reverse sense toward the northeast (Figure 38). The stratigraphic displacement which resulted accounted for approximately 2000 feet of the succession.

The shear zone fabric appears to be less intensely formed to the northwest of the domain, as the zone of deformation transfers from the steep, overturned limb to the less steeply dipping, right-way-up limb of the Valentine syncline/Paradox anticline. However, the stratigraphic offset remains great, with both Cool Creek and Kindblade Formations to the northeast placed against the McKenzie Hill Formation to the southwest.

It is suggested that the central part of the Blue Creek Canyon domain was compressed and downthrown between the reverse movements of the fault complex and shear zone, thus steepening dips on fold limbs and increasing the plunge of the folds. The effect of this is seen to lessen to the northwest as the shear zone's trend changes in the Kimbell domain. This suggestion is supported by dips recorded for the "gentle" limbs of

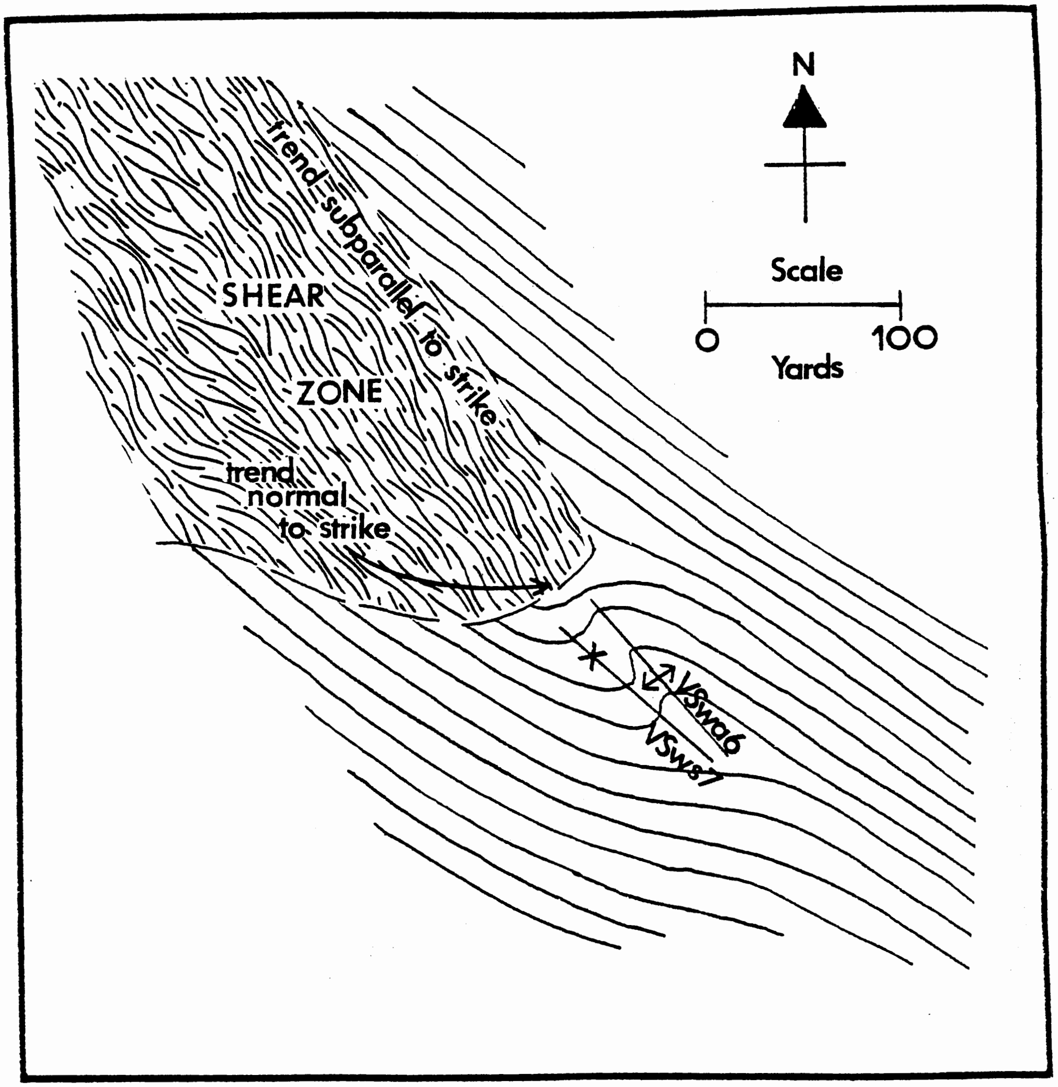


Figure 37. Sketch Map Showing the Termination of the Stumbling Bear Shear Zone (where it becomes aligned normal to strike of bedding in the third order fold pair, section 14, T4N, R13W)

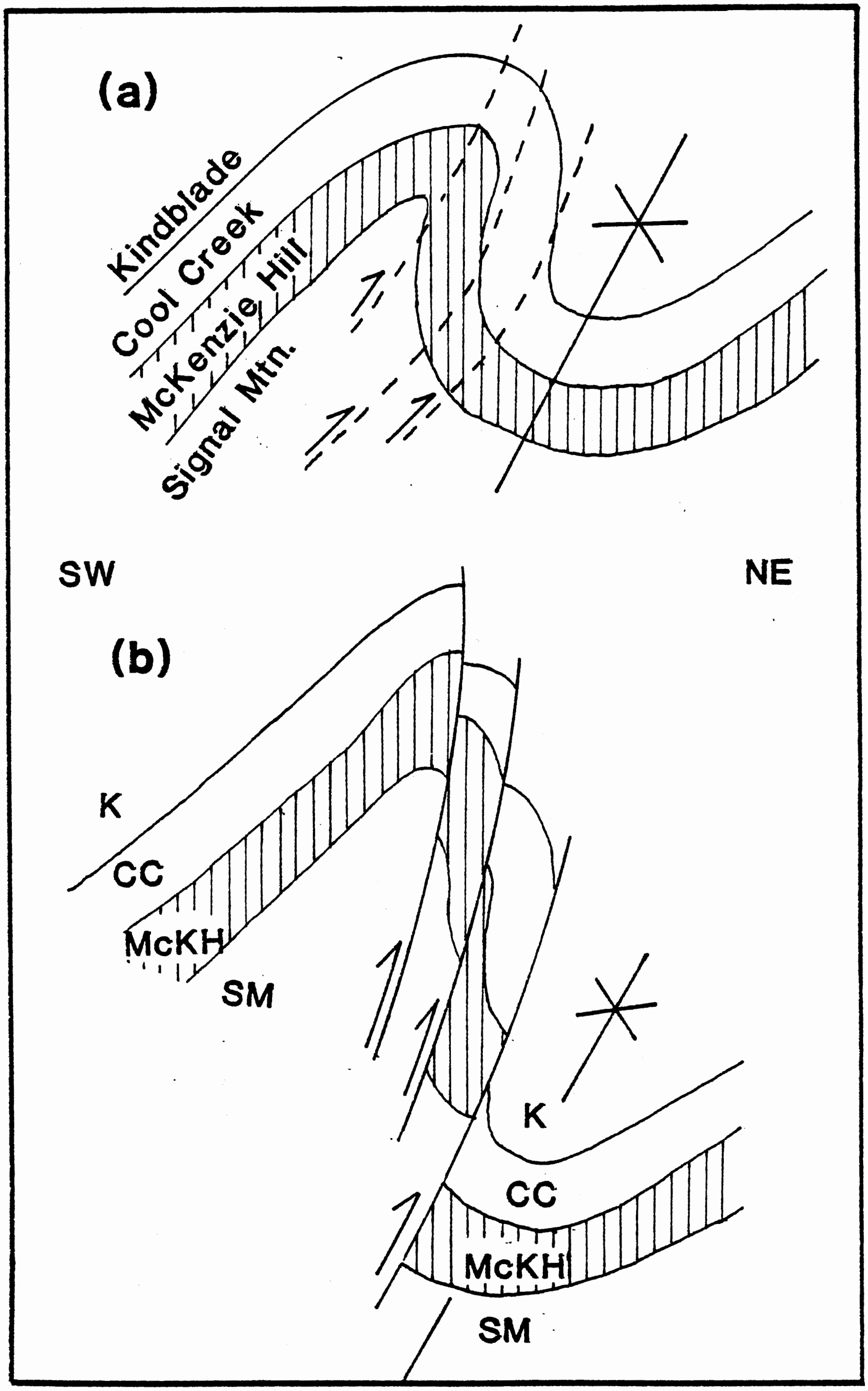


Figure 38. Stratigraphic Relationships Within the Valentine Syncline [(a) before shearing; (b) after shearing of steep limb]

the folds which average ca.45 degrees (10-25 degrees more than dips recorded elsewhere), and by plunges of 28-35 degrees where affected by the shear zone-fault complex couple, compared with 18 degrees or less elsewhere in the domain.

Kimbell Domain

In this domain, the left-handed en echelon folds are fewer and generally larger than those in either the Dietrich or Blue Creek Canyon domains. They are, with the exception of the Kimbell anticline, very gently (less than five degrees) doubly plunging. The folds trends, on average 312, vary between 303 and 325. These folds represent the most obvious analogs to those expected to have been produced in a transcurrent regime. The small angles these folds make with the Meers fault trend (3-25 degrees) supports Brewer's (1982) hypothesis for both convergent and transcurrent movement (i.e., transpression) along the Frontal Wichita fault system. These folds would have been expected to have generated initially at 30 degrees to the eventual fault trace (Moody and Hill, 1956), but, as Harland (1971) pointed out, additional compression would have resulted in the rotation of the fold axes toward the fault trace.

Again, there is a marked parallelism between the trend of the Stumbling Bear shear zone and the strike of bedding; however, the shear fabrics developed are much less intense than those of the Blue Creek Canyon domain. Bedding is nowhere obliterated, but is often steepened and contorted into minor folds. There is steepening of the beds to the southwest, with some overturning to the northeast across a zone ca.300 yards wide. The Kindblade Formation to the northeast is offset against the McKenzie-Hill Formation to the southwest. Therefore, although the shear fabrics produced are not as intense as those of the Blue Creek Canyon domain, they must represent an equally significant displacement.

Minor folds verging to both the northeast and southwest suggest that convergent and transcurrent components of movement occurred within the shear zone (Figure 39). It is possible that some of the northeast verging folds represent minor folds to the major en echelon folds, which were sheared. However, the absence of any unsheared minor folds outside the shear zone's margins precludes this likelihood. The minor folds are observed on the sheared southwest limbs of the Kimbell and Ridge anticlines, section 4, T4N, R13W.

Dietrich Domain

In the Dietrich domain, the folds are more numerous than elsewhere and commonly doubly plunging. Their plunge and azimuth values fall between those of the Kimbell and Blue Creek Canyon domains, suggesting that the Dietrich domain had a history intermediate between those postulated for those domains.

A broad zone of high angle reverse faults, the Bullrun fault complex, juxtaposes the McKenzie Hill and Cool Creek Fromations. Individual faults in the complex have led to the partial repetition of the succession at least three times, and to the consequent tectonic thickening of the succession along the northeast limb of the Bullrun syncline, section 25, T5N, R14W. The presence of the basal Cool Creek member is asymmetric, fault bounded, synclinal outliers suggests that the faults used the complementary overturned limbs of these synclines as planes of movement. Because of the contrast in lithologies between the sandy basal member of the Cool Creek Formation and the more massive micritic limestones of the

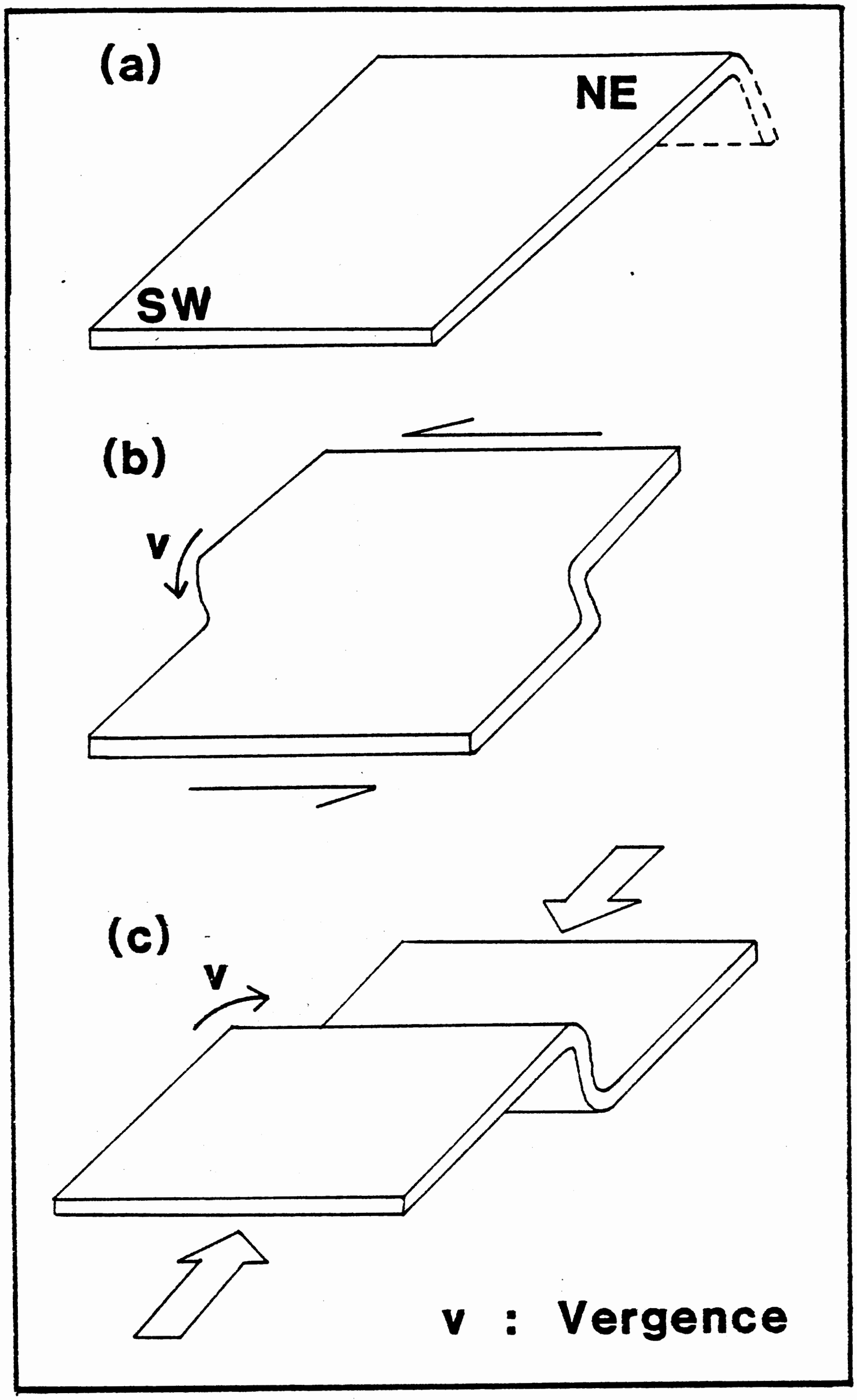


Figure 39. Opposite Vergence of Minor Folds on Gently Dipping Fold Limb [caused by (a) transcurrence; (b) compression with southwest component dominant]

upper McKenzie Hill Formation, the formations contact may have represented a plane of weakness which was susceptible to faulting.

The Dietrich shear zone is a continuation of the Stumbling Bear shear zone to the southeast. At the eastern boundary of the domain, the shear zone narrows abruptly from 300 yards in northeast quarter section 31, T5N, R13W, to less than 50 yards in central section 30, T5N, R13W to approximately 20 yards in eastern half, section 25, T5N, R14W. The types of structures observed within the shear zone also change over this distance, from third order and minor folding in the southeast to shear fabrics and fractured, discontinuous beds in the northwest. Therefore there appears to be some correlation between the way in which the displacement is accommodated and the width of the zone across which displacement occurs. It is possible that, rather than being contained within one broad zone, the displacement took place in a series of smaller zones, each represented by folded or discontinuous beds. Within such zones it is difficult to distinguish individual fault planes, and this problem is further compounded by the absence of easily discerned marker beds within the formations involved.

The sense of displacement across the shear zone is again high angle reverse, causing McKenzie Hill and Cool Creek Formations in the southwest to be placed against the Kindblade Formation to the northeast. The folds to the northeast of the shear zone (associated with the Dietrich anticline) plunge southwest, whereas those to the southwest of the shear zone (associated with the Marshall Anticline) plunge northwest. The result of this is that the stratigraphic displacement is less here than anywhere else in the area, with Cool Creek Formation coming within ca.100 yards of being juxtaposed against itself in central section 24, T5N, R14W. This relatively smaller displacement may be due to a large part of the convergent component (which would normally increase the displacement) being taken up by the Bullrun fault complex.

As elsewhere, the shear zone crosses the fold axes obliquely and its trend is 310±10 degrees. Thus, although its trend is sub-parallel to strike, the position of the shear zone does not appear dependent upon the steepness or direction of dip of the beds.

In the west half, section 24, T5N, R14W, the Cool Creek McKenzie-Hill Formation boundary is displaced left-laterally by small, parallel shear zones. To the north, the complete Kindblade Formation is exposed in the steep-overturned southwest limb of the Cache syncline, with the west Spring Creek Formation consequently outcropping in the core of the syncline.

The southern and eastern margins of the domain are bounded by the Tully disturbed zone containing deformation fabrics (which are not strongly enough developed to be termed shear fabrics) associated with high angle reverse faults (Beauchamp, 1983). The faults extend from section 25 to section 30, T5N, R14W.

Woods Domain

The marked difference in fold style, size and density between the Saddle Mountain syncline in Woods domain and the folds in the other domains suggests that this domain was subject to a separate structural genesis.

The domain is occupied entirely by the Saddle Mountain syncline, principally its southwestern limb, as represented by a continuous, northeast dipping, homoclinal sequence. There are no additional folds, faults, or shear zones. This syncline is the only major fold which is both symmetrical and upright, with no indications of an asymmetric stress component having acted from the southwest.

To the east, the domain is bounded by the Tully disturbed zone, which can be extrapolated to be sub-parallel to the strike of the syncline's northeast limb. The disturbed zone can be inferred to extend beneath the Post Oak cover in the north-south valley, central section 23, T5N, R13W. The trend of this zone is therefore sub-parallel to that of the Blue Creek Canyon fault complex. There is no marked stratigraphic displacement across the disturbed zone; however, the succession is thickened tectonically by faulting.

CHAPTER VI

CONCLUSIONS

Donovan et al. (1982) proposed that a left lateral strike-slip component was active during the deformation of the Slick Hills. Their findings are supported here by recognition of the following:

1. en echelon, left-handed folds within the Kimbell and Dietrich domains;
2. left-lateral displacements within and between shear zones;
3. the Blue Creek Canyon fault (s.s.) acting as a dextral stepover between the Meers and Blue Creek Canyon (s.l.) faults;
4. the anastamosing pattern of the Frontal Wichita's fault system with its fault-bounded phacoidal blocks.

There is strong evidence to suggest that a compressive component was also active during the deformation. This evidence comprises the:

1. asymmetry of the folds;
2. apparent rotation of the en echelon folds;
3. high angle reverse style of the Bullrun fault complex;
4. large scale, high angle reverse stratigraphic displacement (up to 2000 feet) across shear zones which extend for over seven miles through most of the field area.

The sub-parallelism between strike of bedding and the orientation of the shear zones may reflect an indirect relationship between the two, especially as the shear zone is seen to terminate when strike is perpendicular to its trend. It is interesting to note that the closer strike approaches a north-south orientation, the more intense is the shear fabric observed. For example, in the Blue Creek Canyon and Dietrich domains, bedding is obliterated when the shear zone trends ca.340 and ca.320, respectively, but it has a less intense fabric in the Kimbell domain where it trends ca.300.

Assuming a compressional component orientated from the southwest, intense deformation would have occurred in those with a strike subperpendicular to the compression, thereby leading to high angle displacements, e.g., in the Blue Creek Canyon domain (Figure 40). Where the shear zone trends ca.300, as in the Kimbell domain, a transcurrent component of displacement would have been dominant. In general, both transcurrent and compressive displacements would have occurred together (transpression) throughout the length of the shear zone. This resulted in oblique slip across the zone, with either component of displacement likely to have had a dominant role, dependent upon the trend of the zone relative to the principal stress orientation (Figure 40). The characacter of the principal component may also have been responsible for the width of the shear zone and the structures observed within it.

As to why the shear zones should have formed at all when the succession was obviously capable of folding, one can theorize that the rocks had reached their mechanical limit for folding and thus underwent brittle fracture resulting in the formation of shear zones.

Two problems require comment. These are the reasons for the sitings of the shear zones, and the anomalous style of deformation observed in the Woods domain.

It has been suggested (Donovan, 1983, personal communication) that

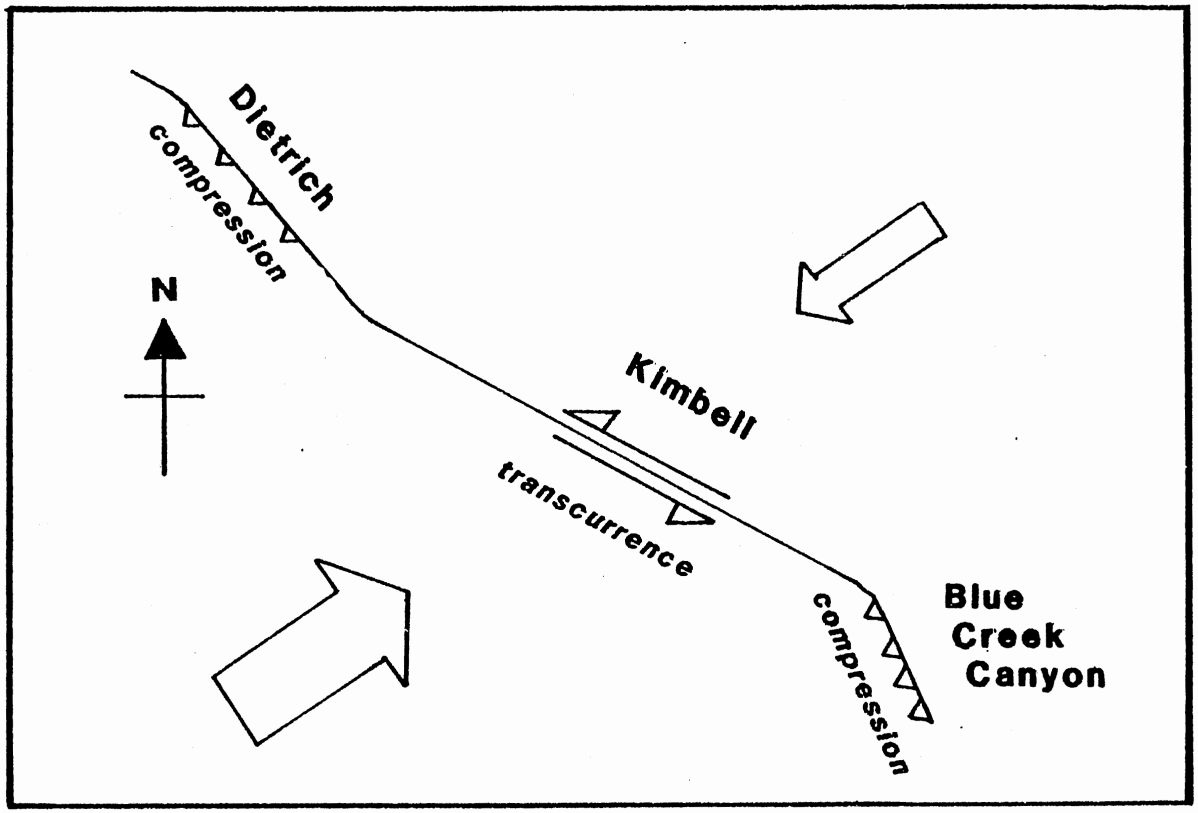


Figure 40. Postulated Principal Components of Deformation Along Shear Zones in Dietrich, Kimbell, and Blue Creek Canyon Domains

the shear zones may be a reflection of earlier faults at depths which defined blocks within the basement. Reactivation of these faults during the Pennsylvanian deformation may have resulted in their propagation up section as shear zones.

The basement blocks, which these faults define, may have served as controls on the style of deformation within the overlying sedimentary succession. A small block, itself faulted, would have deformed relatively easily; whereas a larger, more stable block may have resisted deformation to give a less complicated structual pattern.

It is proposed that two such basement blocks exist in the Slick Hills. The smaller, less stable block is bounded to the south and north by the Meers and Blue Creek Canyon (s.l.) faults, and to the east and west by the Blue Creek Canyon fault complex (s.s.) and the Tully disturbed zone, respectively. This block contains the Kimbell, Blue Creek Canyon, and Dietrich domains. The second block has less easily defined boundaries; the Tully disturbed zone to the east, the Meers fault to the southeast, the Blue Creek Canyon fault (s.l.) to the northeast, but elsewhere, to the west, a boundary is difficult to define (perhaps in itself suggestive of a larger block). This block contains the Woods domain (Figure 41).

Both blocks would have been subject to a regional compression aligned northeast-southwest. The effect of this compression was most marked at the southeast and northwest corners of the blocks, and resulted in the alignment of structures in these regions along a north-south (rather than east-west) trend, assuming compression to have had a greater effect than transcurrence. This would account for the folds of the Dietrich and Blue Creek Canyon domains trending more toward north than those

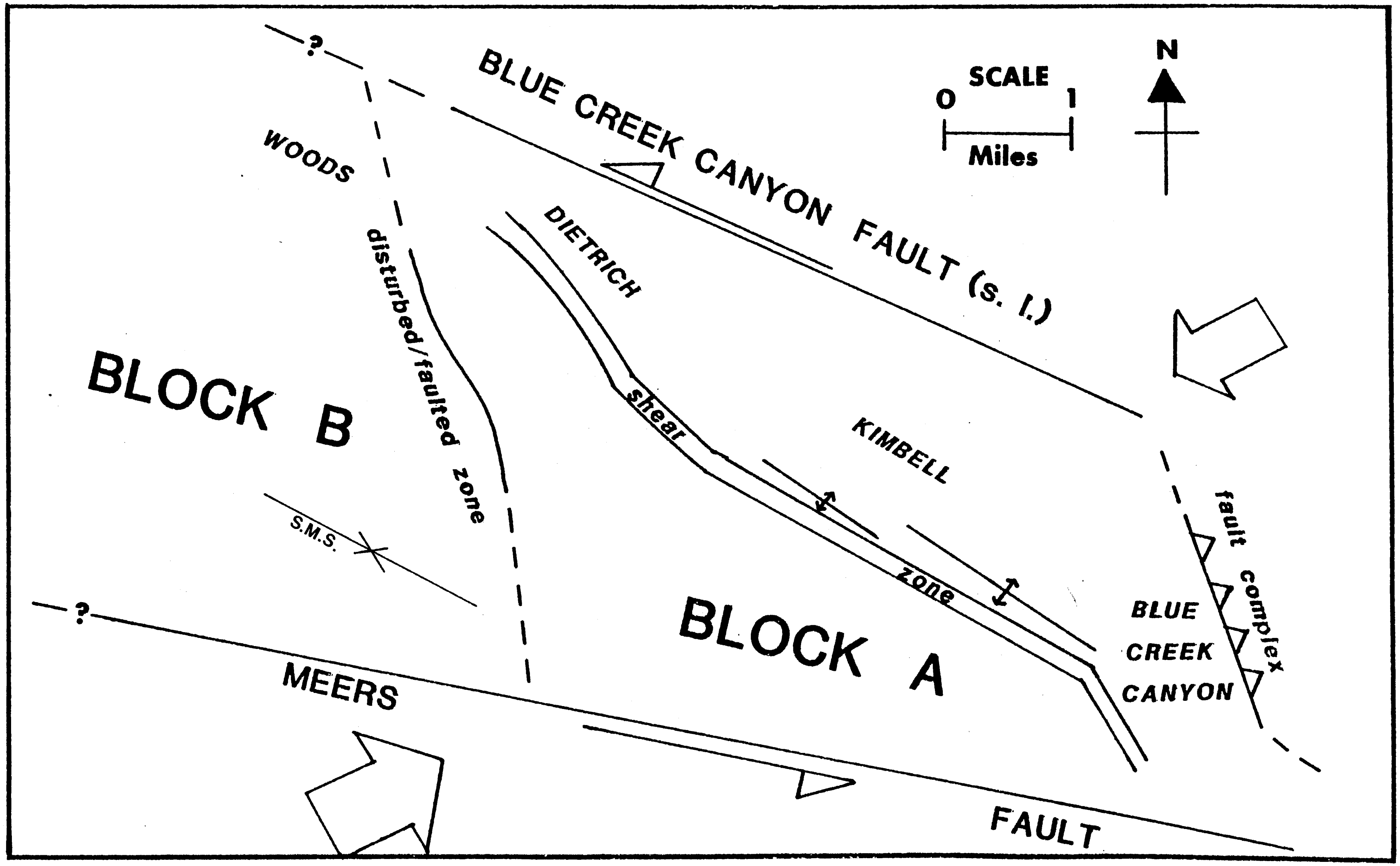


Figure 41. Theoretical Basement Configuration Within the Slick Hills (S.M.S., Saddle Mountain Syncline)

of the Kimbell domain.

The Saddle Mountain syncline in Block B (Figure 41), being open and symmetrical, may have undergone relatively less compression than transcurrence or the compressional component may have been taken up elsewhere in the block perhaps on the bounding faults. If the block is open, or at least less well defined to the west, then the compressional component may have been translated into transcurrence.

In summation, of the structures mentioned in Chapter III as representative of transcurrent fault systems, en echelon folds, Riedel, conjugate Riedel, and P-shears, extension faults and anastamosing fault complexes with phacoidal blocks are all present within the Slick Hills or the Frontal Wichita fault system. In addition, a strong compressional component is evidenced by high angle reverse faults, overturning and rotation of folds and high angle reverse movement along shear zones. Further evidence for compression is the 30-40 degree dip (to the southwest) of the major faults in the Frontal Wichita fault system (Brewer, 1982). The combination of compressive and transcurrent components produces a transpressive deformational regime to which the structures within the northern Slick Hills can be attributed.

Brewer et al. (1983) declared that their COCORP data "could be consistent with oblique slip along the Wichita trend." They stated that "some degree of left lateral oblique slip is suggested by en echelon faults flanking the south side of the Wichita Mountains, and in the Frontal Wichita fault system."

Kluth and Coney (1981) suggested a regional mechanism for a transpressive regime. They supported the premise that the Ouachita-Marathon orogeny, caused by the collision of North America with South America/

Africa, during the Pennsylvanian, resulted in foreland deformation within the mid-continent. They noted that "the largest component of movement along the faults bounding the uplift was vertical . . . we suggest that many of these zones also had at least some component of strike-slip."

Therefore, on both a regional and local scale in the Wichita uplift and the northern Slick Hills, transpression has been responsible for the evolution of the structures observed.

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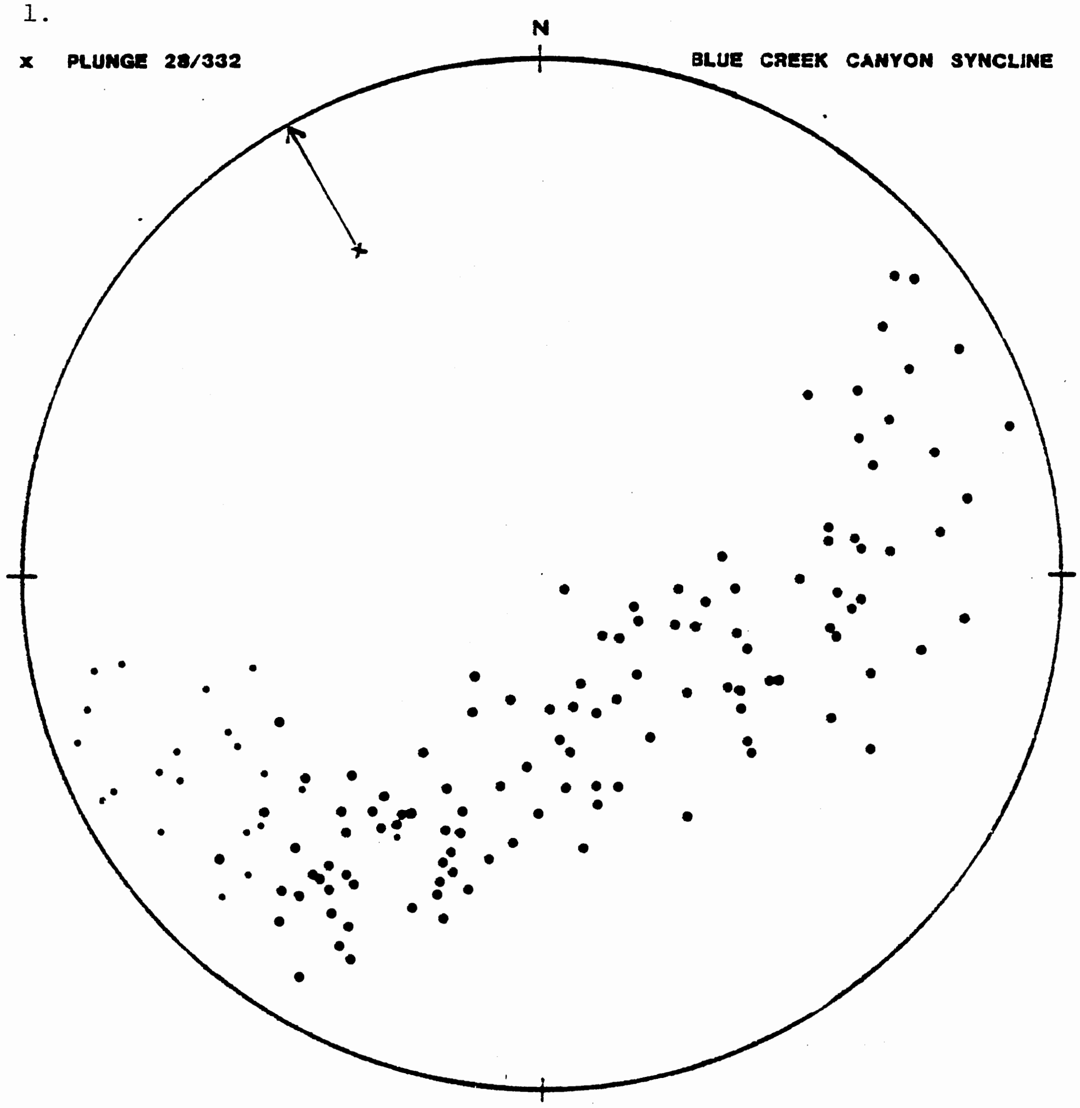
APPENDIX

STEREOGRAMS OF FOLDS

LEGEND :

●	BEDDING, RIGHT-WAY UP
•	BEDDING, OVERTURNED
←—×	PLUNGE/AZIMUTH
(N)	NORTH
(S)	SOUTH
(SZ)	SHEAR ZONE

1.



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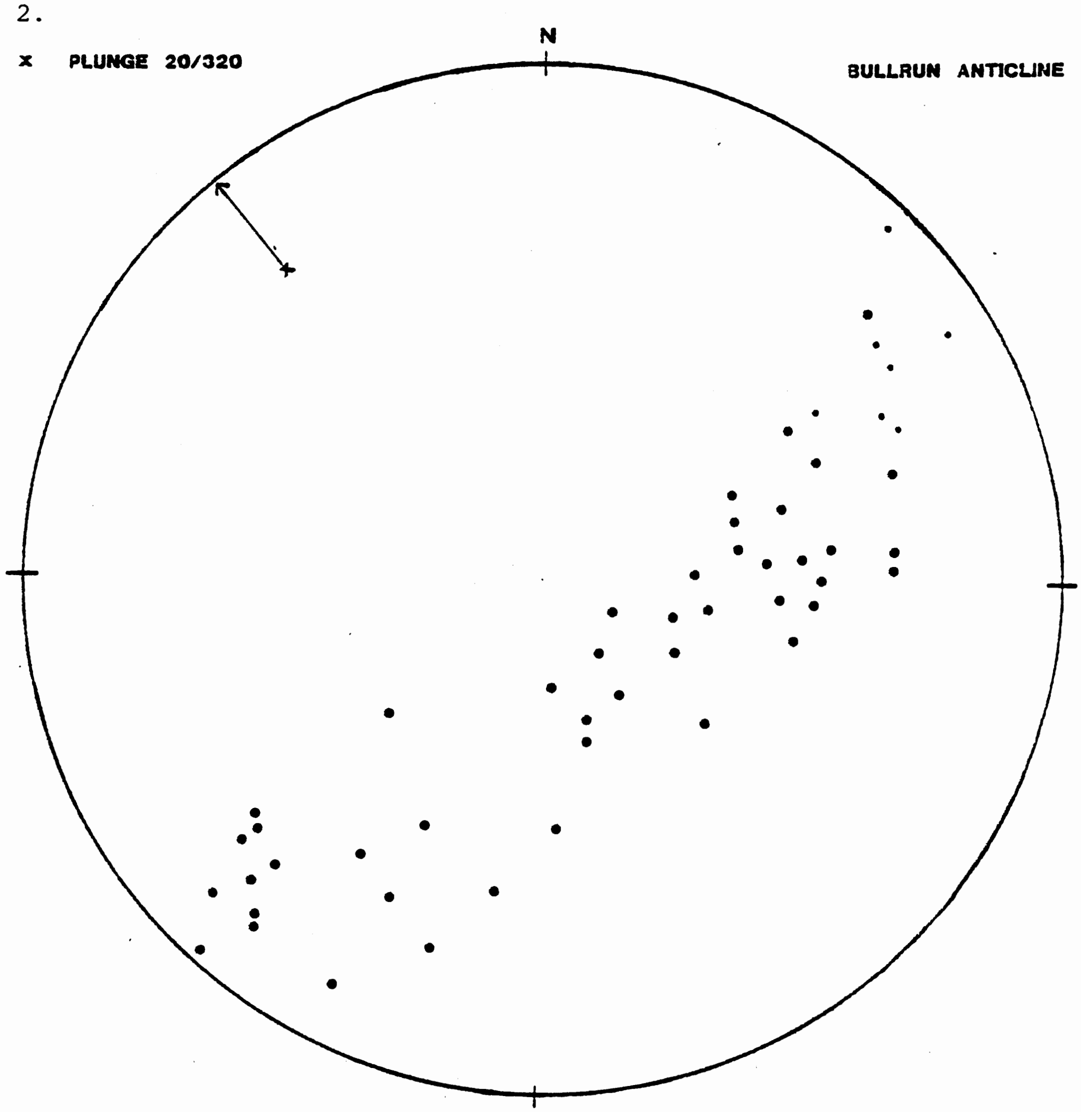

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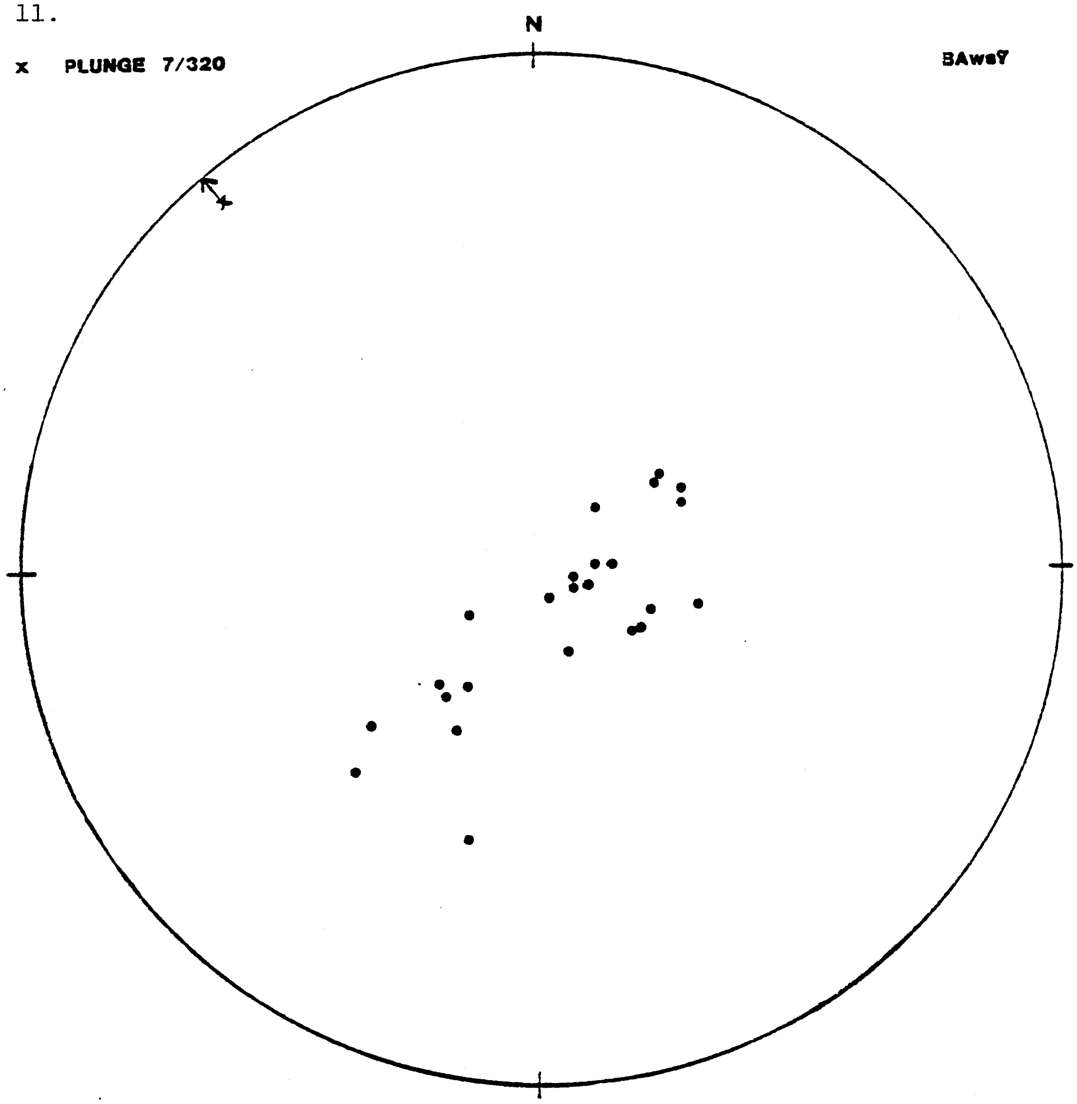

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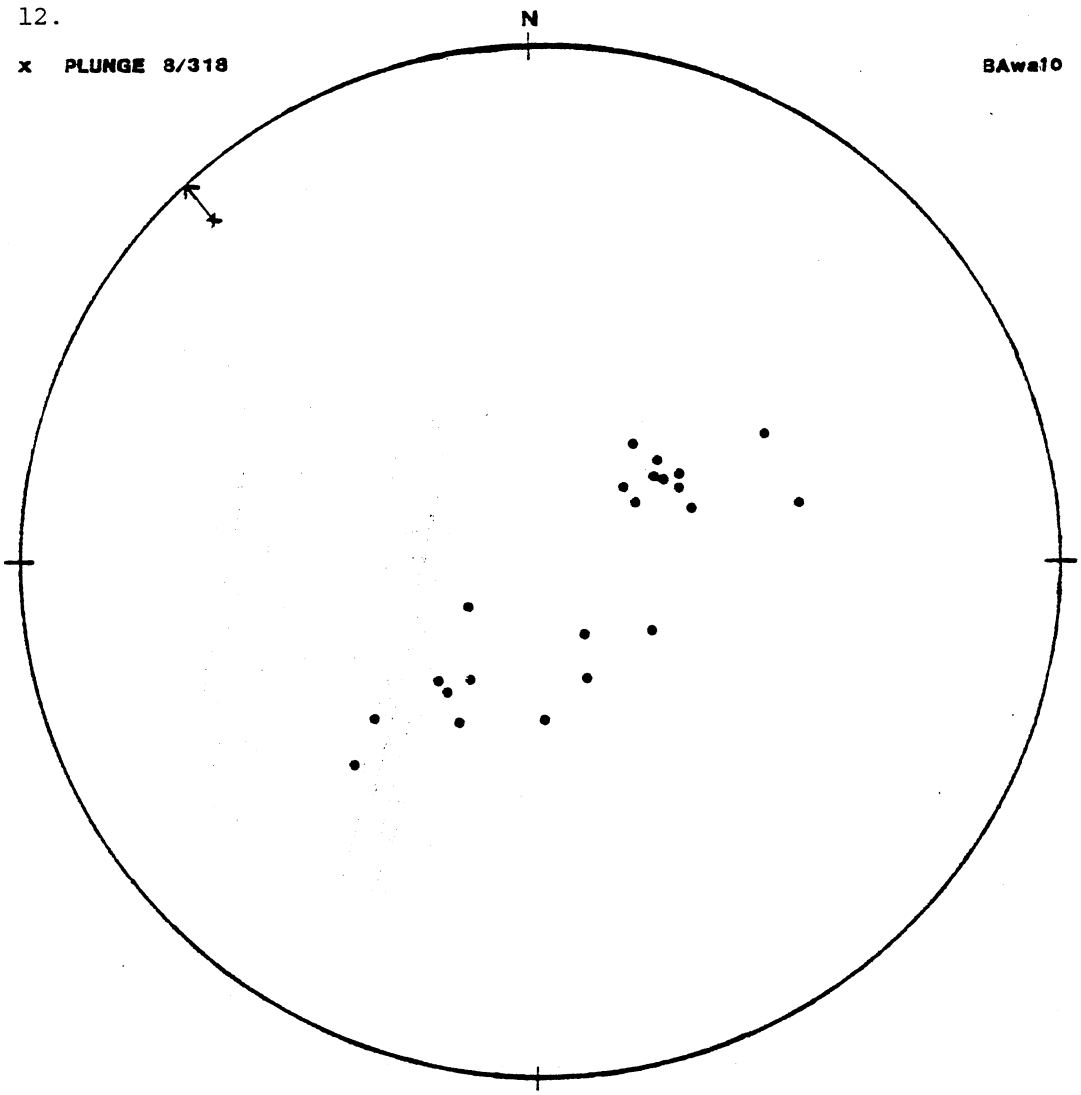

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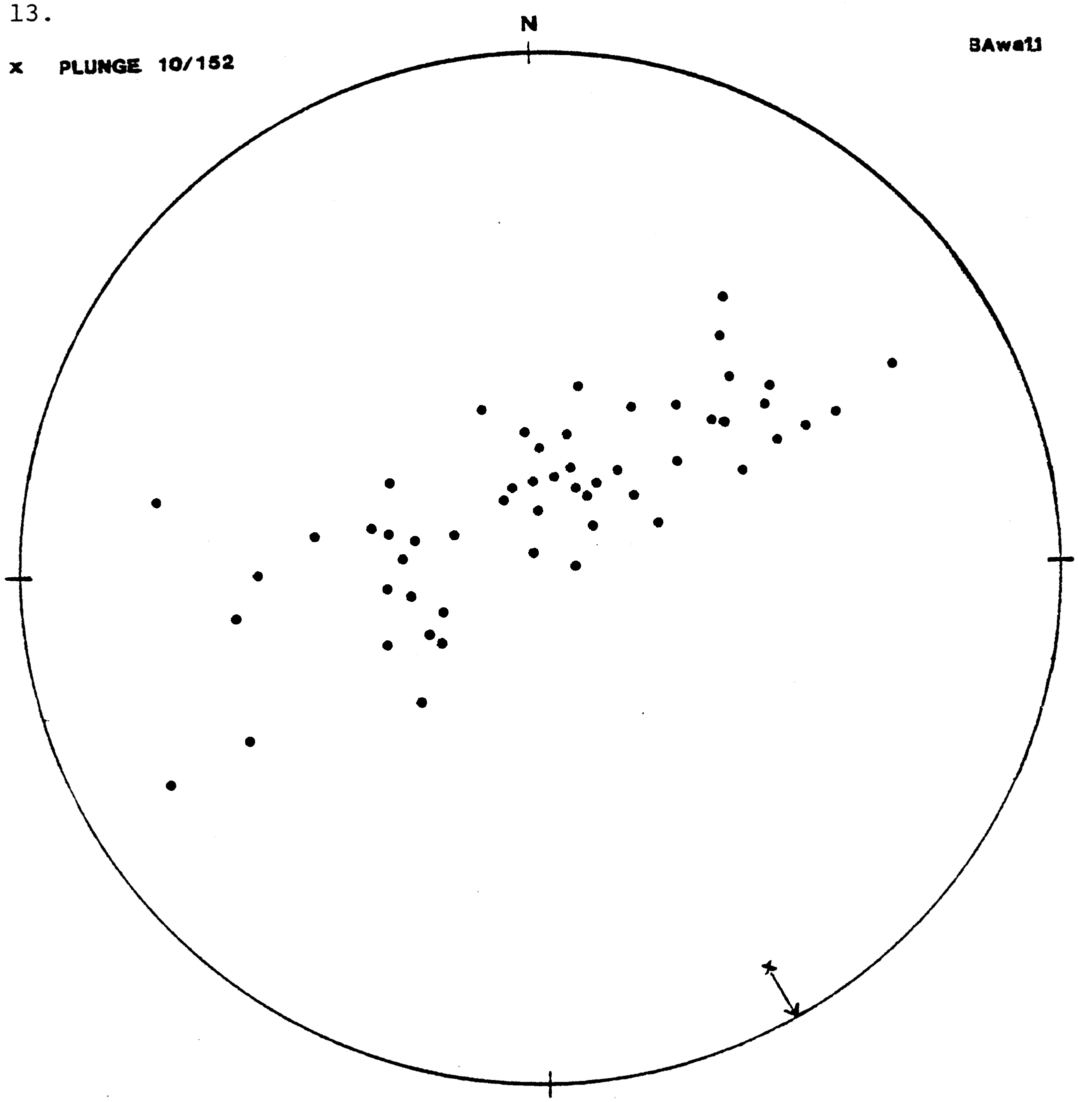
x PLUNGE 10/152



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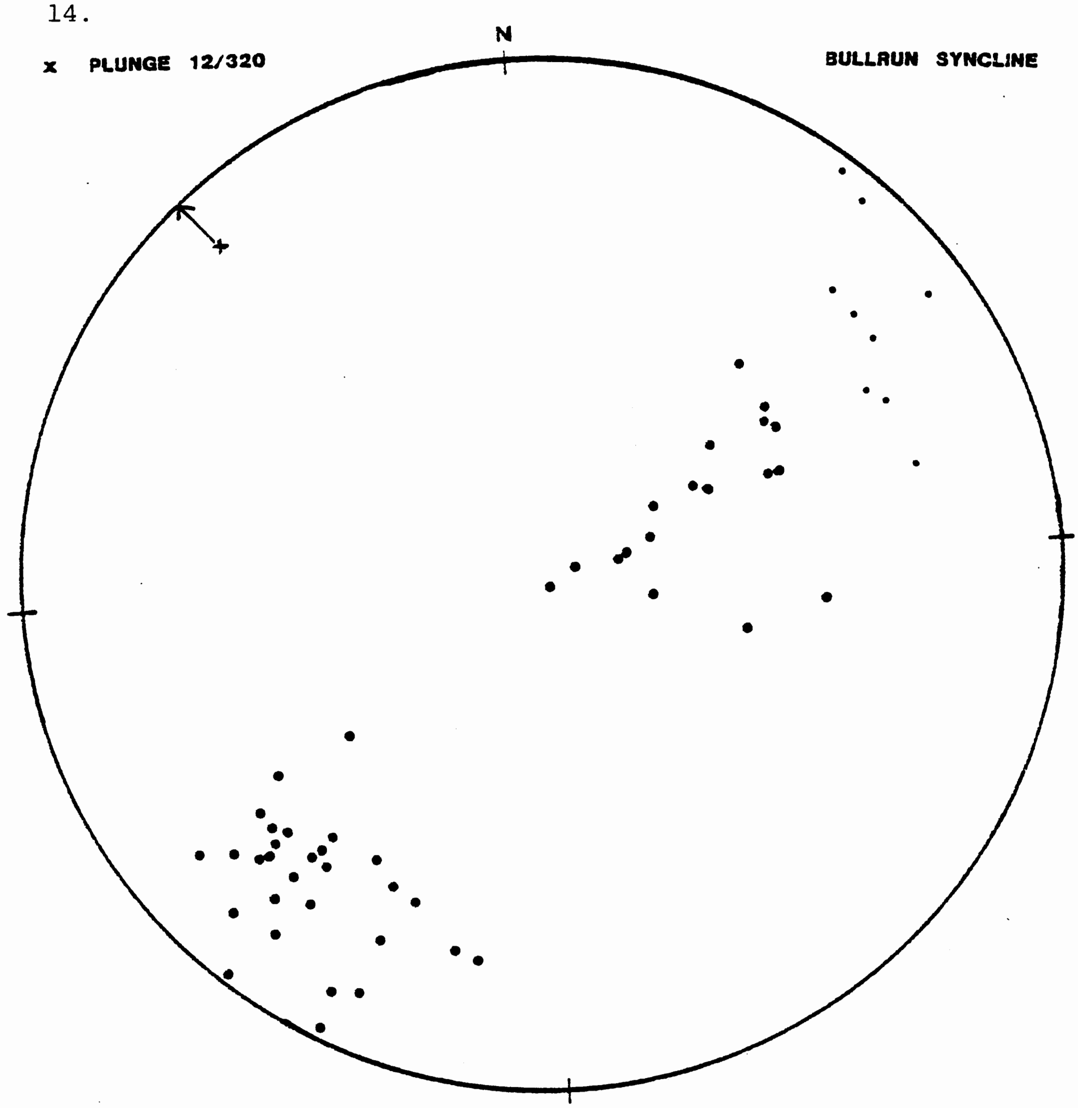

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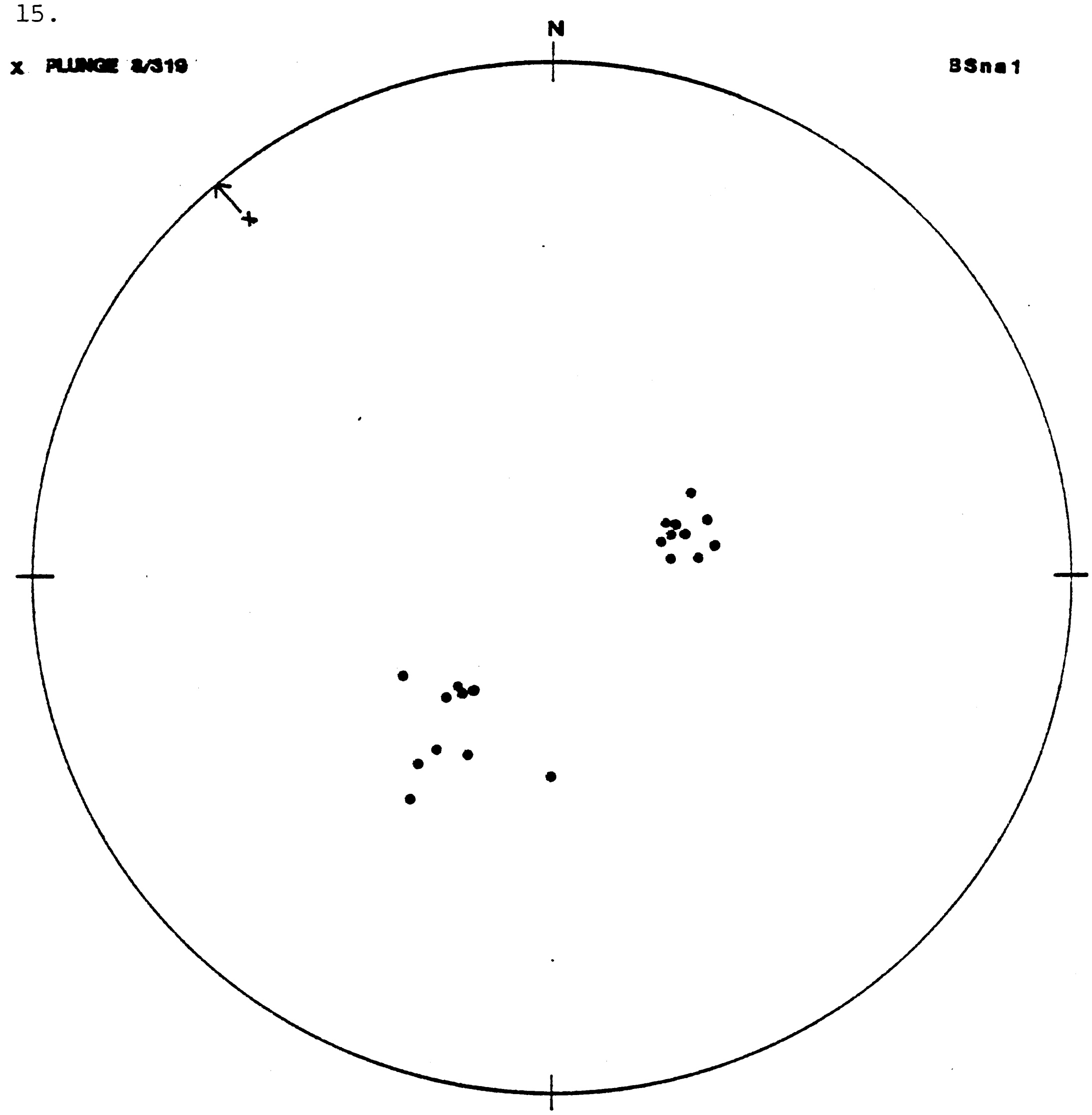

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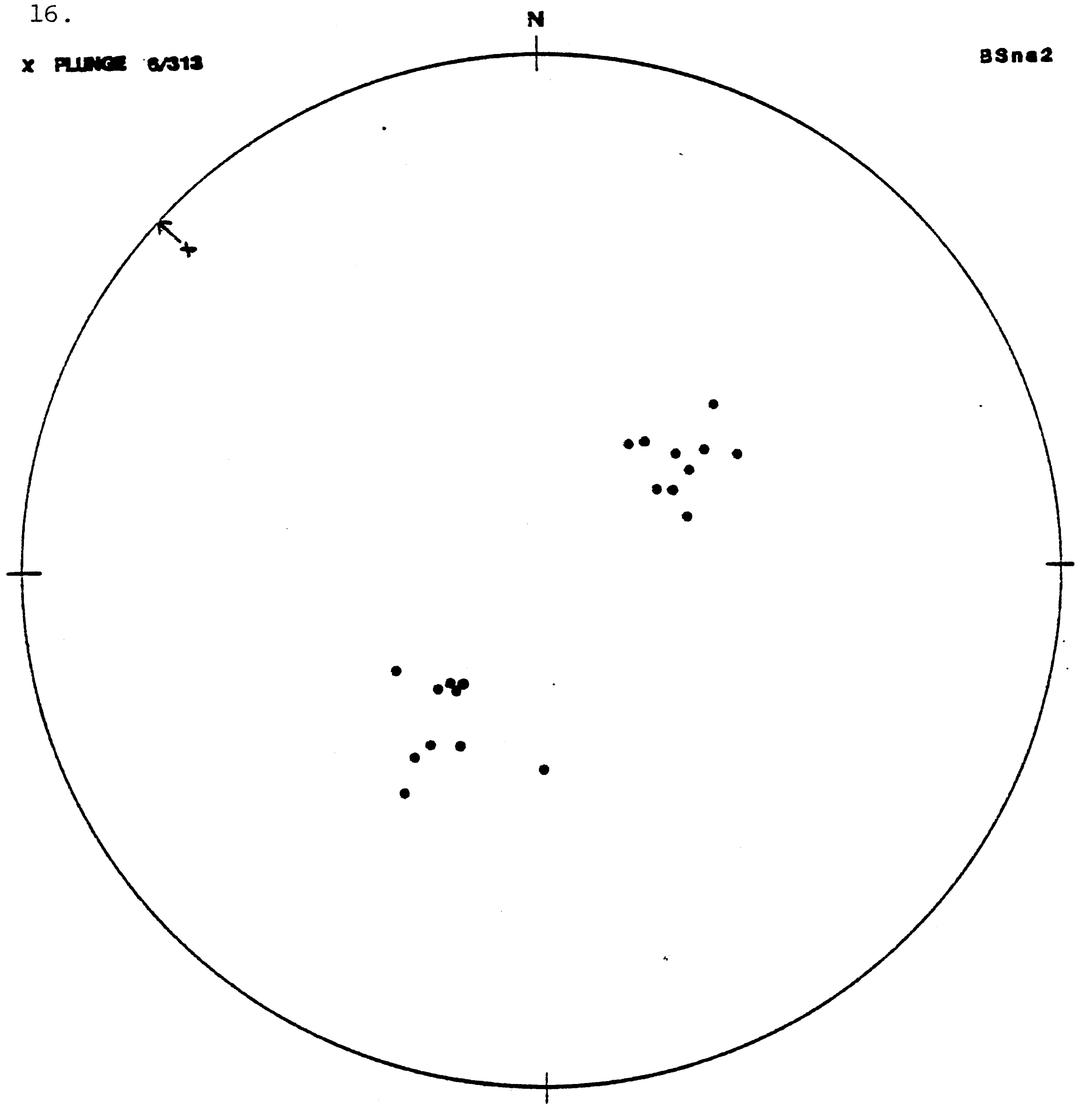

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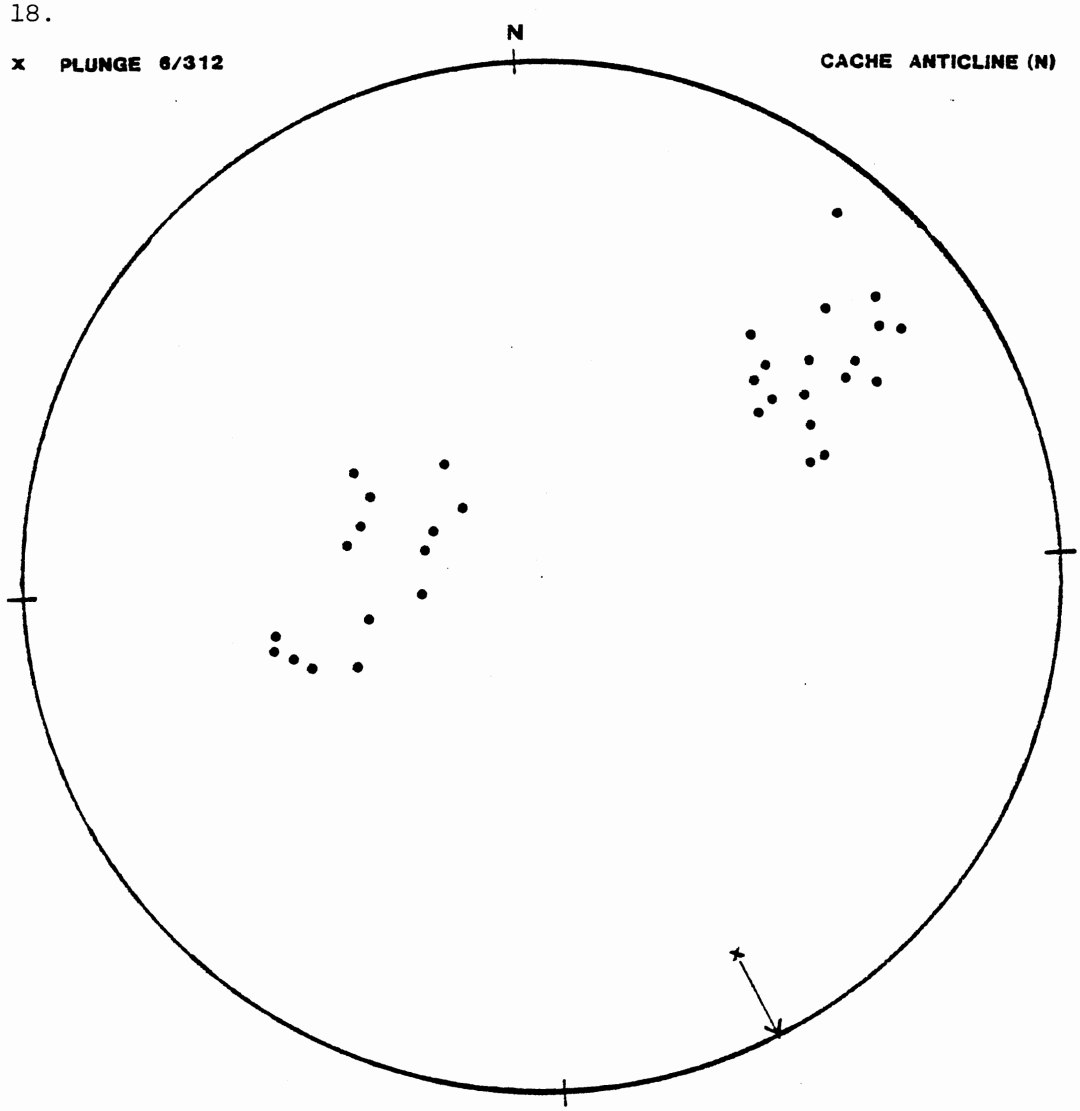

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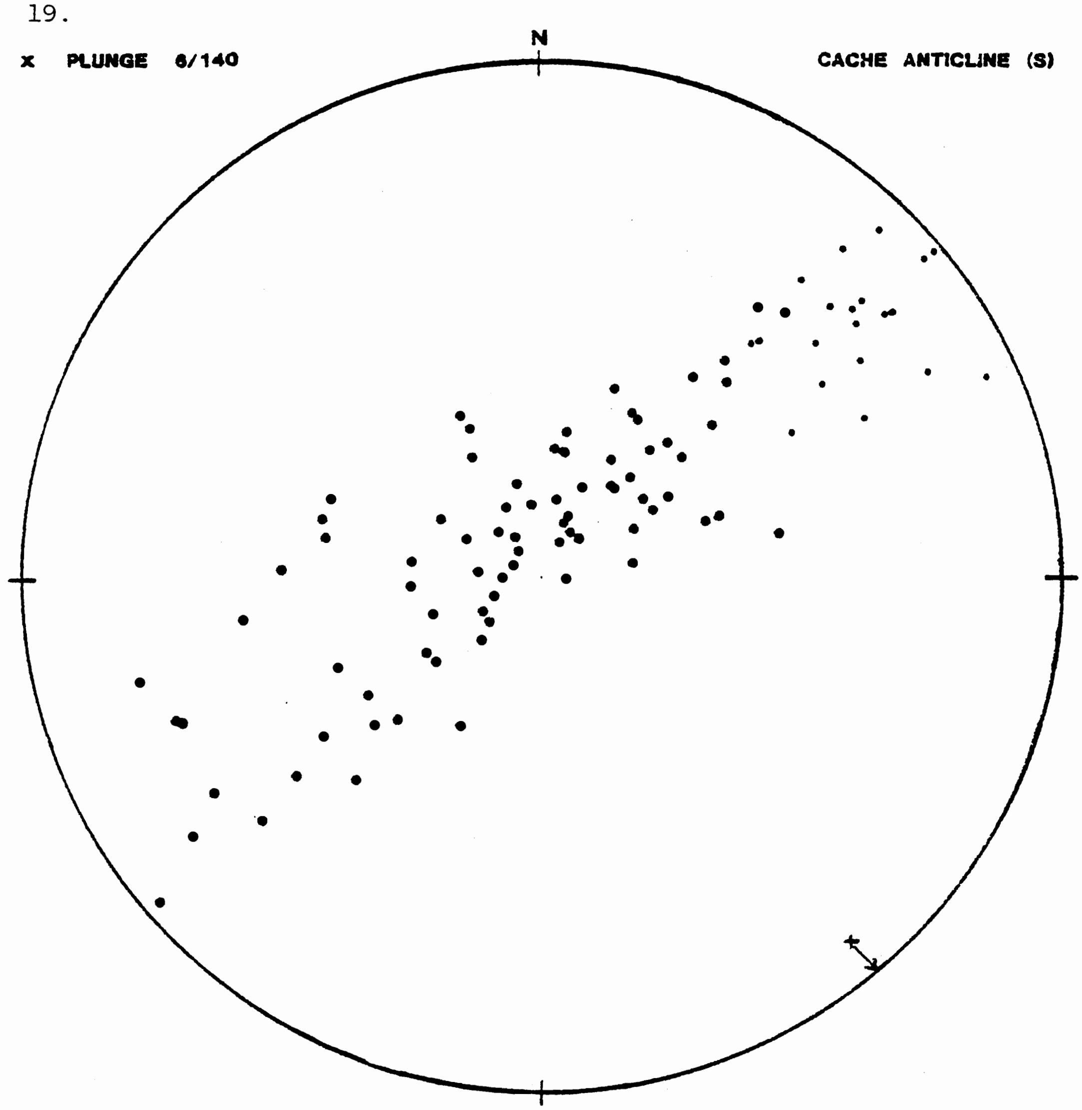

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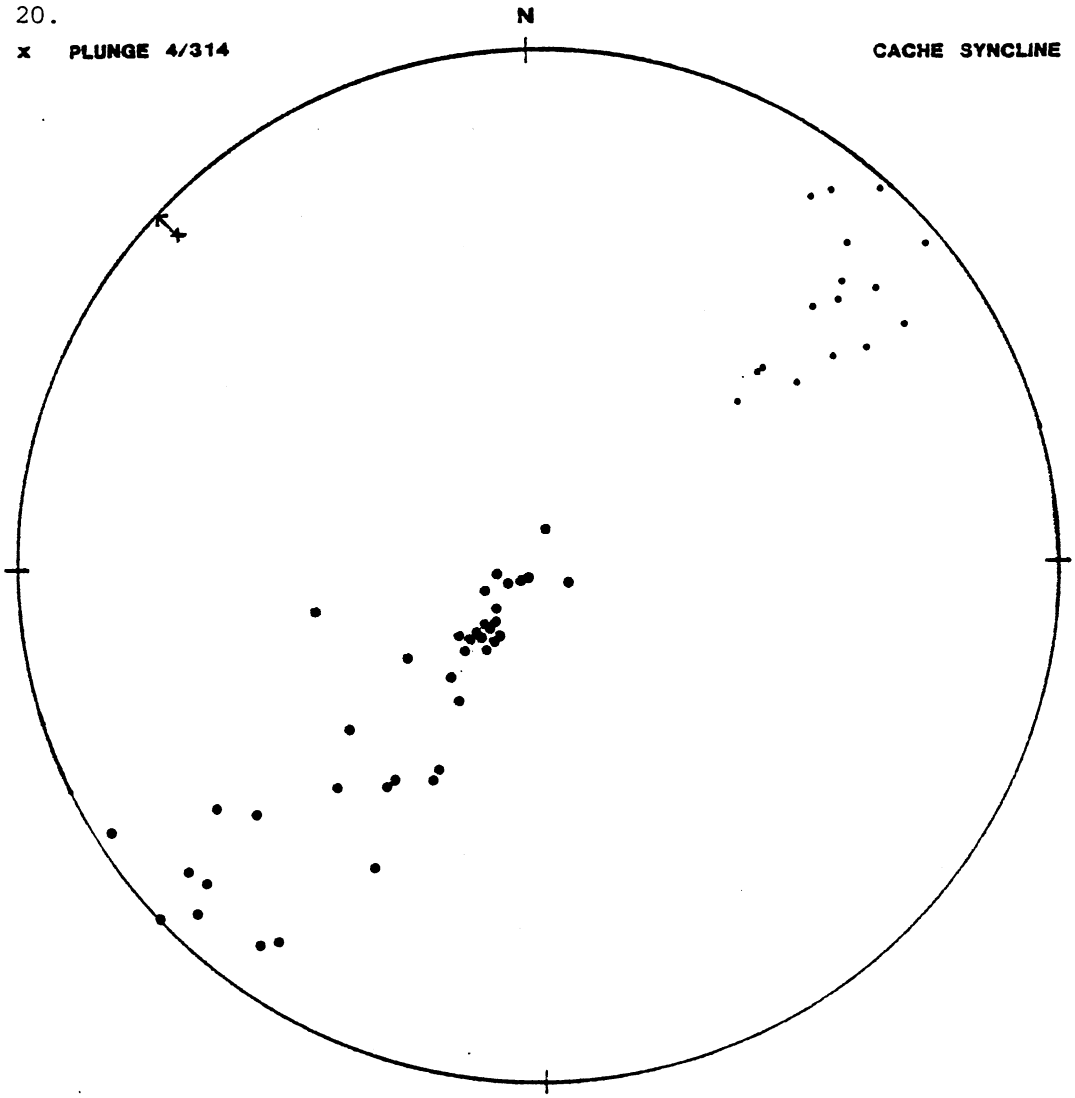

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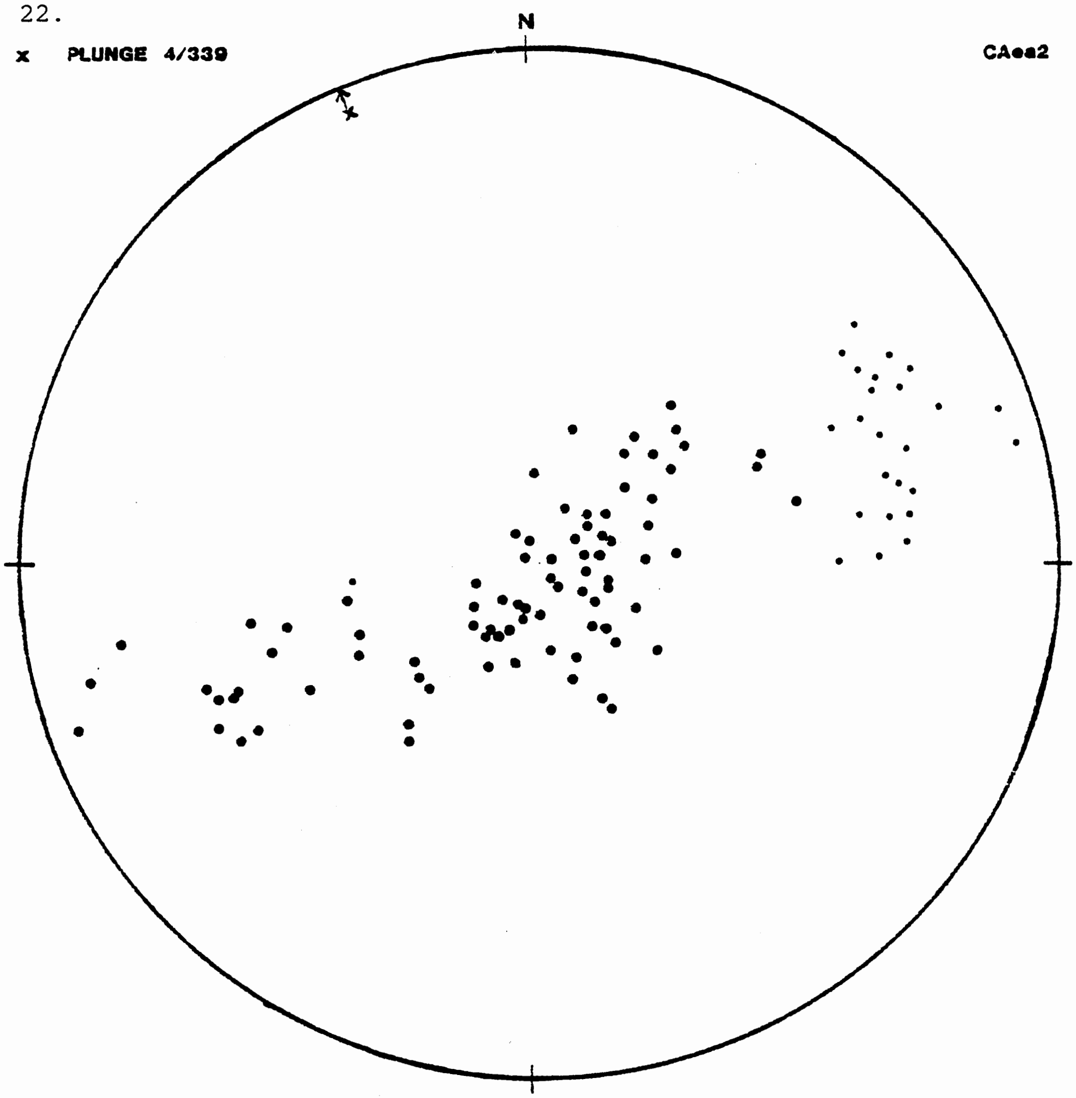

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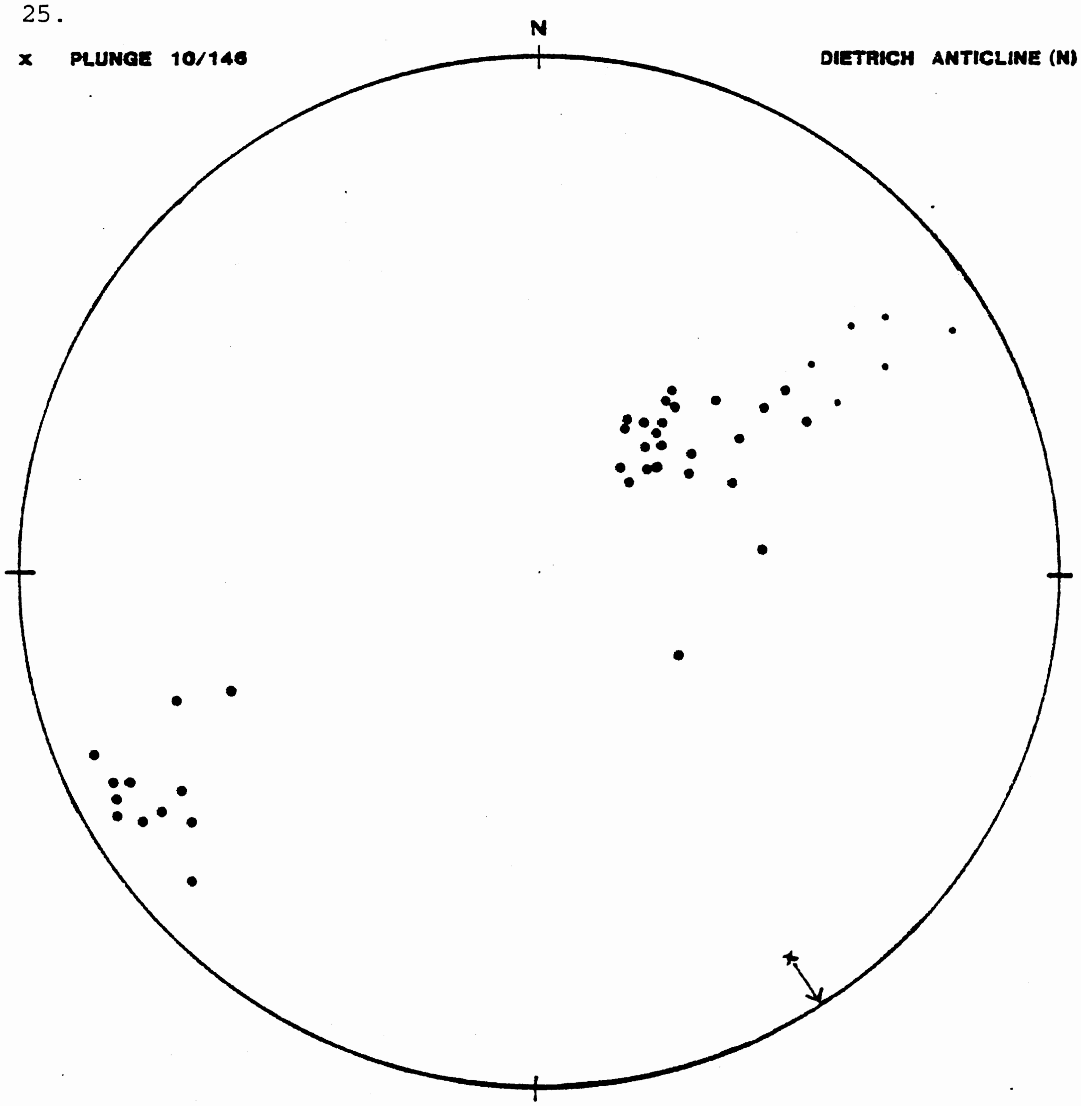

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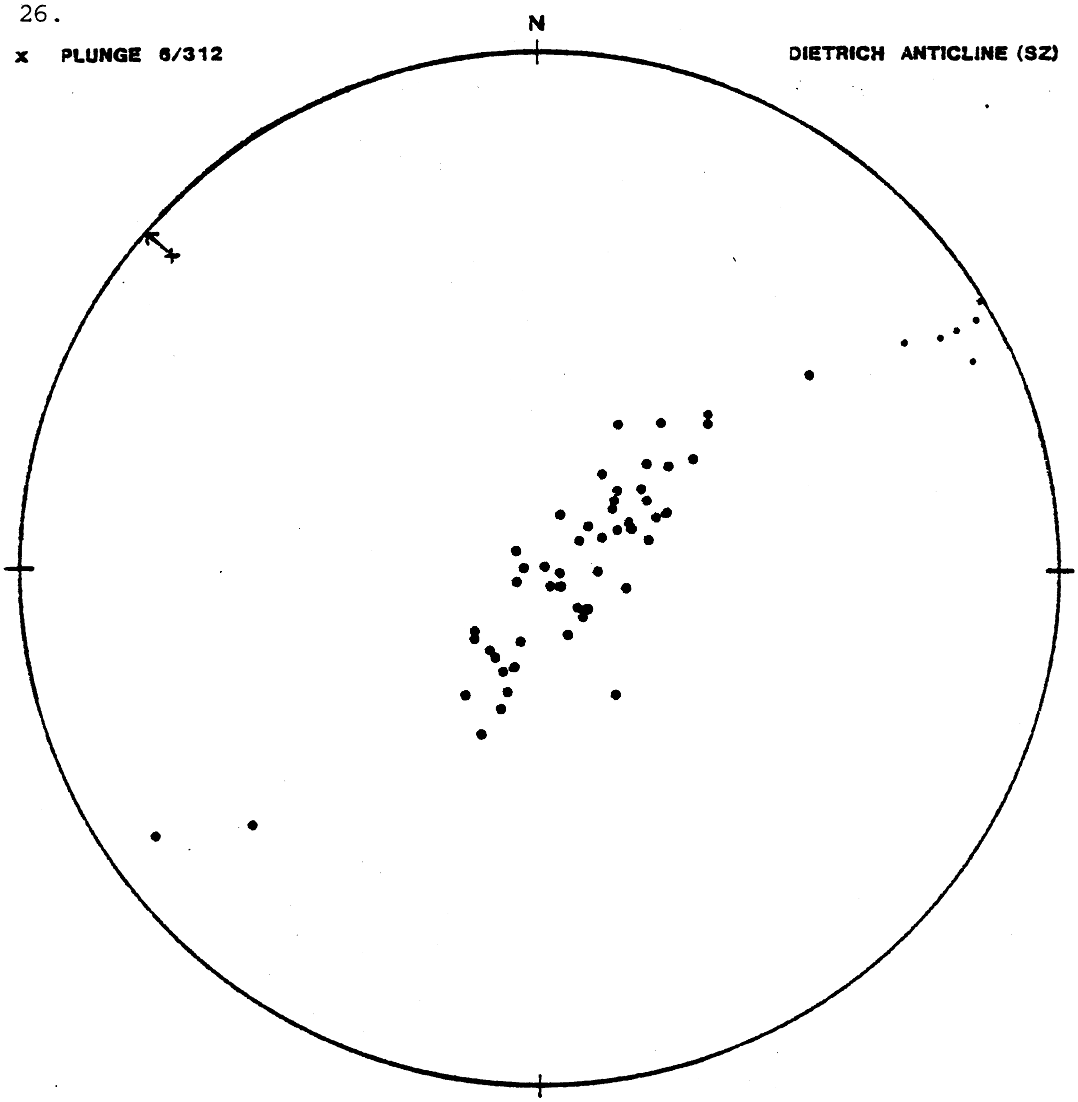

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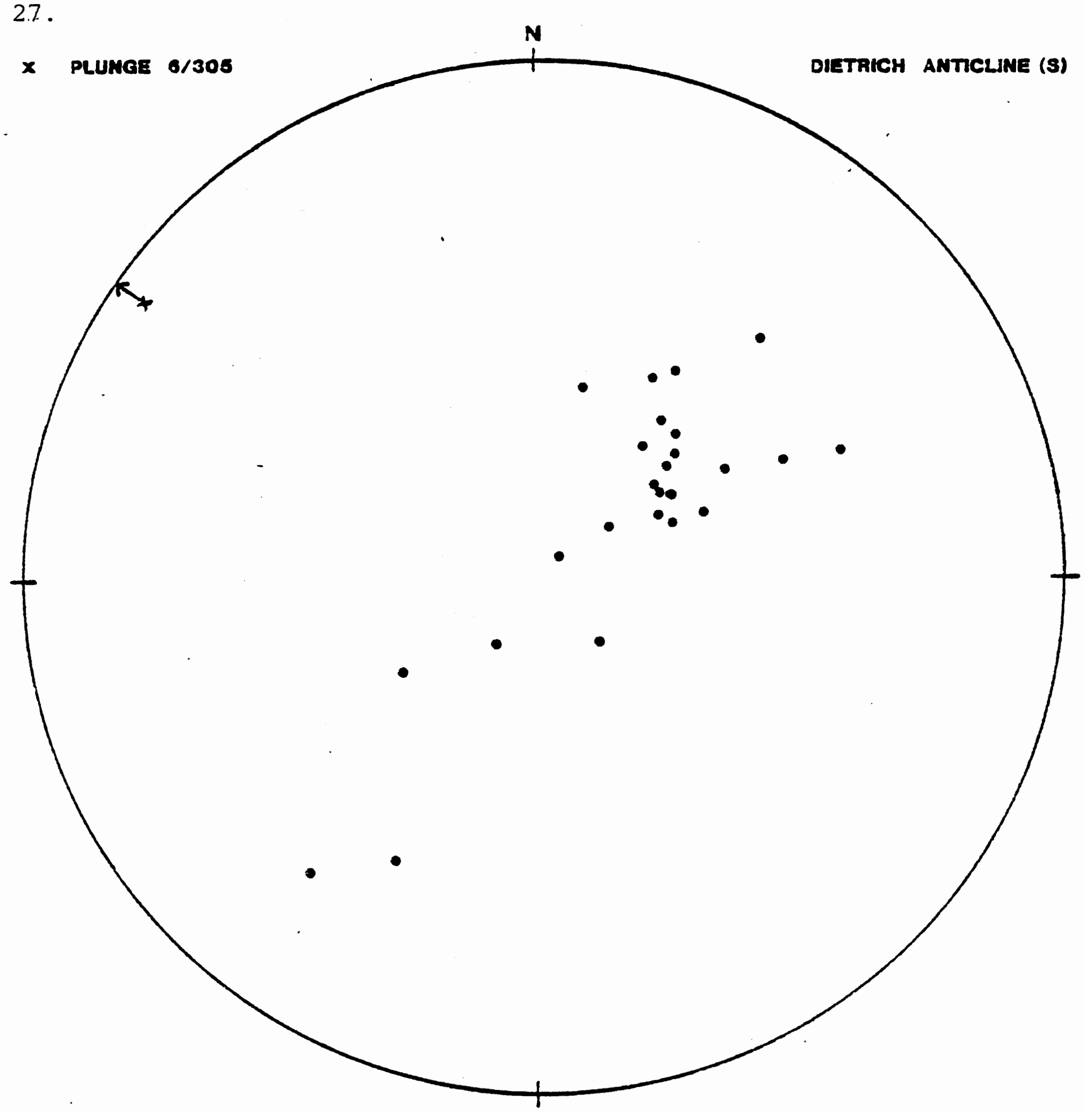

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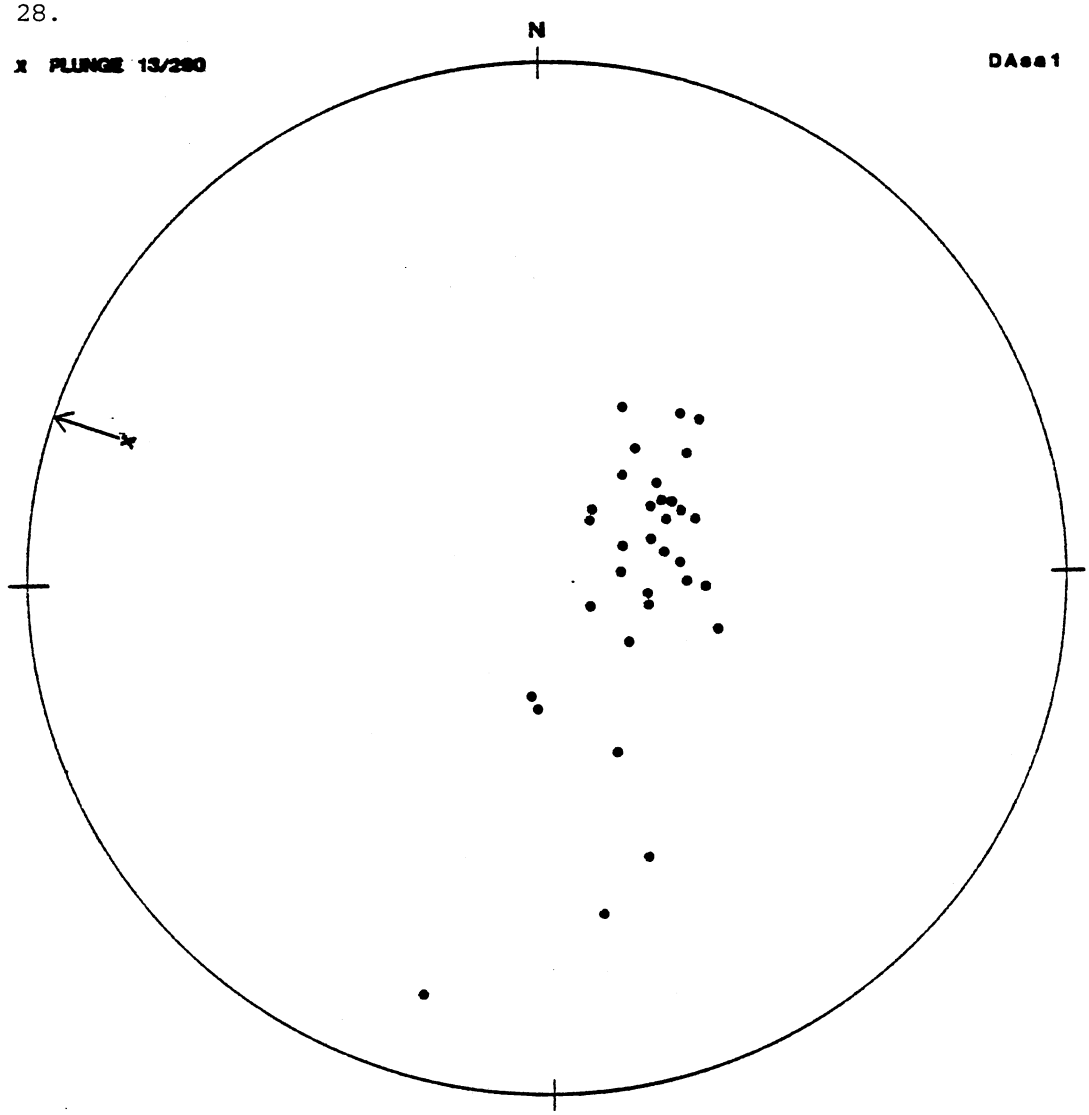

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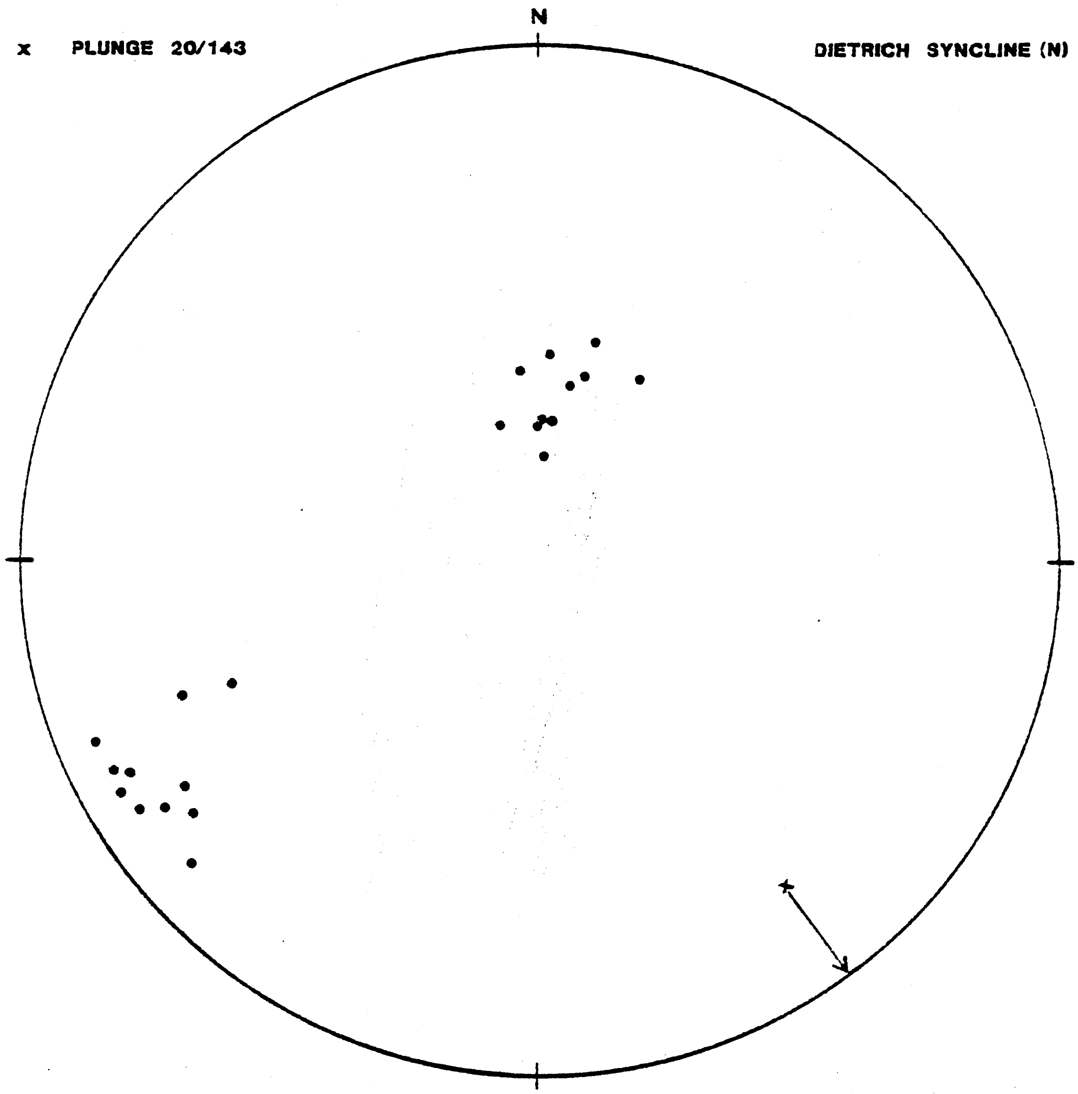

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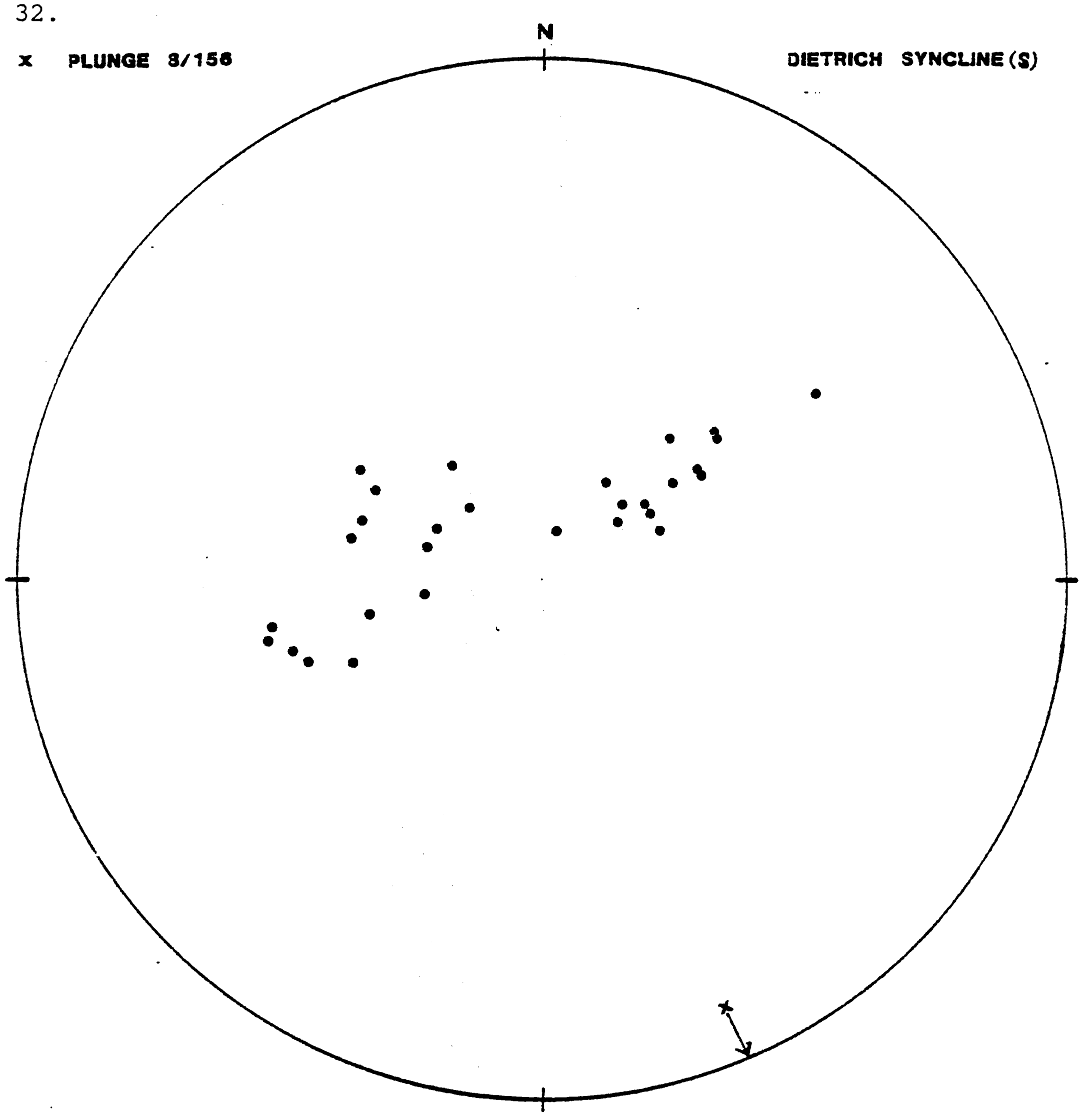

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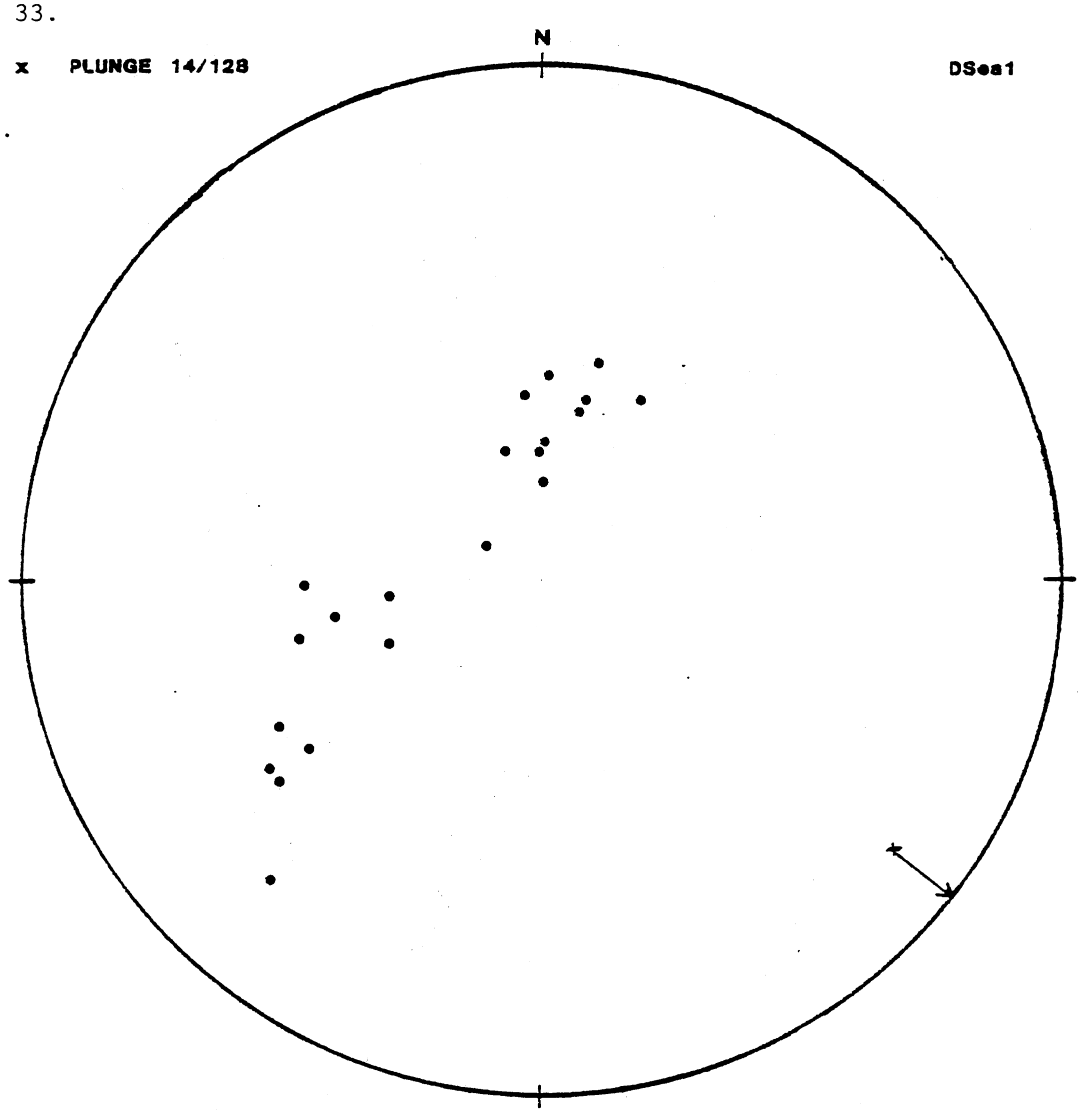

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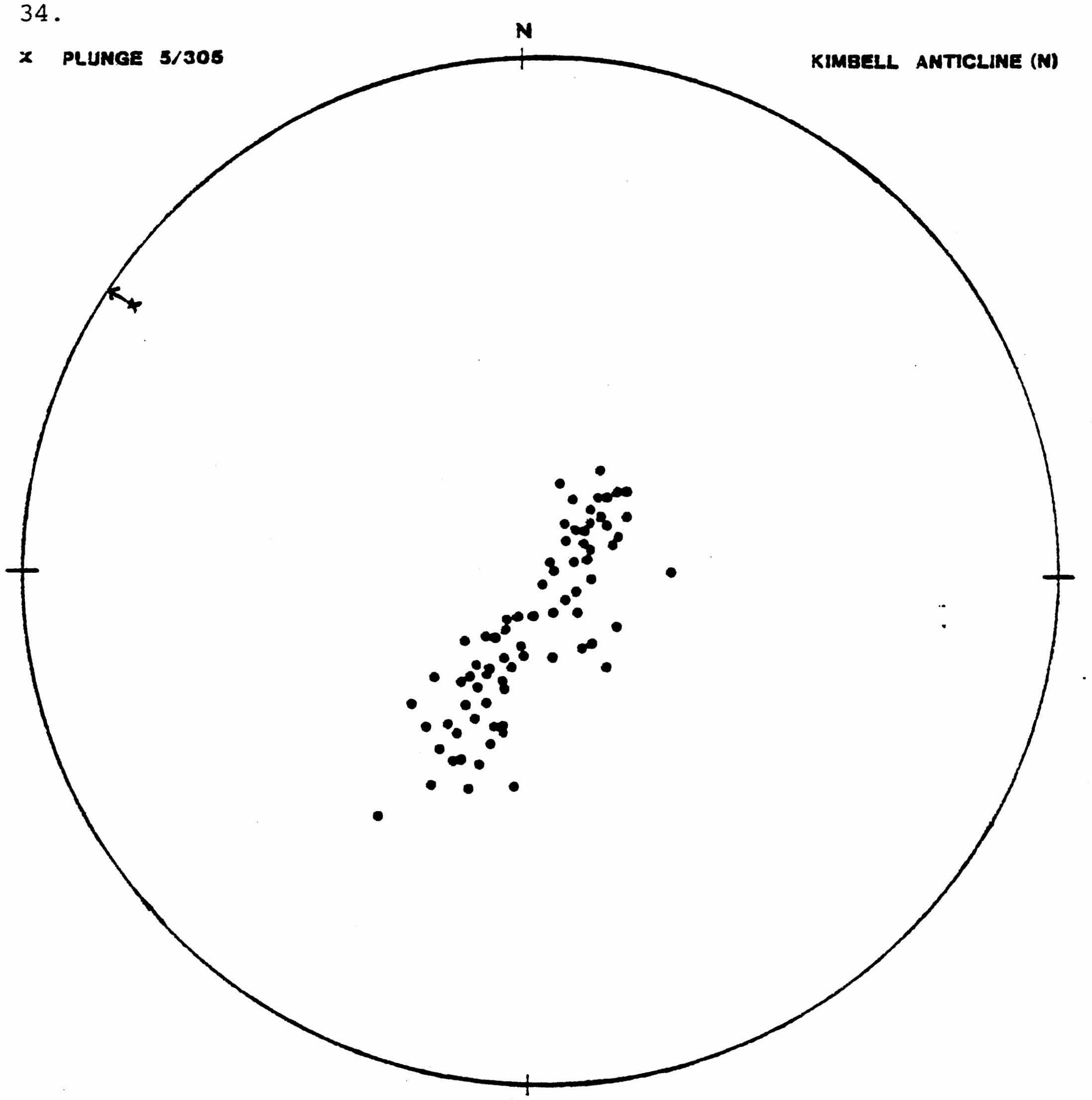

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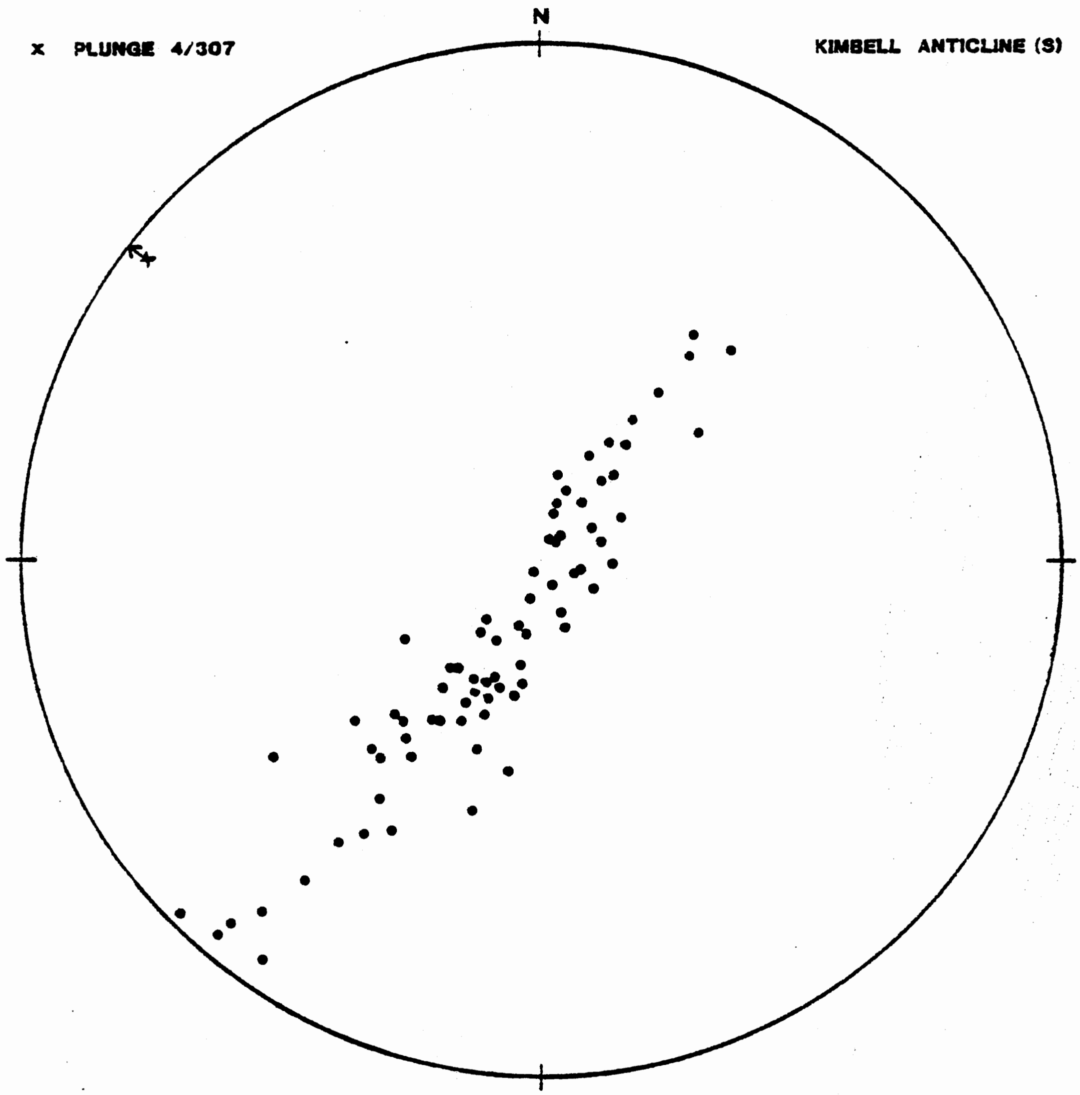

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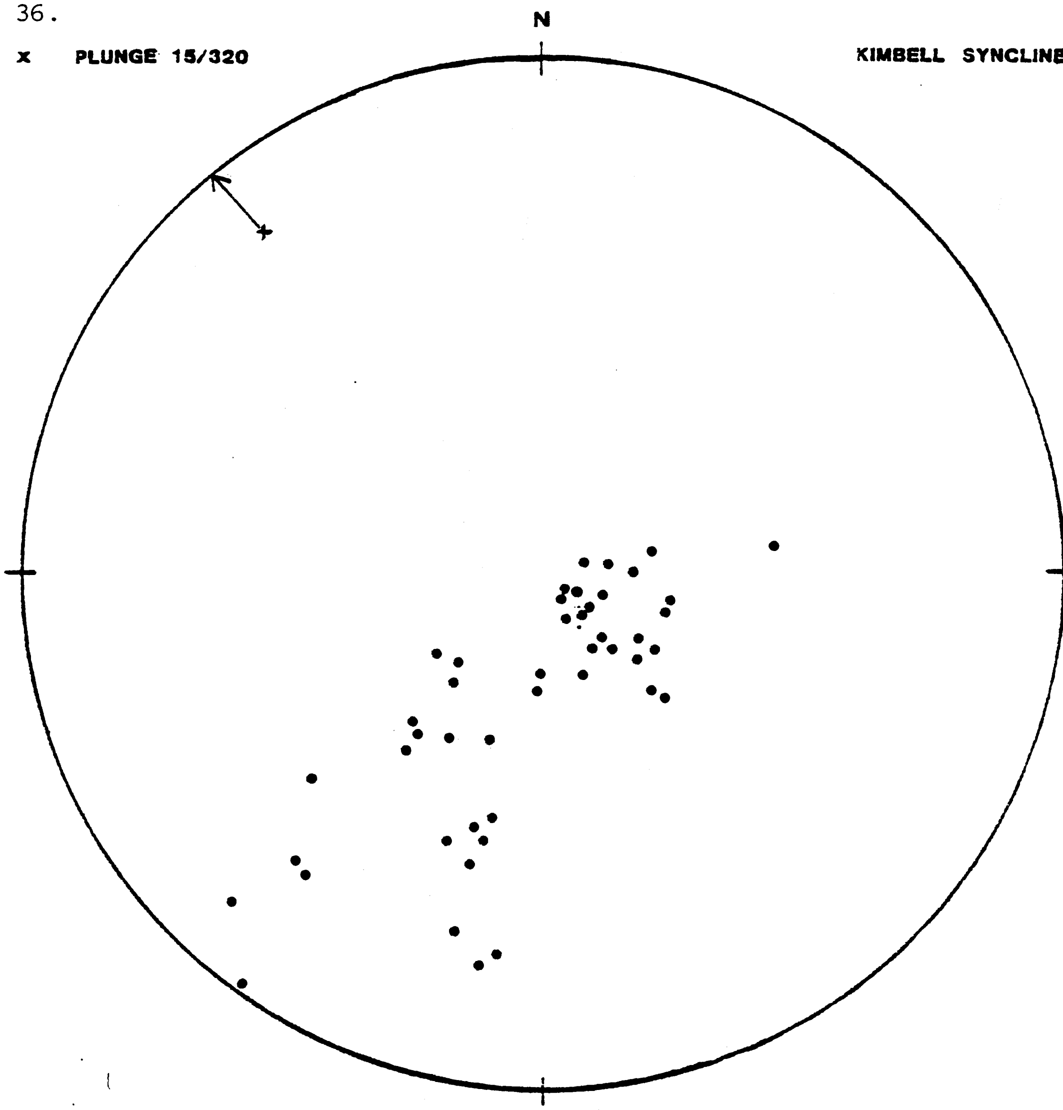

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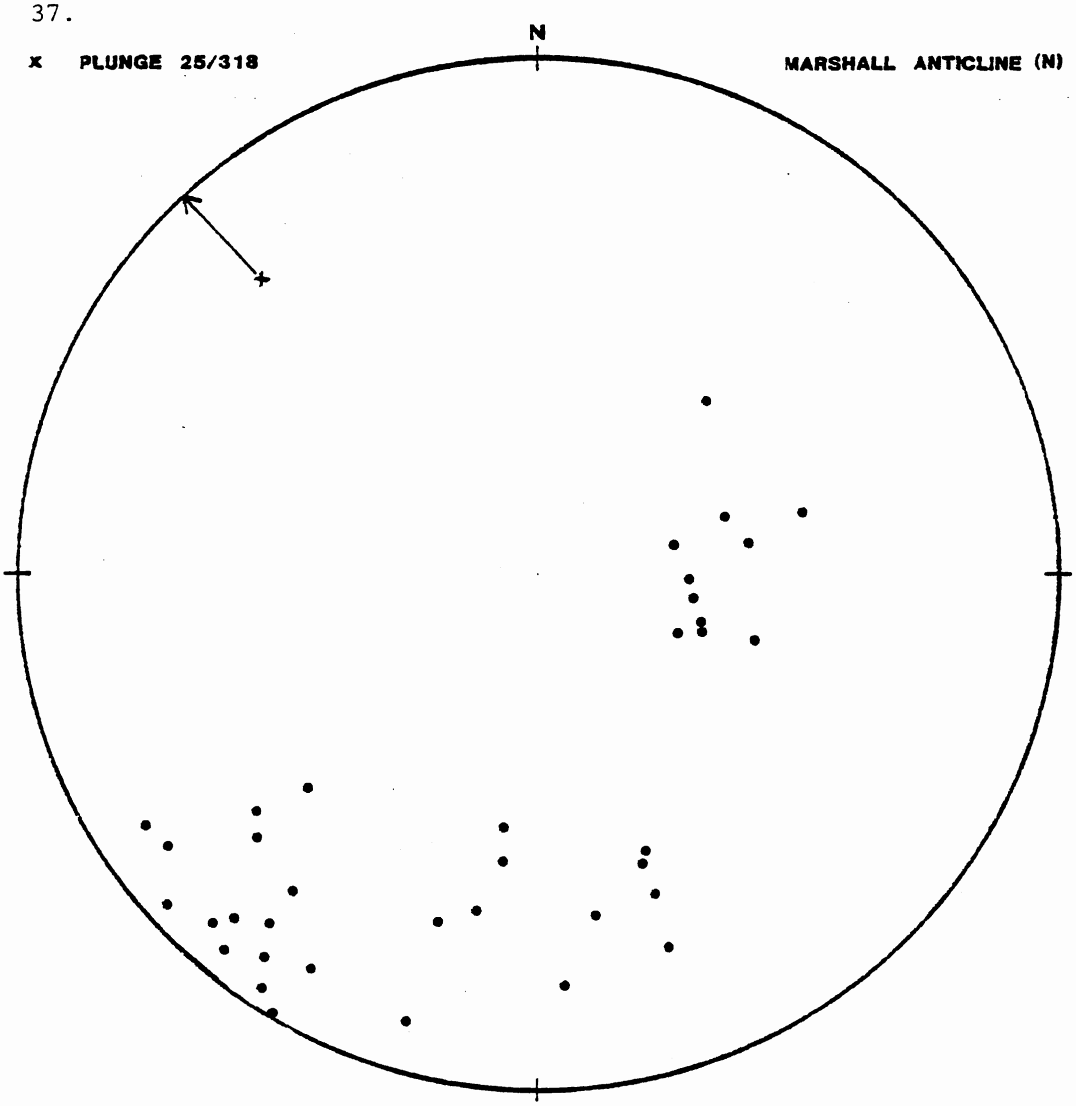

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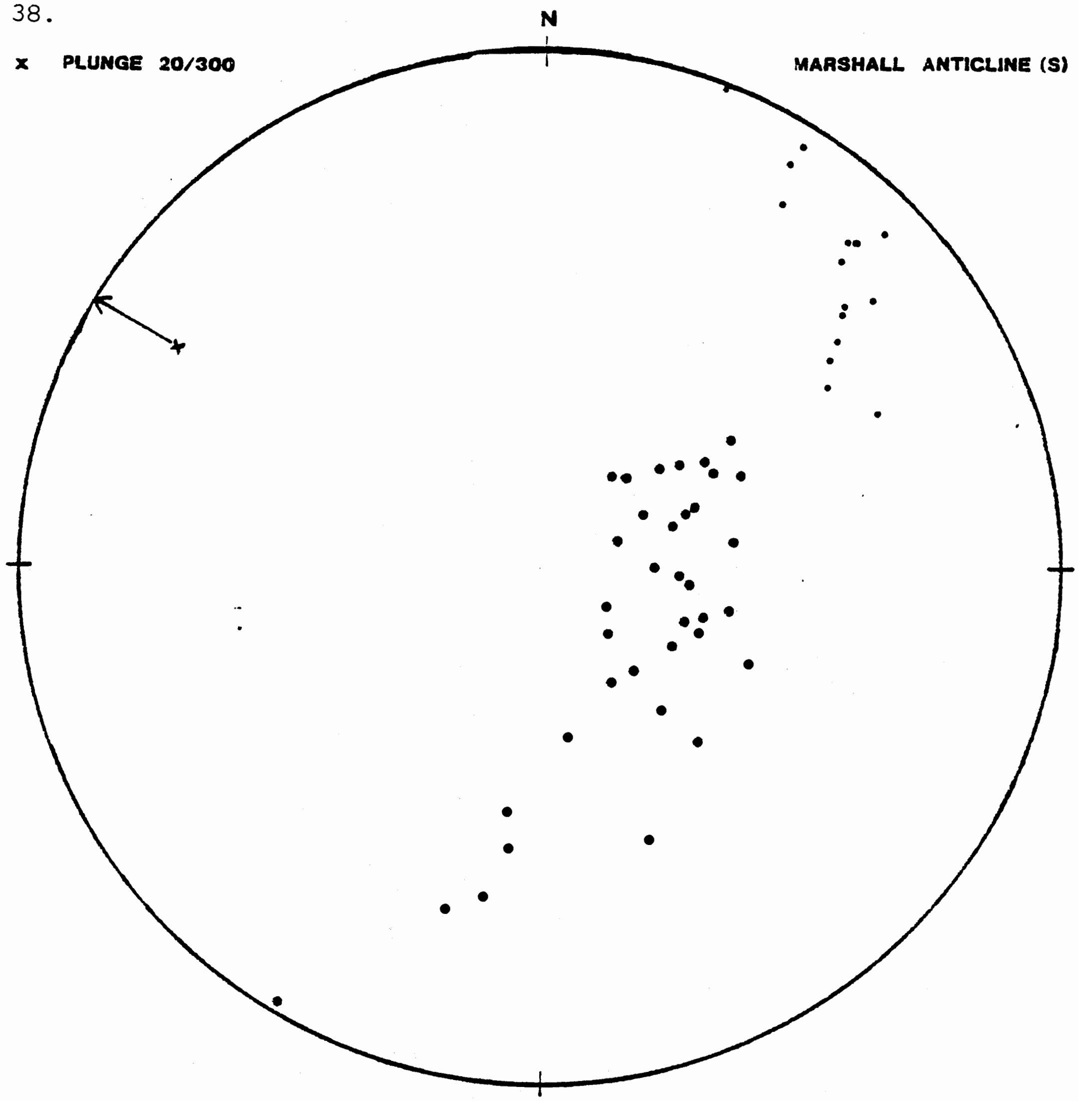

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x PLUNGE 3/137

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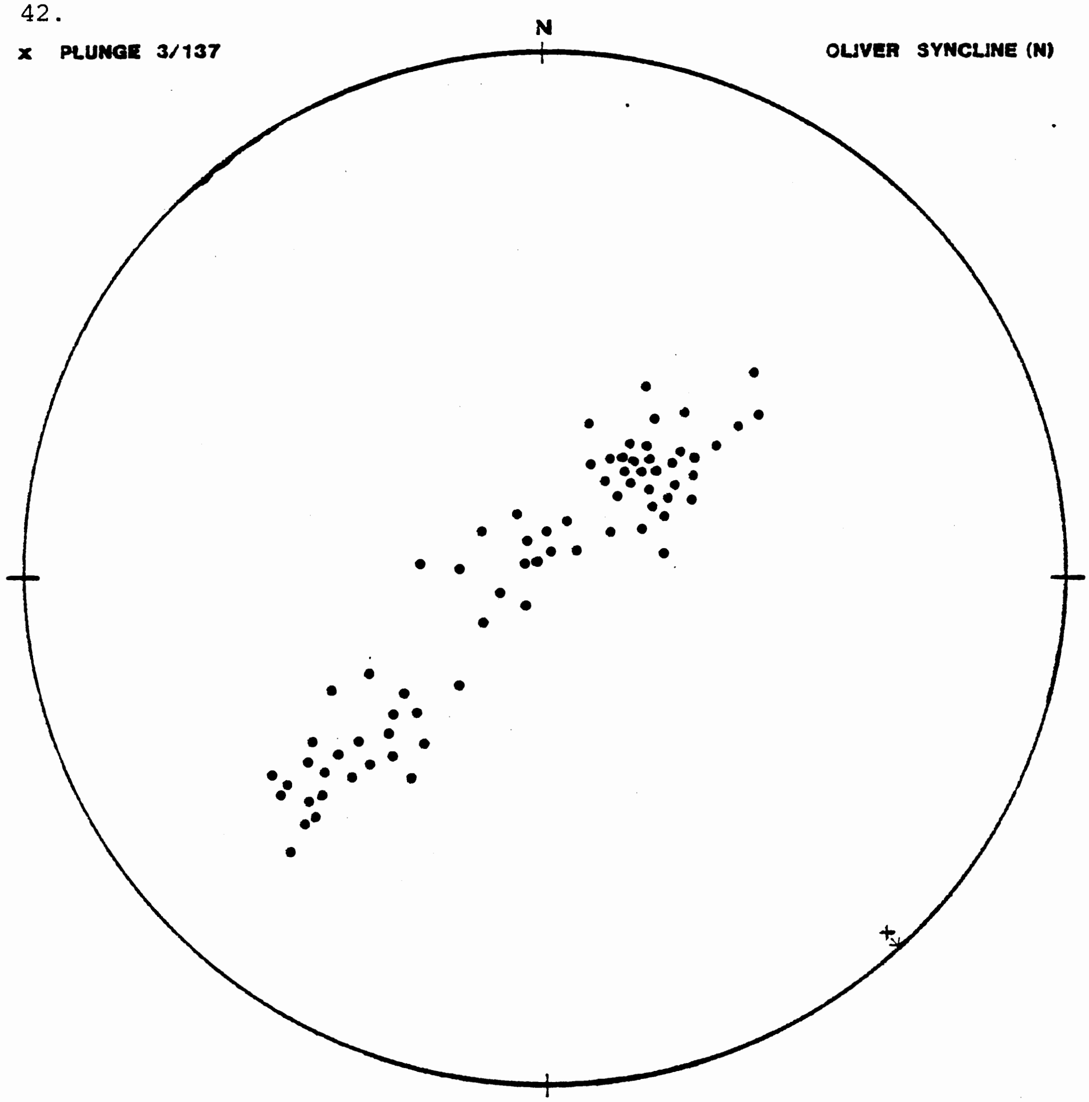

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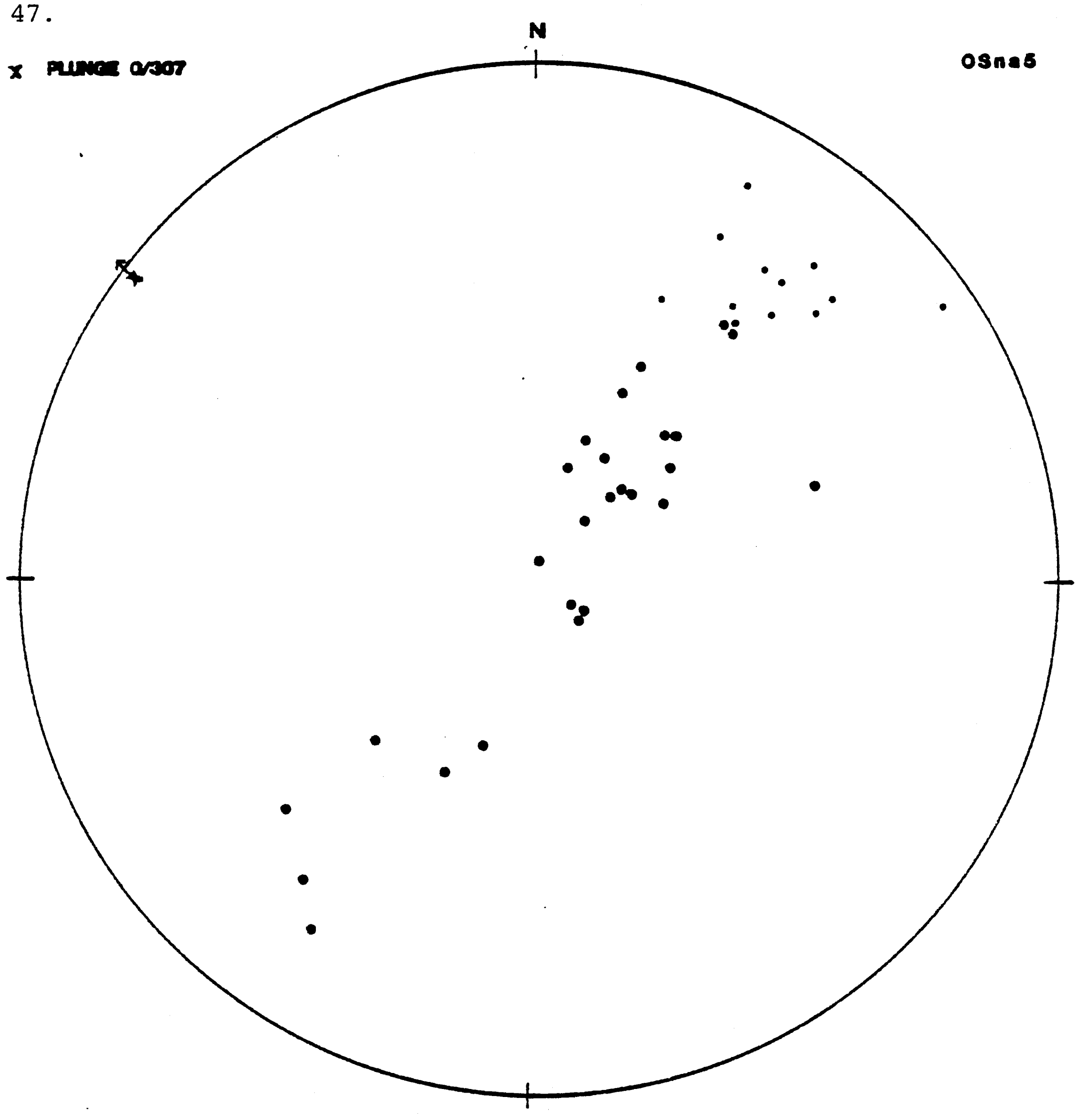

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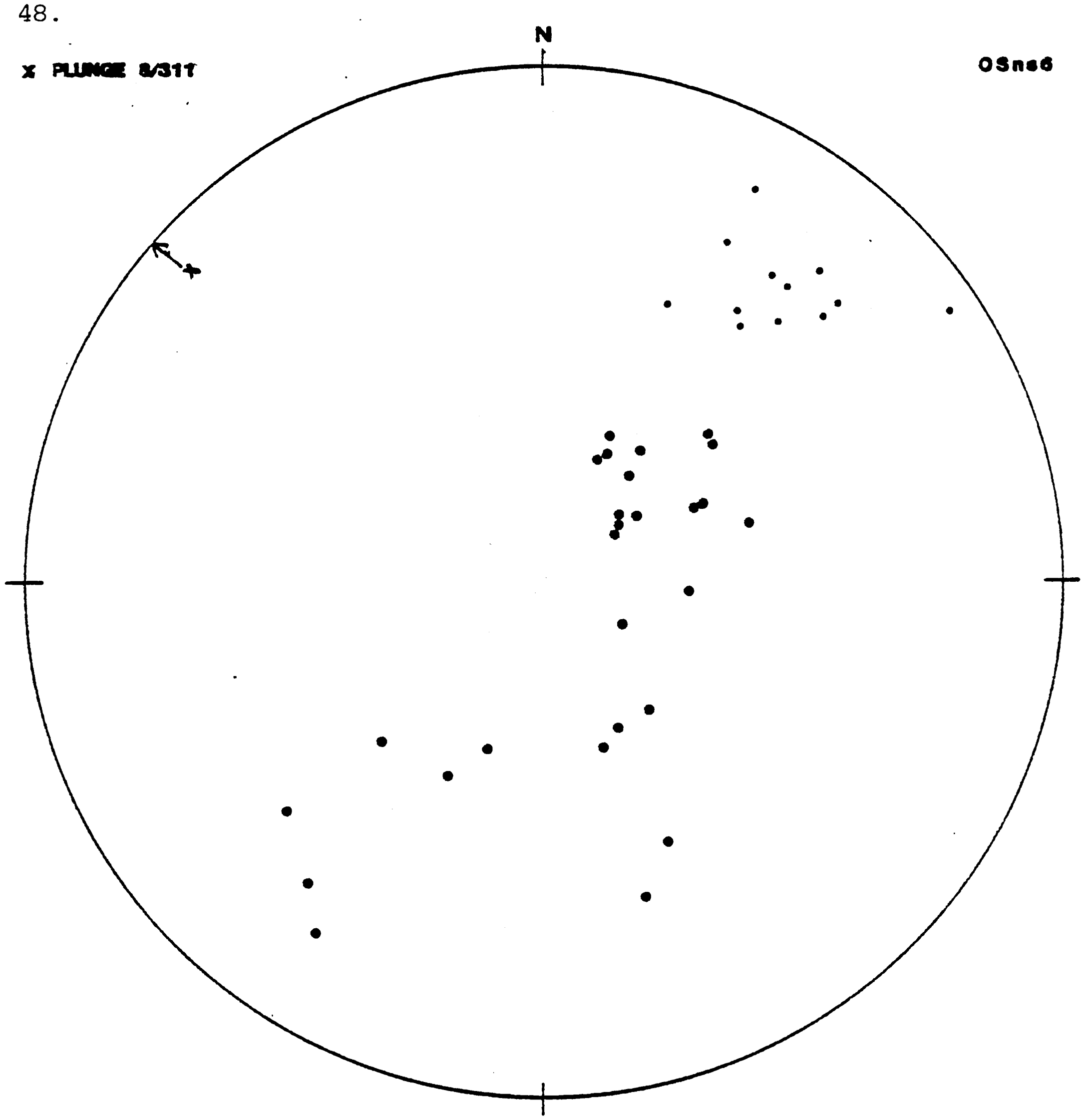

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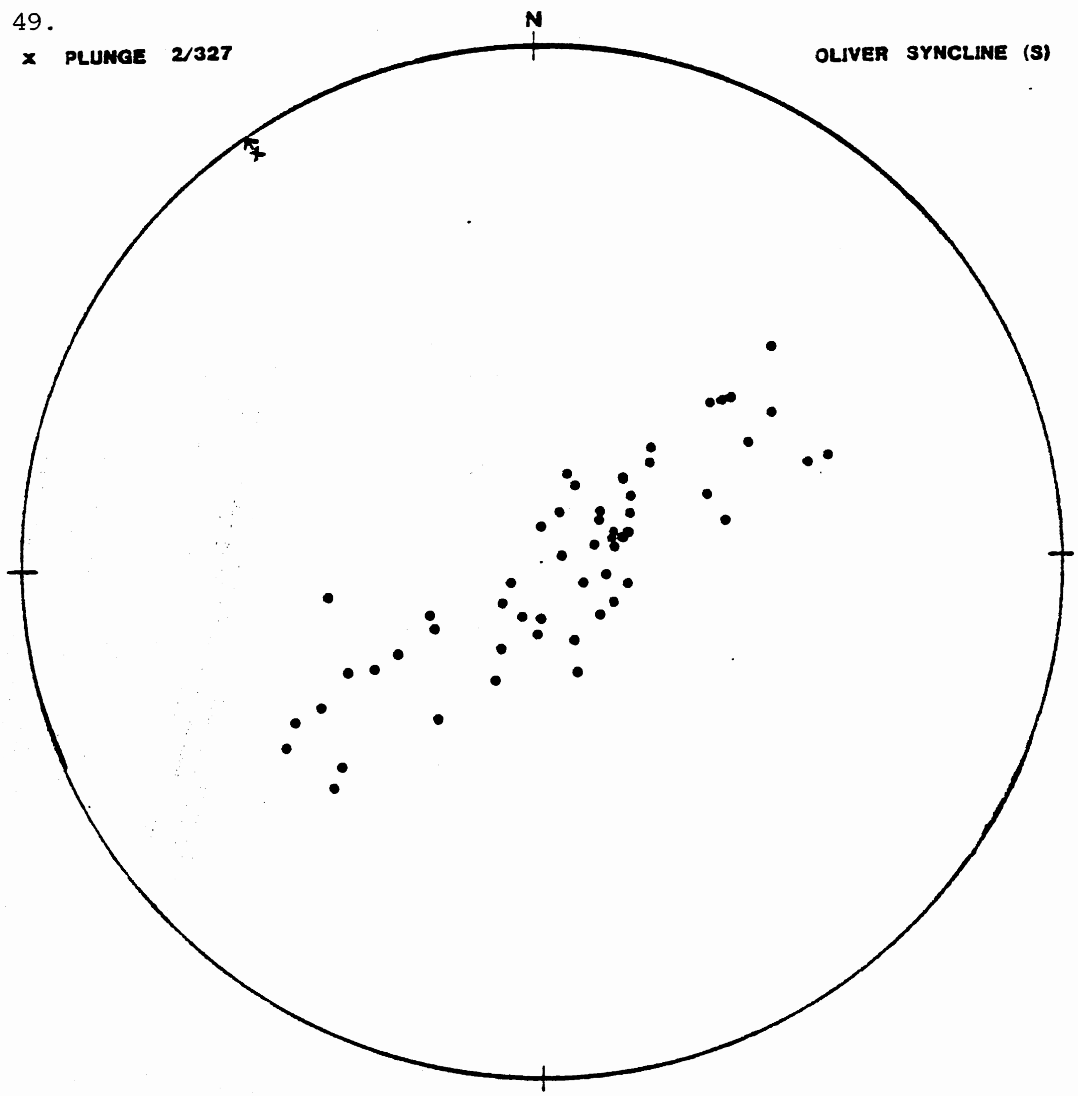

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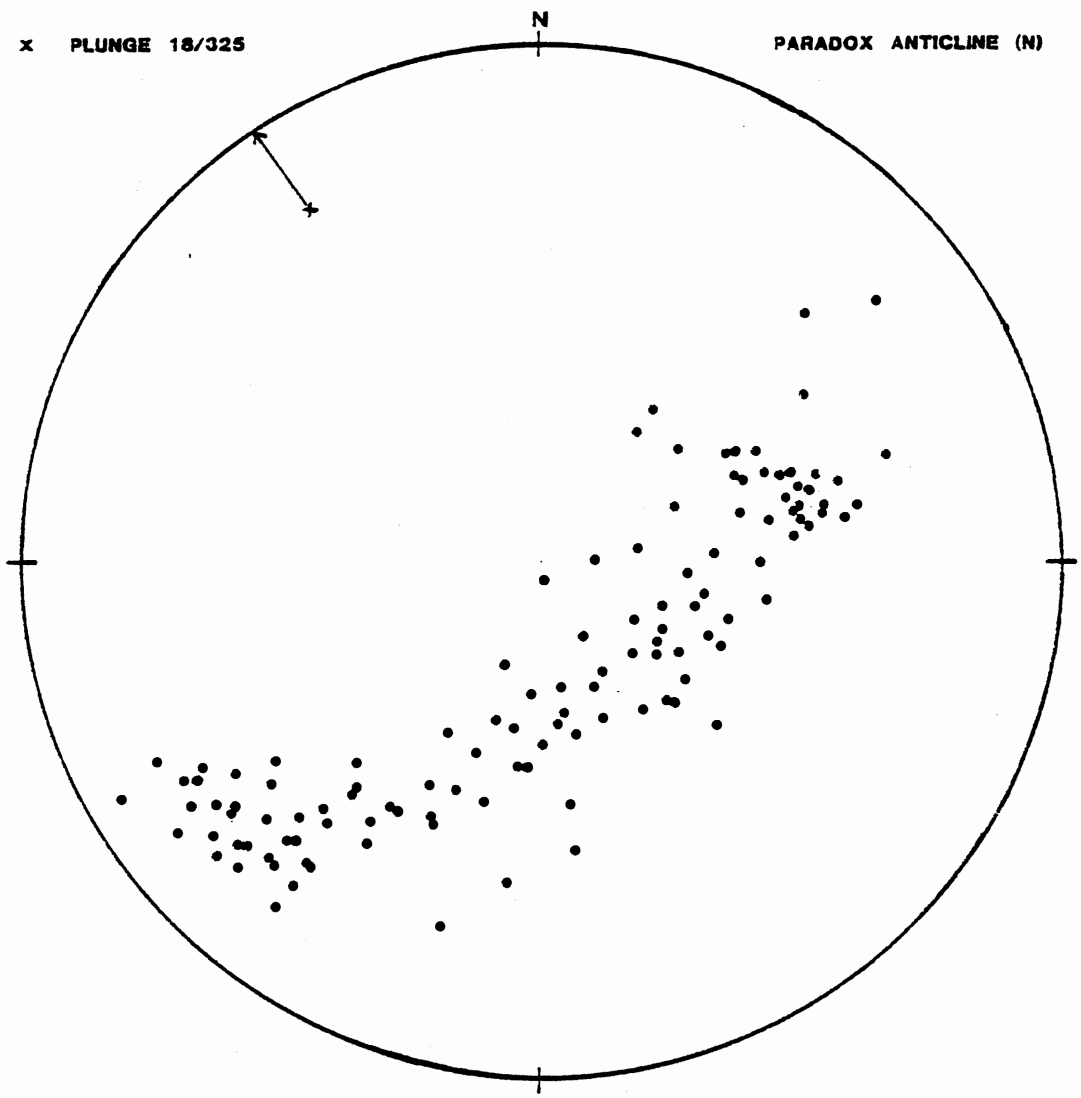

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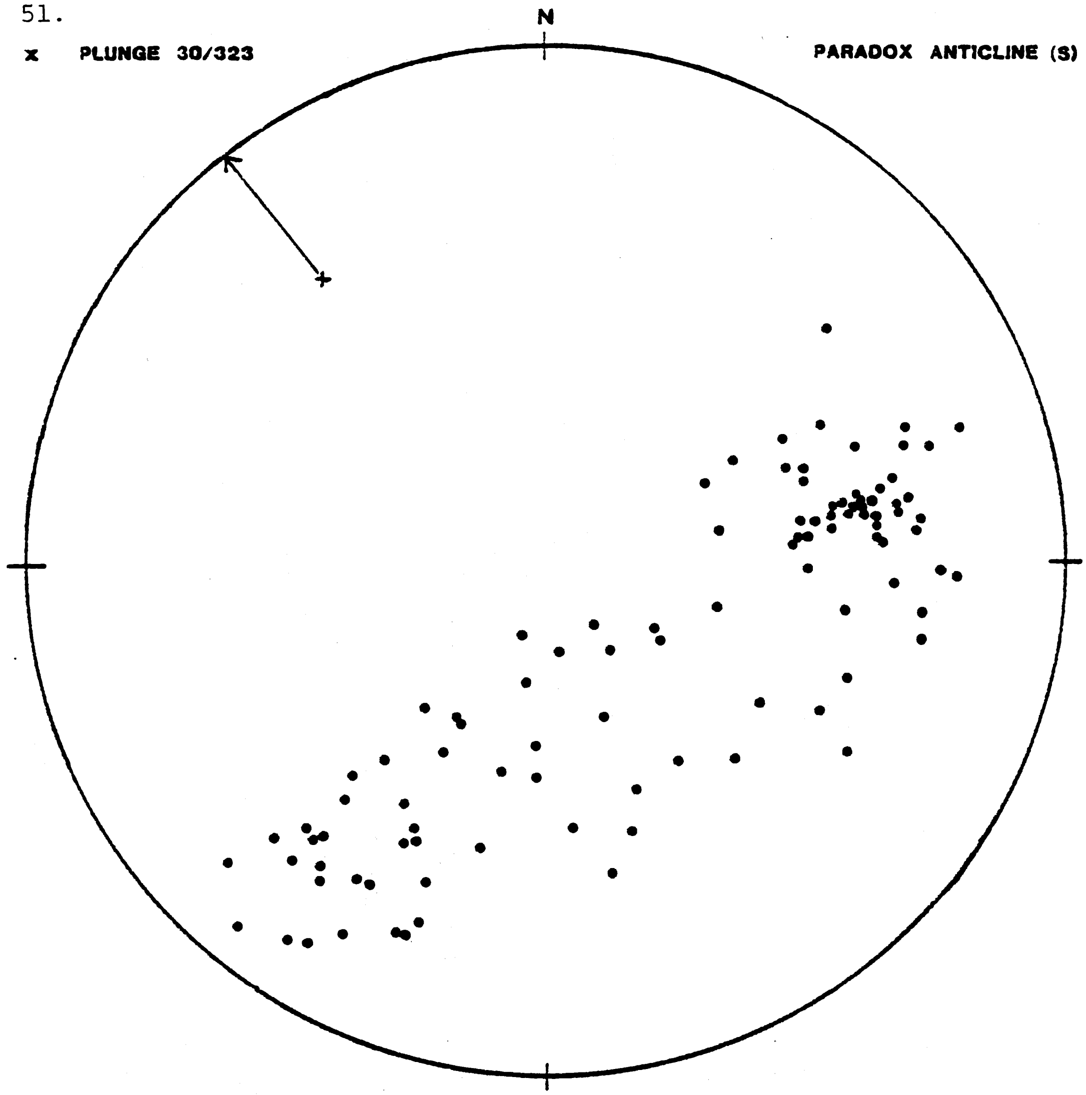

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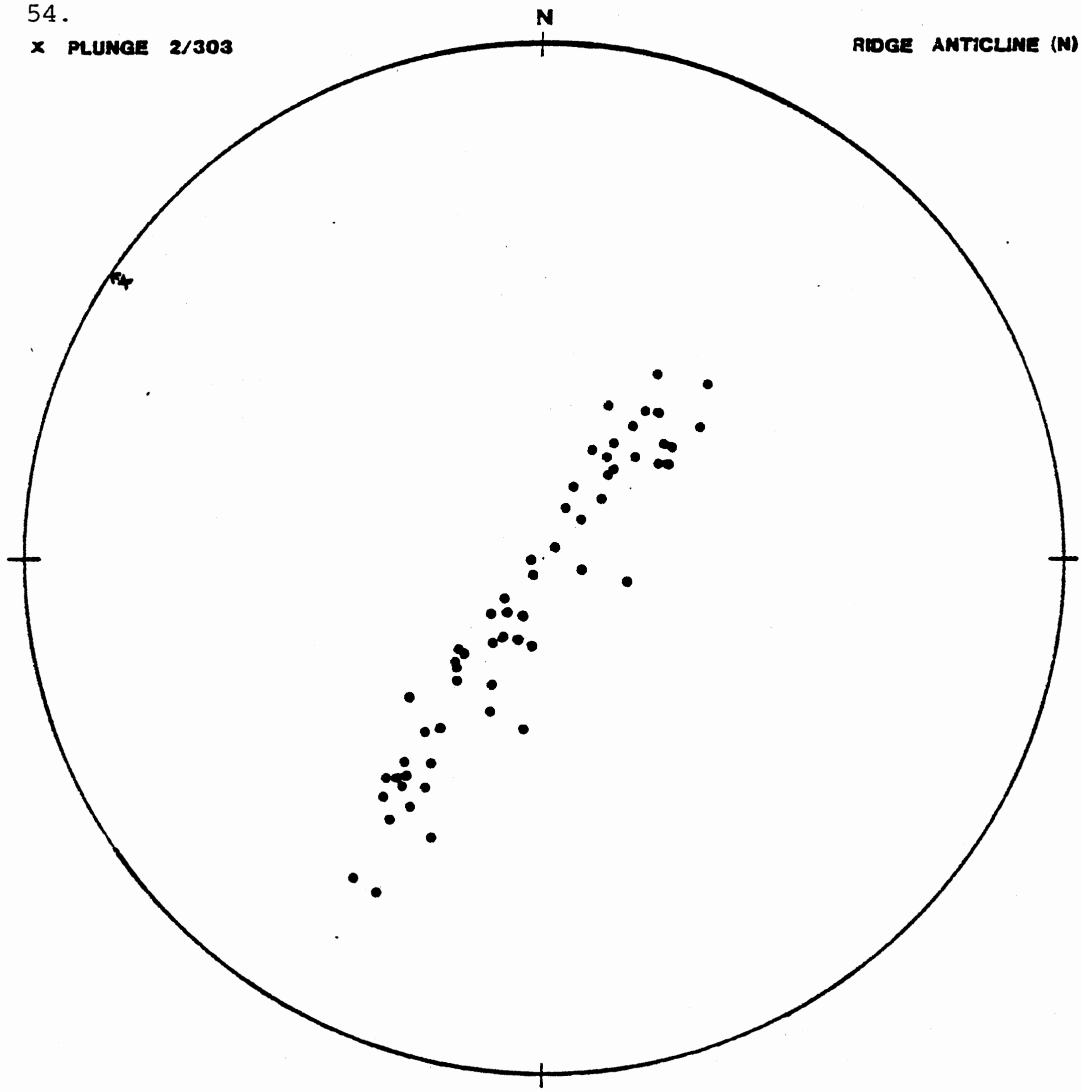

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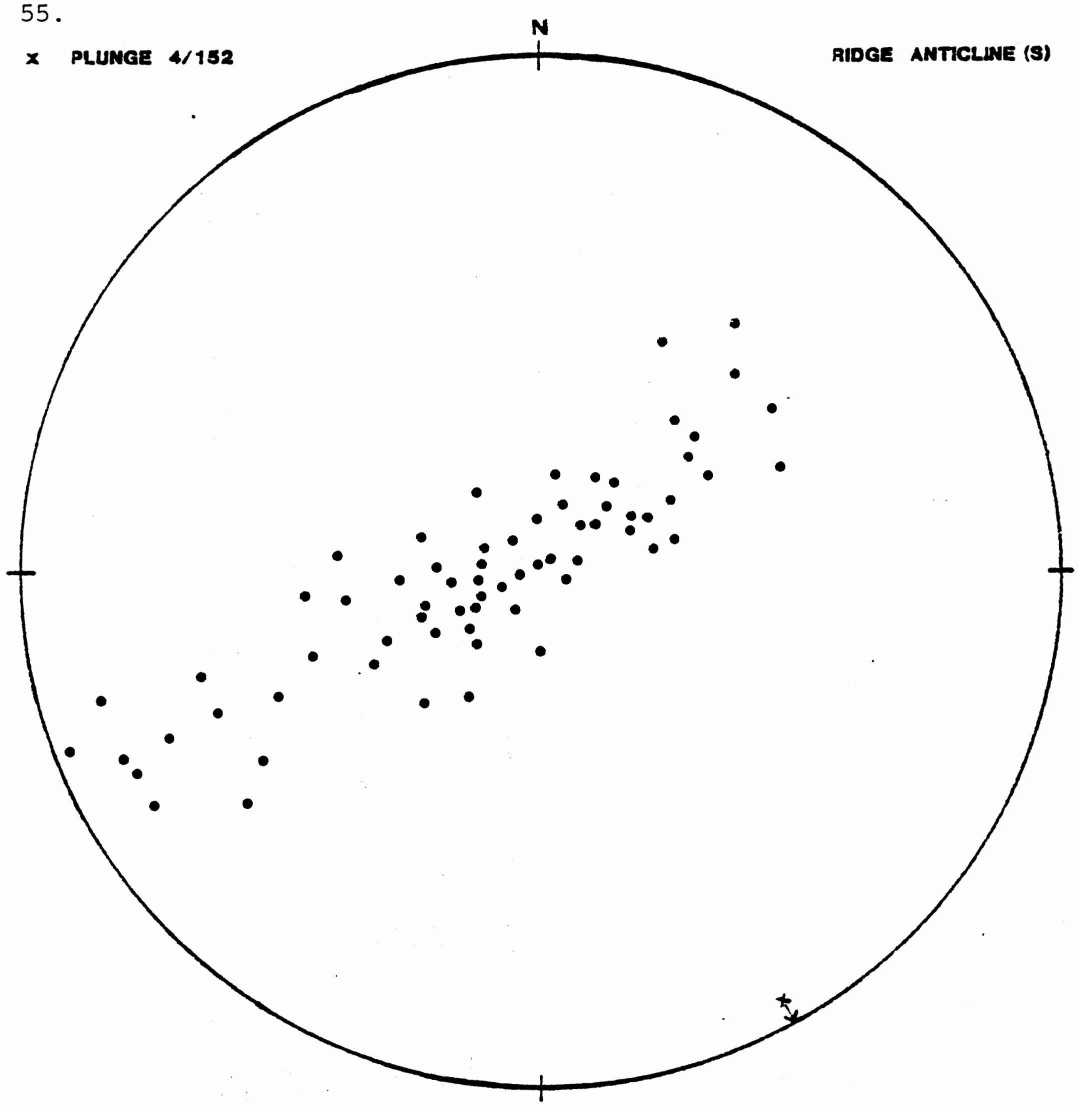
x PLUNGE 4/152



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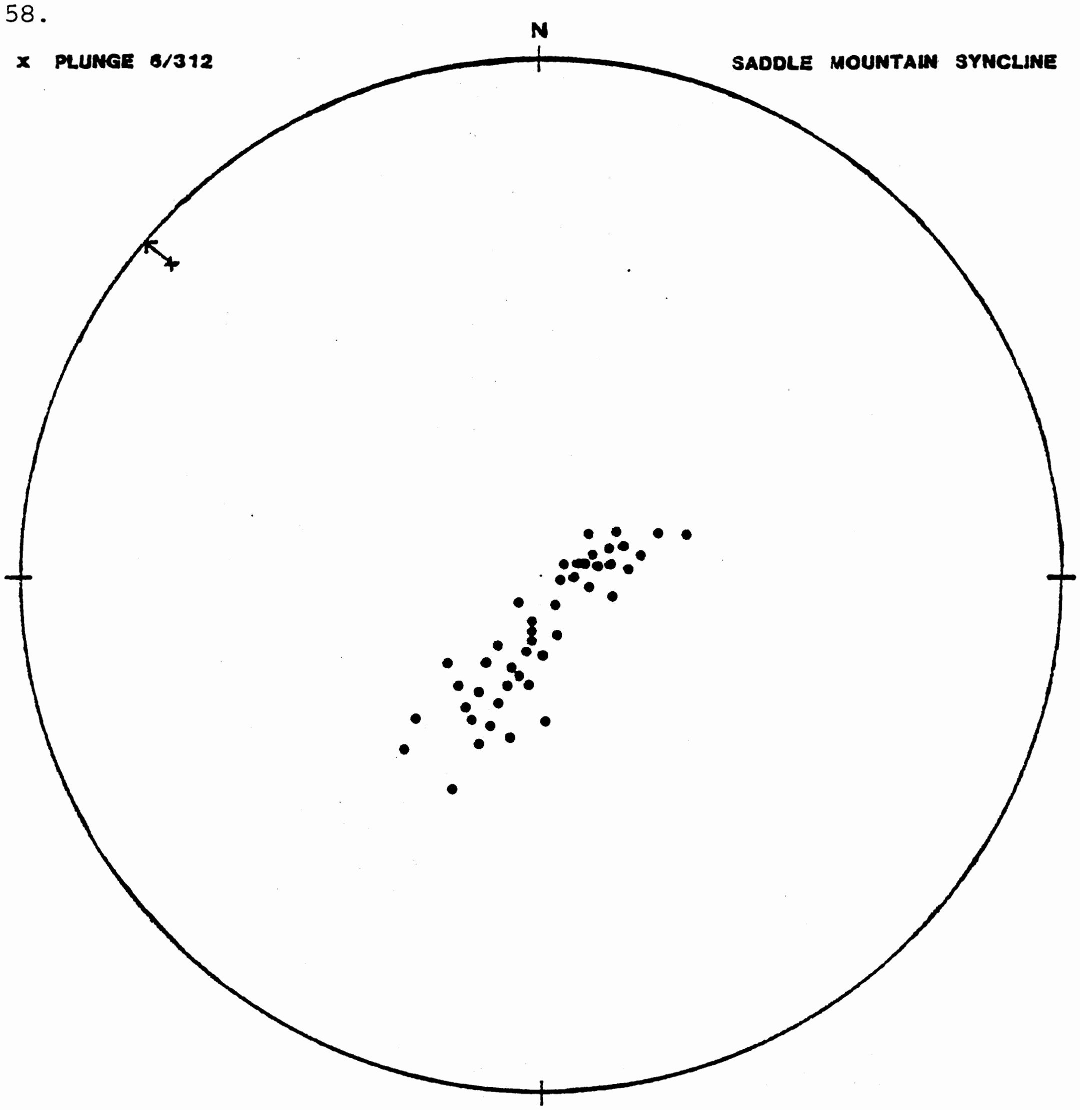

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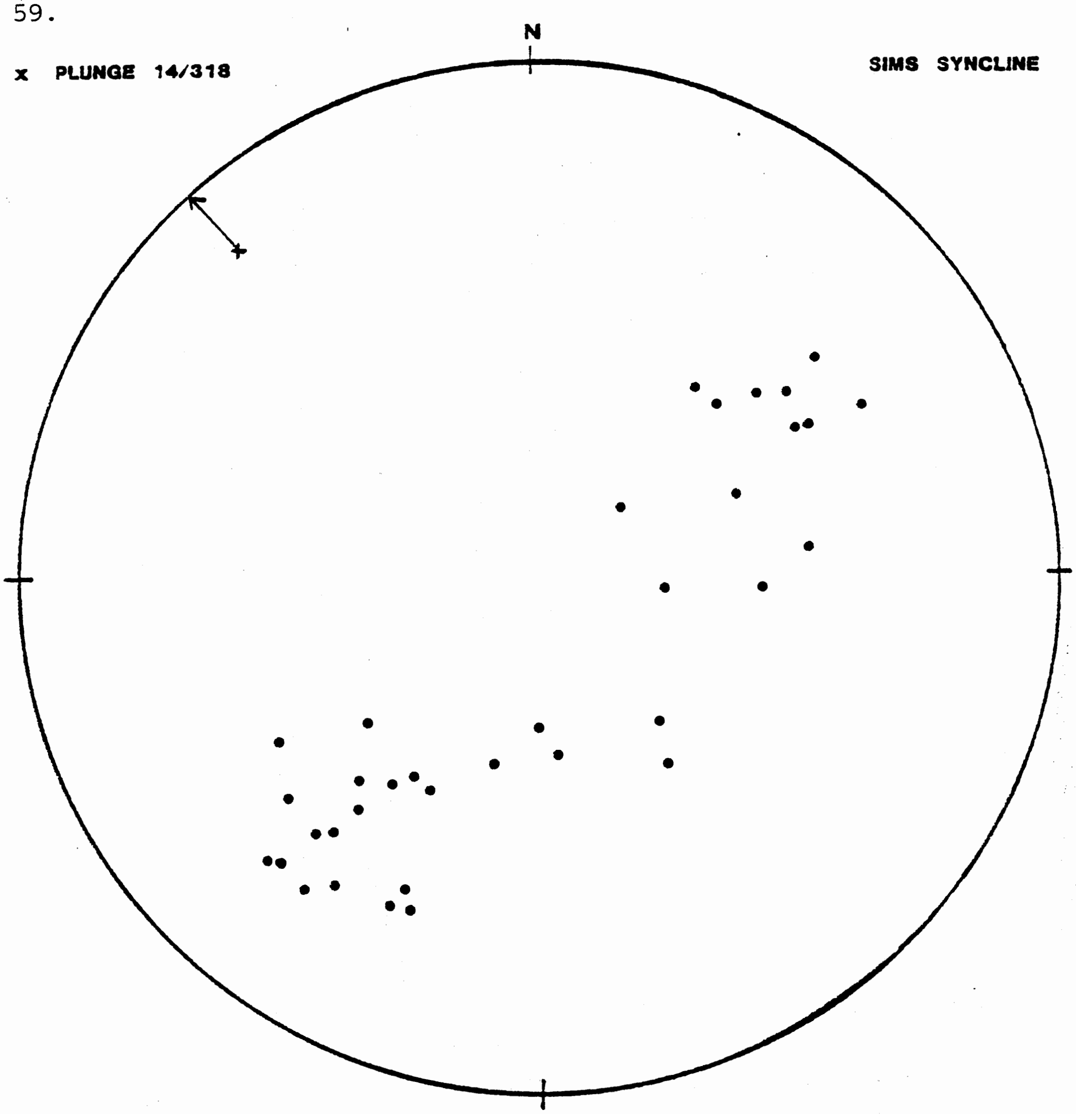

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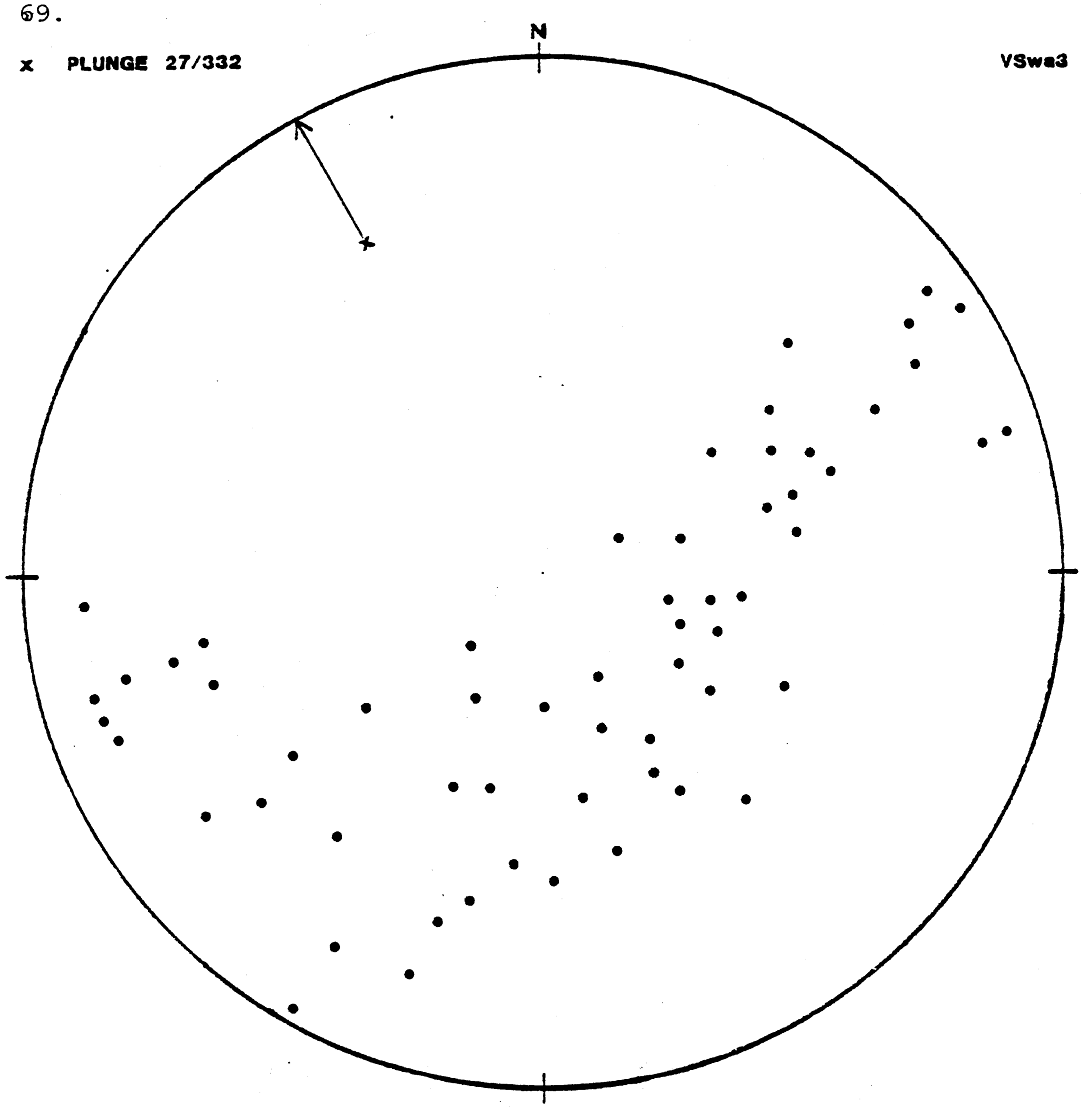

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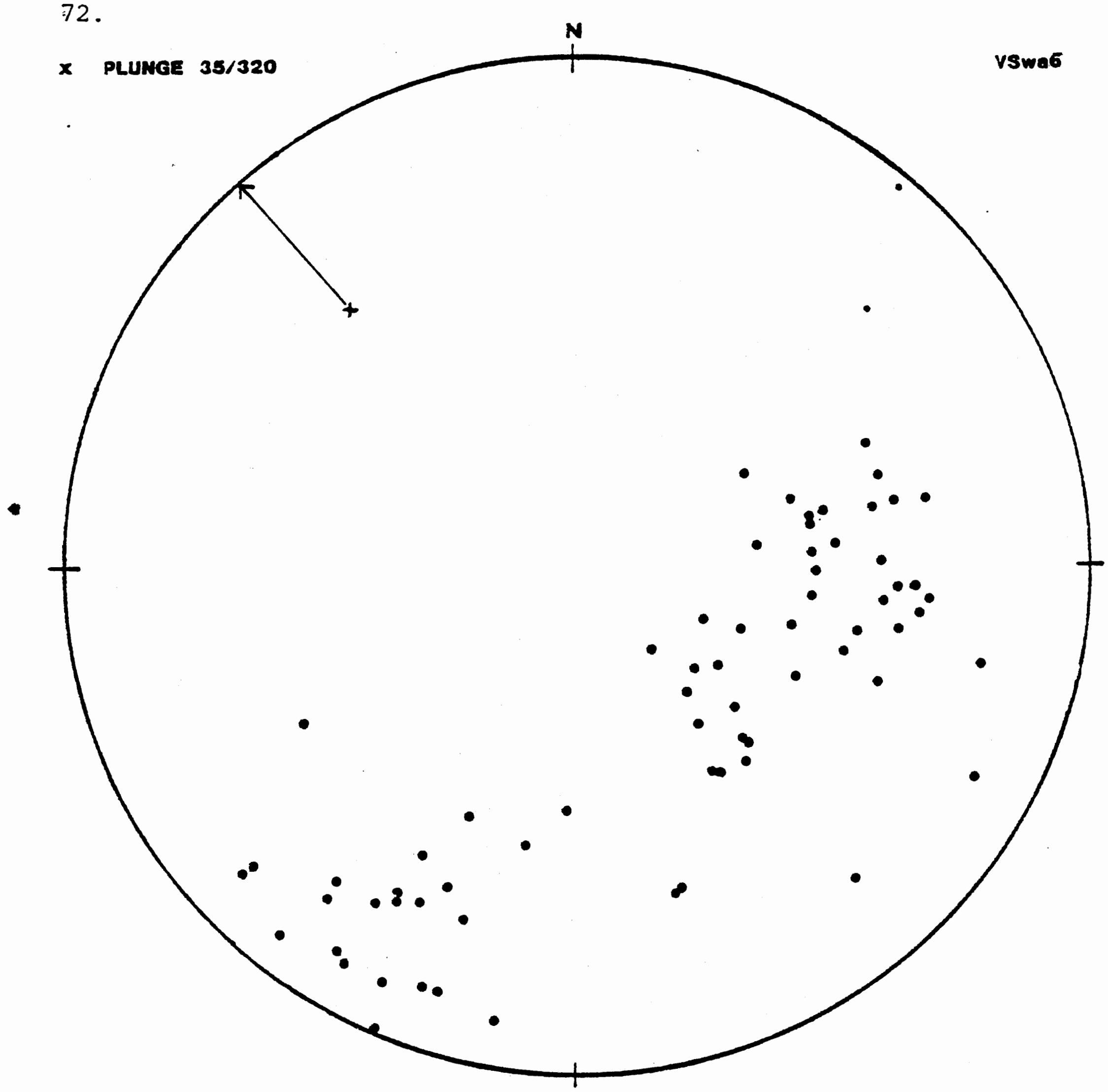
x PLUNGE 35/320

VSwa6



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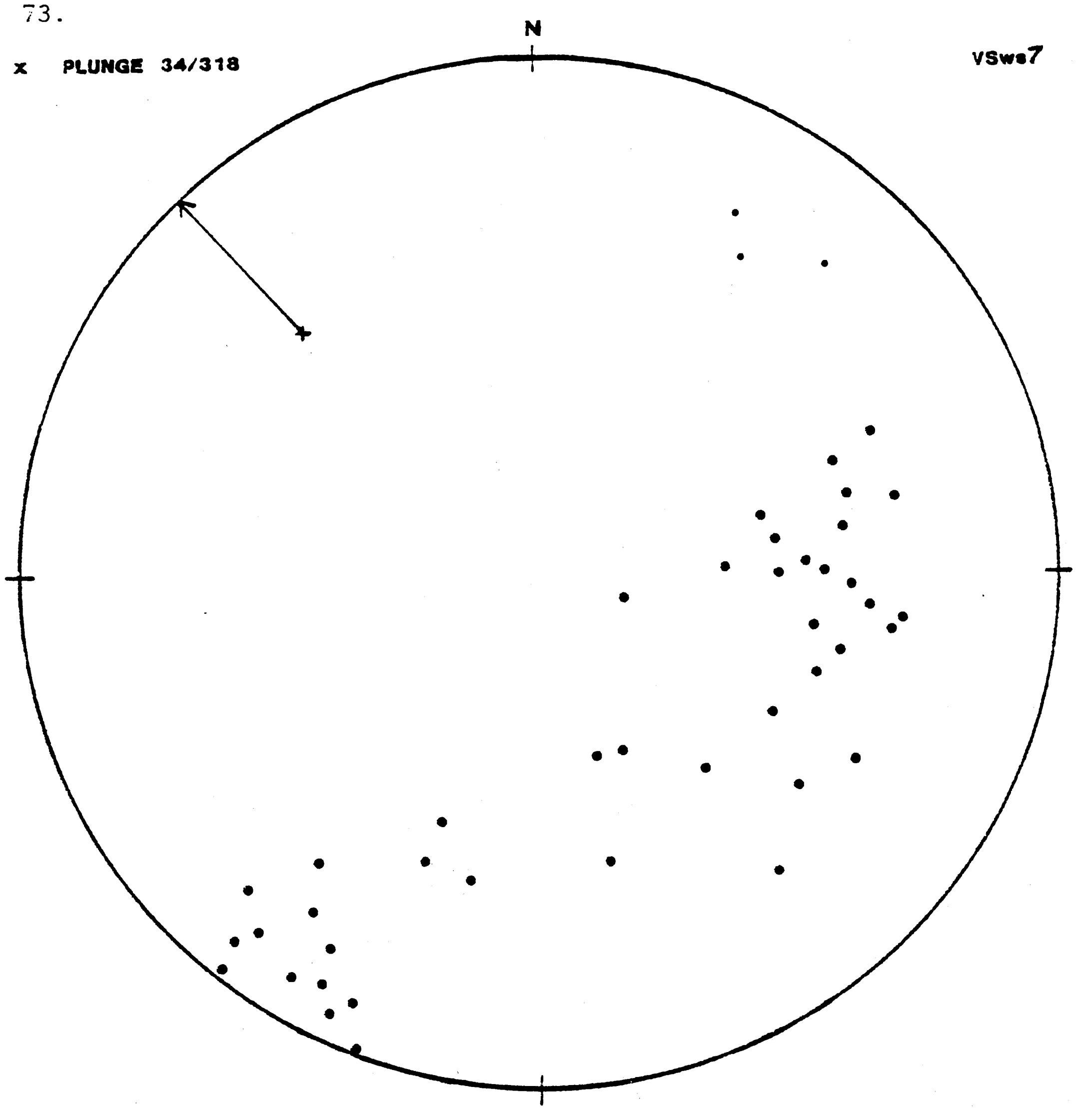

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Master of Science

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