UNIVERSITY OF CINCINNATI

July 10 *19* 64

I hereby recommend that the thesis prepared under my supervision by John David Sims

entitled A Sedimentary Petrographic Study of the Upper Fort Union Group, Northern Crazy Mountains, Montana

be accepted as fulfilling this part of the requirements for the degree of Master of Science

Approved by:

Hans J. Hofmann

William F. Jenks

Harvey C. Sunderman

Form 668—Grad. Sch.—1M—4-61

A SEDIMENTARY PETROGRAPHIC STUDY OF THE UPPER FORT UNION GROUP, NORTHERN CRAZY MOUNTAINS, MONTANA

A dissertation submitted to
The Graduate School
of the University of Cincinnati
in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE

1964

by

John David Sims

B. S. University of Illinois 1963

17.2.65 LW

Table of Contents

List of Figures

Tables

A Sedimentary Petrographic Study of the Upper Fort Union Group, Northern Crazy Mountains, Montana

by

John David Sims

Abstract

The stratigraphic position of the strata in the Crazy Mountains of southwestern Montana has long been in doubt. Terminology has been loosely applied and borrowed from other Tertiary basins.

This study provides the first bed-by-bed description of these strata. New paleontological evidence indicates a late Paleocene age of the strata. Environmental interpretation of the rocks concurs with previous authors.

The entire sequence studied is placed in the Melville formation of the Fort Union Group of Simpson(1937). The terminology of Simpson is adhered to because of the proximity of the area studied to the type sections described and mapped by Simpson.

The paragenesis of the minerals in these sediments is interesting. The upper 200 feet of the strata measured contain possibly diagenetic chlorite derived from finely comminuted biotite and has a 28 Å (001) d-value. Antipathetic relationships between calcite and quartz are also exhibited. These relationships are explained by the reorganization, in place, of limestone fragments and the concomitant corrosion of the quartz and feldspar fragments.

Criteria for subdivision, which may be applicable to more extensive areas, were investigated. Those which appear to be of most use are: clay mineral variations, and sandstone: shale ratios.

PART I

INTRODUCTION

Purpose and Scope

This investigation is part of a research program at the University of Cincinnati aimed at a geological analysis of the Crazy Mountains, Montana and surrounding areas. The present work was undertaken in order to obtain a more exact understanding of the stratigraphy and sedimentological history of the sedimentary rocks in the Crazy Mountain Basin.

The Shields River area (Figure 1) was chosen for the initiation of the study of the sedimentary rocks because exact stratigraphic descriptions and information are lacking. Also, the correlation of the strata in the Crazy Mountains has long been in doubt. These strata have been variously assigned to the Livingston formation, the Fort Union Group, and even the Eocene Gray Bull formation of the Big Horn Basin.

This investigation has a threefold purpose: 1) to provide the stratigraphic data necessary for a more accurate interpretation of the igneous history, 2) to clarify the position of the sedimentary strata in the Crazy Mountains, and 3) to examine criteria for the subdivision of these strata into small enough units so that detailed mapping would be possible to further delineate the igneous and structural history of the Crazy Mountains and surrounding areas. These criteria will then be applied to more exten-

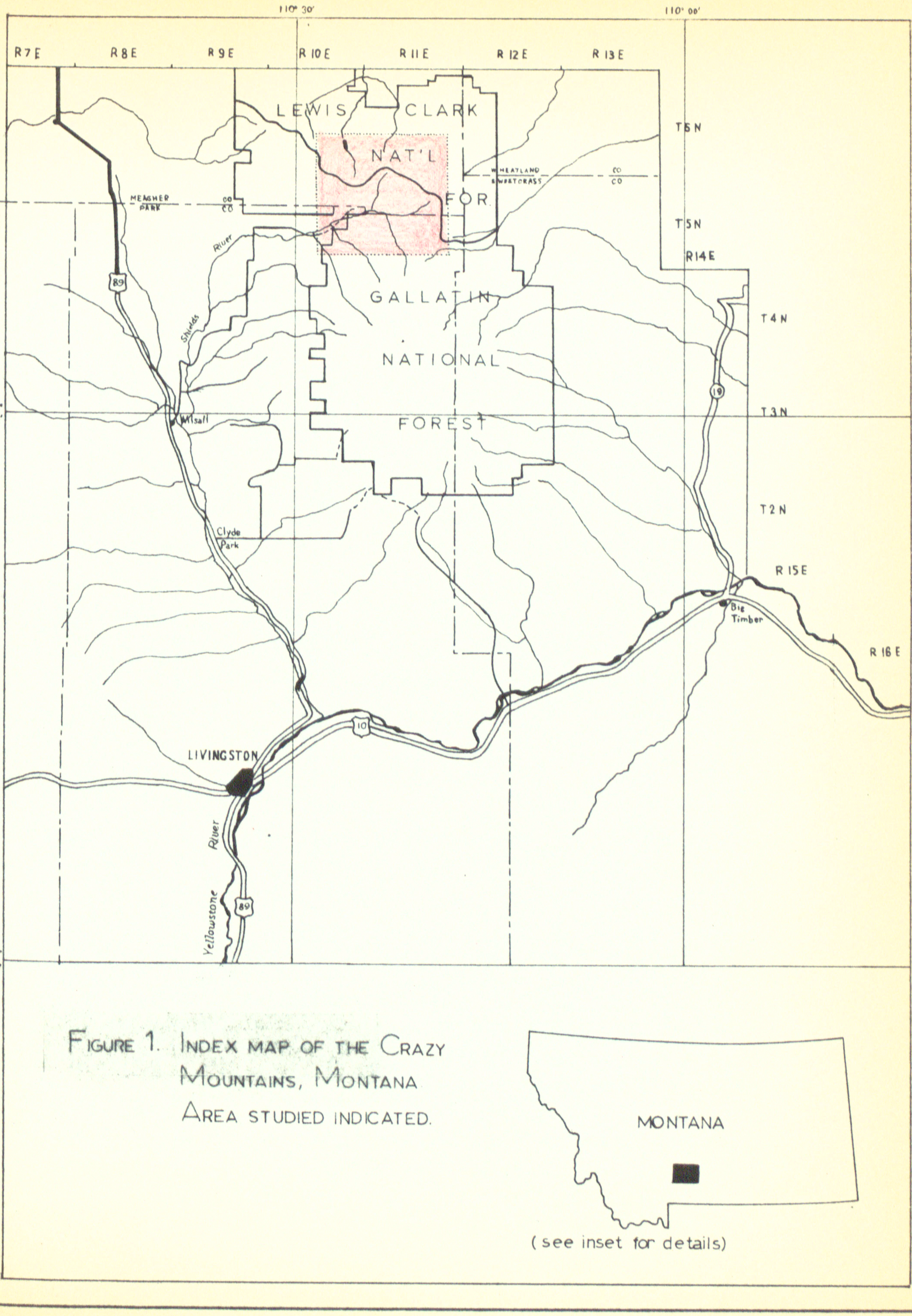


FIGURE 1. INDEX MAP OF THE CRAZY MOUNTAINS, MONTANA
AREA STUDIED INDICATED.

sive areas for detailed mapping.

It is not intended to disprove any present subdivisions but to test, refine, and extend them into greater areas, and to provide as uniform a treatment of the Crazy Mountain Basin as possible.

Location

The area studied is located in Southwestern Montana in the borderland between the Northern Rocky Mountains and the dissected Great Plains. The Shields River Valley area is located in the Gallatin and Lewis and Clark National Forests in the Northern Crazy Mountains, approximately 45 miles northeast of Livingston, Montana.

The Crazy Mountain Basin is a structural basin bounded on the north by the Castle Mountains, a deeply eroded volcanic remnant; on the northwest by the Big Belt Uplift; on the west by the Bridger Range; on the south by the Beartooth Mountains and the Nye-Bowler Lineament; on the east by the Pryor Arch and The Fromberg Fault; and on the northeast by the Lake Basin Fault Zone, and the Little Belt Mountains (Figure 2).

Accessibility of the area is by secondary macadam road from Wilsall to the Goat Mountain Ranch, and by all weather gravel road up to the Gallatin National Forest boundary. Within the national forest the roads are dry weather graded earth and "jeep" trails. Within the forest, also are numerous pack trails of varying passability.

While much of the Crazy Mountain Basin is semi-arid, the upper Shields River Valley borders the Crazy Mountain stocks, and has a high enough elevation to have rather high rainfall. Consequently much of the area is pine timbered. The forest is largely made up of second growth lodgepole pine. Numerous

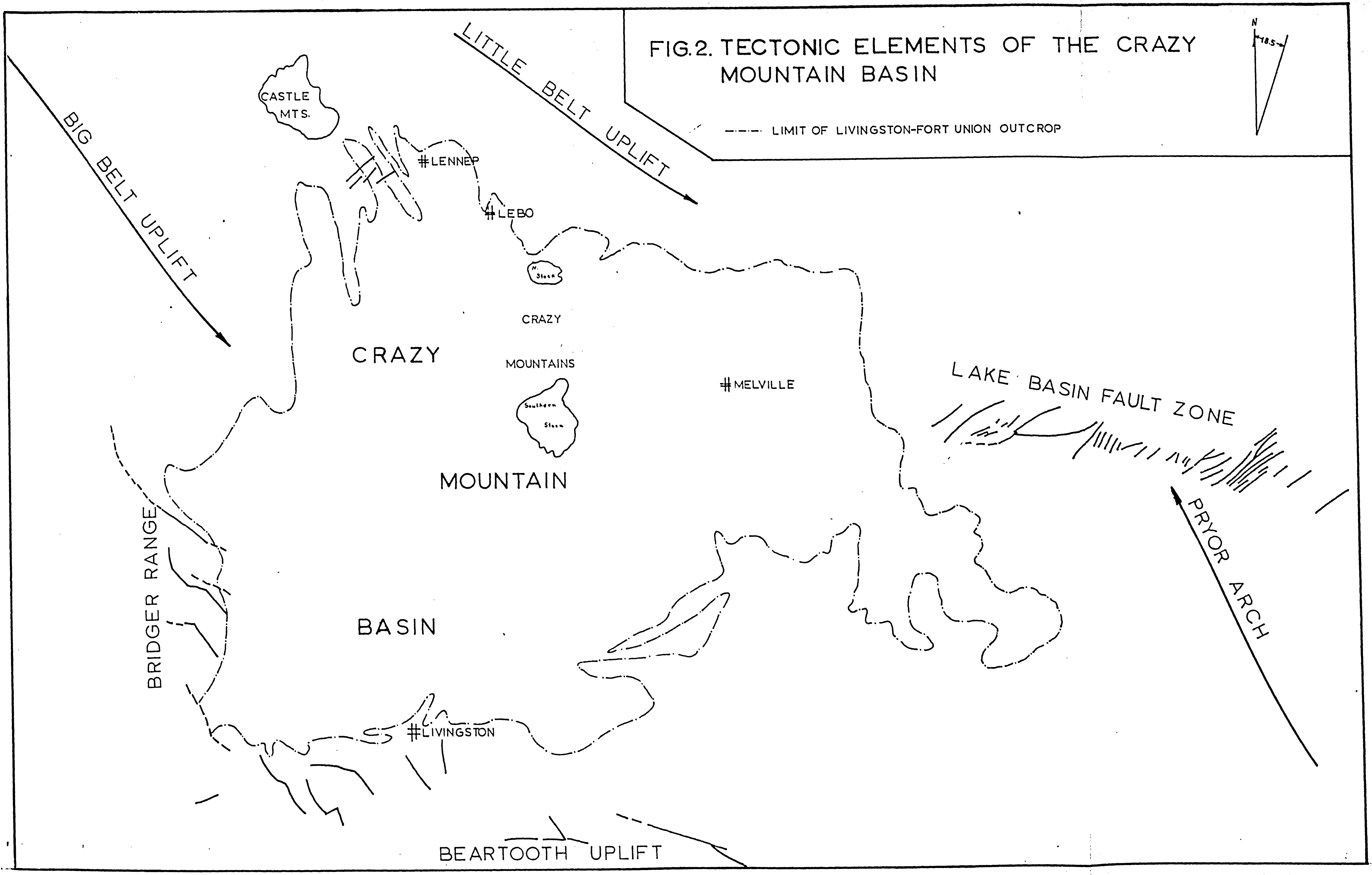


FIG. 2. TECTONIC ELEMENTS OF THE CRAZY MOUNTAIN BASIN

grassy parks occur on the hillsides and along streams. Estimated maximum relief of the area is about 4000 feet, ranging between 6000 and 10,000 feet.

Field work for this investigation was carried out in the summer 1963. Field work consisted of detailed measuring and sampling of stratigraphic sections, collecting data on primary directional sedimentary structures, and structural data. The latter was used for making cross sections and projecting outcrops in order to determine the order of superposition of the measured sections. Fossils were also collected for stratigraphic information.

Laboratory work consisted of thin section analysis of mineralic and lithic content, fabric, and roundness. Studies of clay mineral content, insoluble residues, sieve analyses and heavy mineral analysis were also completed.

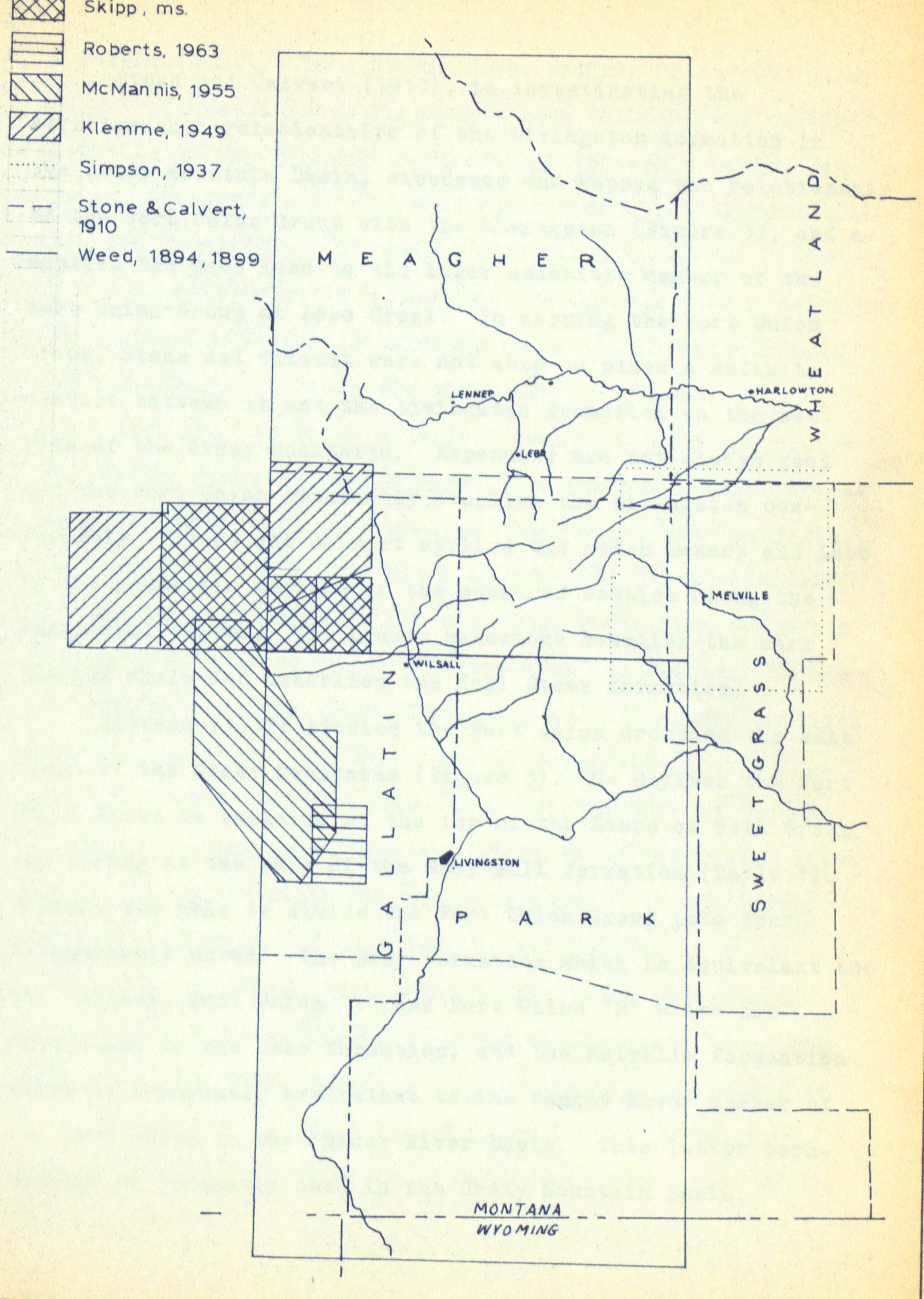
Previous Work

The earliest geological work in this and surrounding areas was by W. H. Weed. In a report on the coal resources of the region (1893), Weed indicated the presence of the Fort Union Group, 4000 feet thick, on the east flanks of the Crazy Mountains. In the same report Weed first named the Livingston formation. Weed (1894, 1899) mapped the Crazy Mountains (Figure 3), and assigned the sedimentary rocks present to the Livingston formation. Weed (1899) referred the upper 4700 feet of the strata mapped as Livingston formation to the Fort Union Group and gave a general measured section for the Crazy Mountains:

> "The dark-colored series of rocks composing the lower and typical Livingston formation are conformably overlain by a series of beds designated the Fort Union beds, which are not distinguished on the map. These are composed of 4650 feet of sediments, and consist of gray clay shales with occasional lenticular concretions of impure limestone and interbedded sandstones. The sandstones are loose textured and crumbly, frequently crossbedded and generally light colored. The grains are water worn and consist of quartz with some feldspar. The shales are generally gray, weathering into fine cubical debris, and rarely calcareous. The limestone concretions are dense and flint-like, breaking with a conchoidal fracture; they weather with a brownish surface, are sometimes netted with calcite films, and contain Unios and other fresh water fossils. Beds of impure, soft lignite sometimes occur with shales that carry fern and leaf impressions of Eocene-Paleocene species." (Weed, 1899, p. 3)

Weed (1896) also discussed the Fort Union strata of the Crazy Mountains region in a general way and presented a measured section on Lebo Creek on the northern flank of the range.

FIGURE 3. Map of previous work.



Stone and Calvert (1910), in investigating the stratigraphic relationships of the Livingston formation in the Crazy Mountain Basin, discussed and mapped the relationship of the Fort Union Group with the Livingston (Figure 3), and a applied the name Lebo to the lower andesitic member of the Fort Union Group at Lebo Creek. In mapping the Fort Union Group, Stone and Calvert were not able to place a definite contact between it and the Livingston fromation on the west side of the Crazy Mountains. Exposures are nat always good and the Fort Union apparently overlies the Livingston conformably. Stone and Calvert applied the names Lennep and Lebo to the andesitic members of the measured section along the Musselshell River. The Lennep sandstone overlies the dark Bearpaw shale and underlies the Hell Creek formation.

Simpson (1937) studied the Fort Union Group on the east flank of the Crazy Mountains (Figure 3). He defines the Fort Union Group as begining at the top of the Lance or Hell Creek and ending at the base of the Gray Bull formation (Table 1). Simpson was able to divide the Fort Union Group into four recognizable units. The Bear formation which is equivelant too the Tullock, Fort Union "1" and Fort Union "2" which are equivelant to the Lebo formation, and the Melville formantion which is apparently equivelant to the Tongue River member of the Fort Union in the Powder River Basin. This latter terminology is presently used in the Crazy Mountain Basin.

Tanner(1949), in a study of the Sixteen Mile Creek area (Figure 3), encountered Tertiary strata which he was unable to assign to the Livingston formation. However, he did not assign these strata to the Fort Union Group, but divided them into two formations, "A" and "B".

McMannis(1955), in a study of the Bozeman Pass area(Figure 3), provided a five-fold subdivision of the Livingston-Fort Union succession. These divisions are as follows: 1) a lower dark gray to green andesitic sandstone sequence equivalent to the Clagget, Judith River, Bearpaw and Lennep formations, 2) variegated fine grained sandstones, hackley shales, and bentonitic clays equivalent to the Hell Creek sandstone, 3) conglomerate and andesitic sandstone containing fragments derived from igneous rocks of Cretaceous and Precambrian age and sedimentary rock fragments as old as that of the Cambrian Flathead sandstone, but there are no fragments derived from the Belt Series rocks in this unit, and the unit is perhaps equivalent to the Bear formation (Tullock of the Powder River Basin), 4) an andesitic sandstone sequence, but with less andesitic material and more quartz, and lighter in color than the lower units, equivalent to the lower Lebo shales of the Fort Union Group, 5) an upper conglomerate identical with the lower conglomerate and approximately equivalent to the upper Lebo shale of the Fort Union Group. Overlying this is a 4000 foot sequence of sandstones and shales of the Melville formation.

Recently there has heen renewed interest in the Crazy Mountian Basin. Roberts (1963) has redefined, in the Livingston area, the Livingston formation of Weed, and Stone and Calvert as the Livingston Group, and has divided this group into four new units, as shown in Table 1: the Cokedale, Miner Creek, Billman Creek, and Hoppers formations. Conformably overlying the Hopper formation is the Fort Union Group. This terminology will be reviewed in greater detail later in this paper.

Skipp (oral communication, 1963) has been able to divid the Livingston Group into eight units in the Maudlow area. Completion of projected mapping programs by Skipp and Roberts is expected to indicate lithologic equivelance of these units.

Table 1. Stratigraphic terminology used in the Crazy Mountain Basin.

	Weed, 1894, 1899	Stone and Calvert, 1910		Simpson, 1937
PALEOCENE	Fort Union formation	Fort Union Lebo	Fort Union fm.	Melville Lebo 1 Lebo 2 Bear fm.
CRETACEOUS	Livingston fm. Laramie fm	Lance fm. Lennep fm. Bearpaw fm. Judith River fm. Claggett fm. Eagle ss.		Hell Creek fm Lennep fm. Bearpaw fm. Judith River fm. Claggett fm. Eagle ss.

	McMannis, 1955	Roberts, 1963	This Paper
PALEOCENE	Fort Union fm. Lebo fm. Tullock fm.	Fort Union fm.	Melville fm. Lebo fm. Bear fm.
CRETACEOUS	Livingston Fm.	Hoppers fm, Billman Creek fm. Miner Creek fm. Cokedale fm Eagle ss.	Hell Creek fm Lennep fm. Bearpaw fm. Judith River fm. Claggett fm. Eagle ss.

Acknowledgements

The writer wishes to acknowledge the advice and many stimulating conversations with Drs. Hans J. Hofmann, Frank L. Koucky, and Leonard H. Larsen. Thanks also go to Dr. Warren Huff for his advice and help concerning the clay minerals, and to Dr. William F. Jenks who provided comparison material and advice on thin section analysis. Special thanks go to Mr. F. E. Simms for his help and discussions while in the field. Also, many thanks are due my fellow students a for their help and stimulating conversations.

The writer is indebted to Mrs. Betty Skipp and to Messrs. A. E. Roberts and James Gill of the U. S. Geological Survey for their encouragement and for giving him free access to supplementary information concerning our common problem. Thanks also go to Dr. Malcolm McKenna of the American Museum of Natural History for identifying the mammal remains and providing the excellent stereo photograph of ?*Gidleyina silberlingi*.

General Geology - Regional Stratigraphy

The rocks expssed marginal to and in the Crazy Mountain Basin are briefly reviewed, because the Livingston-Fort Union sequence is composed of locally derived sediments.

Early Precambrian igneous and metamorphic rocks are present in the cores of the Little and Big Belt Mountians to the nortn, in the Bridger Range to the west, and in the Beartooth Mountains to the south. Unconformably overlying these is the Late Precambrian Belt Series to the west and north. This is a sequence of low grade metamorphosed sediments deposited in the Belt geosyncline. The Greyson and Spokane shales are the only two units exposed in the vicinity of the Crazy Mountain Basin. The Greyson shale overlies the Newland limestone, exposed near Whitehall, Montana, and is a dark grey, highly indurated, calcareous, moderately fissile shale and contrasts strongly with the Greyson shale. The Spokane shale is a hard, red, argillaceous, siltstone with greenish-grey stringers and intercalations. The Spokane also shows primary structures, such as raindrop prints, trace fossils and ripple marks.

The Paleozoic sedimentary rocks rest unconformably on the Precambrian. The Cambrian succession begins with the Middle Cambrian Flathead sandstone, a shallow marine pink quartz sandstone. The Flathead sandstone is followed by the Wolsey shale, a brown, glauconitic, micaceous shale; the Meagher limestone and the Park shale. The Upper Cambrian

Pilgrim limestone is conformable with the Middle Cambrian. An unconformity separates the Devonian from the Upper Cambrian. The Upper Devonian succession consists of the Jefferson dolomite, a fetid black to gray dolomite, and the Three Forks shale, consisting of orange and green shale.

An unconformity again separates the Mississippian from the Devonian. The Mississippian succession consists of the Madison limestone with some anhydrite in the Charles Member and the Big Snowy Group, a succession of limestones and sandstones and shale.

The Amsden formation is transitional from the Mississippian to the Pennsylvanian, and is a series of limestones, sandstones, and red shales. The Amsden formation is overlain by a dolomitic orthoquartzite, the Pennsylvanian Quadrant formation.

The Jurassic unconformably overlies the Paleozoic sequence and is a regressive series beginning with shaly, oolitic limestones of the Rierdon formation, to the calcareous sandstones of the Swift sandstone, and finally closing the Jurassic record with the thin shales and limestones of the Morrison formation.

The Precambrian through Jurassic strata are exposed only at the edges of the basin where the tilted strata have been beveled by erosion. Within the basin proper, the oldest formations observable are the thick Cretaceous Kootenai formation consisting of conglomerates, sandstones, red sa shales, coals, and limestones. These are visible in local domes and folds.

The Colorado shale overlies the Kootenai formation. To the west this is a thick sequence of marine black shale and quartzitic sandstones. In this area it is represented by soft sandstones and siltstones of lagoonal and terestrial environments (Klemme, 1949). Vulcanism is evidenced by tuffaceous material present in the middle part of the Colorado shale (Klemme, 1949).

The Montana Group is the most extensively exposed stratigraphic unit in the Crazy Mountain Basin. The greater portion of the Montana Group is composed of the Livingston Group. The original Montana Group to the east included the Telegraph Creek, Claggett, Judith River, Bearpaw, and Lennep formations. These formations could not be differentiated in the Crazy Mountain Basin, but they were correlated with the Livingston formation of Weed, (1893) and Stone and Calvert (1910). Roberts (1963) restricts and redefines the Livingston formation of these authors (Table 1).

Roberts raised the lower half of the Livingston formation to group status and named four new units: the Cokedale, Miner Creek, Billman Creek, and Hoppers formations. The Hoppers and Miner Creek formations are depicted as more source-ward facies of the Hell Creek formation(Roberts, 1963). These formations also include a small portion of the Lennep sand-stone. The upper Lennep sandstone is correlated, by Roberts, with the Fox Hills sandstone of the Powder River Basin. The

Fort Union Group conformably overlies the Livingston Group in the Livingston area.

Northeast of the Livingston area the Tullock formation is intercalated between the Livingston Group and the Fort Union Group. Simpson(1937) working on the east flanks of the Crazy Mountains, proposed the name Bear formation for the interval between the recognizable Hell Creek sandstone and the Lebo formation of the Fort Union Group. He could further divide the Lebo formation into two recognizable units for mapping. Attempts by Simpson to carry these subdivisions to the west side of the Crazy Mountains were unsuccessful. Simpson(1937) further proposed that the name Melville formation be applied to the strata superjacent to the Lebo formation of Stone and Calvert(1910). It is assumed that the Melville formation is for the most part equivelant to the Tongue River, a term applied to the upper member of the Fort Union formation of the Powder River Basin in Wyoming. The Tongue River member contains thick coals and forms a prominent escarpment above the clinker-capped lowlands formed from the baked Lebo shales.

Several authors(Weed, 1899; Stone and Calvert, 1910; and Simpson, 1937) have recognized the possibility that the uppermost strata in the Crazy Mountains may be of even younger age, perhaps as young as the Gray Bull(Eocene) formation of the Big Horn Basin(Simpson, 1937). This has yet to be clarified.

At present the author prefers to follow Simpson(1937) and use Bear, Lebo, and Melville formations as subdivisions of the Fort Union Group. This terminology is preferred because of the proximity of the rocks studied to the type sections of the Bear, Lebo, and Melville, near Melville, Montana. These formations are identifiable and mappable in m many areas (Stone and Calvert, 1910; and Simpson, 1937), thereby justifying the escalation of the Fort Union to Group status from formation status. The stratigraphic nomenclature used in this paper is summarized in Table 1.

General Geology--Stratigraphy of Area Studied

The structure of the Shields River Valley area is relatively simple(Figure 4). The Davey Butte Anticline, an extension of the Robinson Anticline, trends north-northwest and the Shields River Syncline trends south-southwest. The western boundary of the area studied is near the intersection of these two broad open folds.

The sediments in the Shields River Valley area are much like the description of Weed(1899). The series is drab, mostly thin bedded, silty sandstones. Occasional limestone nodules are present in lenticular bands. Upon weathering these nodules have an orange-brown color.

An average sandstone is medium to fine grained, subangular to subrounded, calcareous, has very little clay sized material(2μ) or clay minerals, moderate amounts of lithic material, and some carbonaceous material. Mudstones are generally very silty with only moderate amounts of clay minerals. Bedding fissility is almost totaly lacking. The best bedding fissility is observed when large amounts of carbonaceous material are present in the mudstones. Some soft coaly shale layers were noted in the middle one third of the measured sequence. These were extremely variable and never exceeded one inch in thickness.

One of the most striking features of the sandstones is the ubiquitous nature of the calcite cement present in large quantities, and its apparent corrosive nature on the quartz and feldspar grains. Previous workers had not even

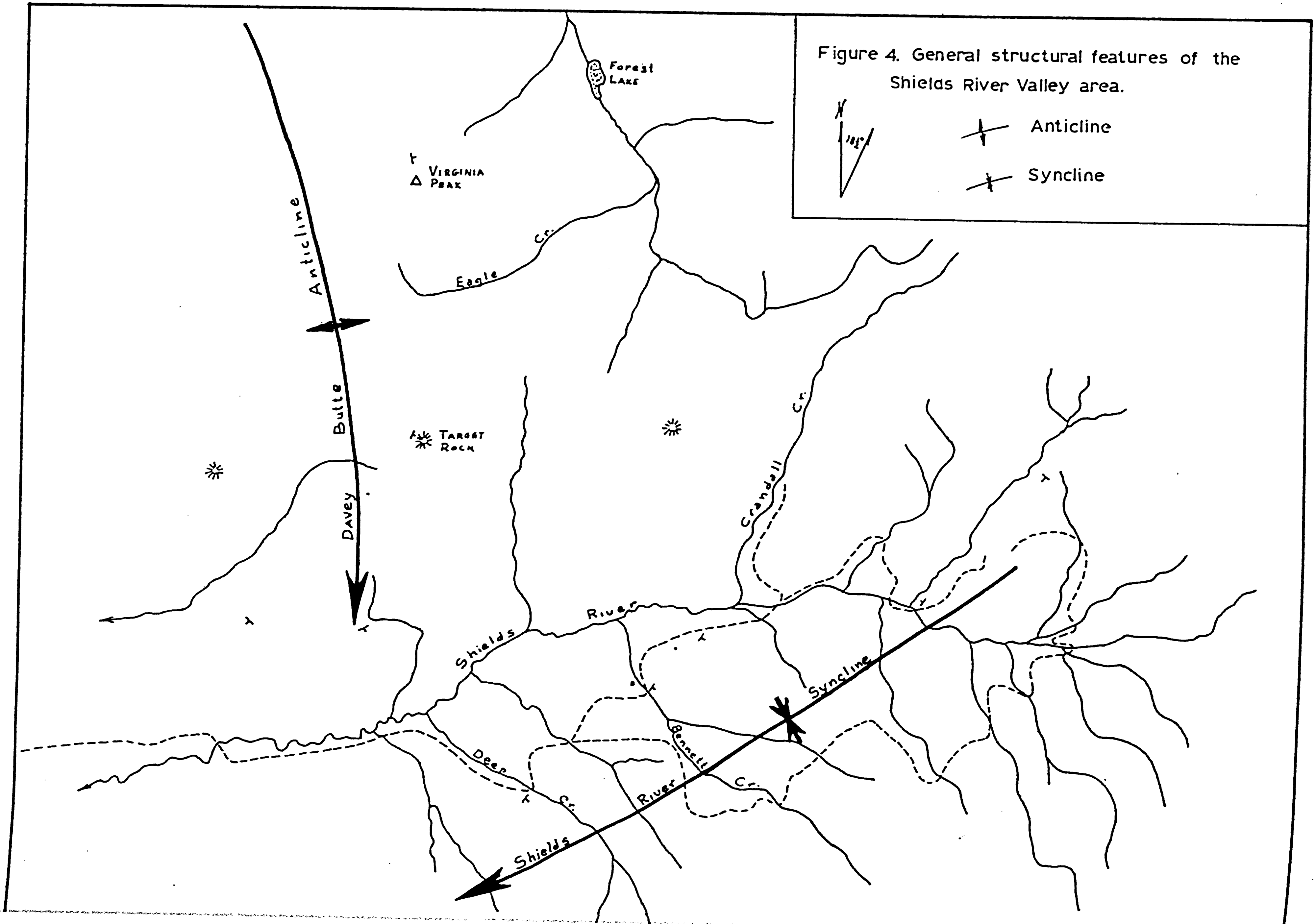


Figure 4. General structural features of the Shields River Valley area.

Figure 5. Panoramic view of the North side of the Shields River valley. 1) Nose of Davey Butte anticline, 2) Target Rock, 3) Loco Peak, 4) north trending basic dike, 5) section X-53.

commented on this, although Stone and Calvert (1910) studied these rocks in thin section.

Figure 6 shows a moving average of the sandstone-to-shale ratios in groups of three for twenty-five foot intervals of the longest sections of the rocks studied. It can be seen that the upper one-fourth has a rather high sandstone:shale ratio, dropping rather low in the middle one-half, and rising sharply again in the lower one-fourth.

The entire measured sequence studied has been placed in the Melville formation of Simpson (1937) on the basis of lithologic similarity and paleontological evidence cited later.

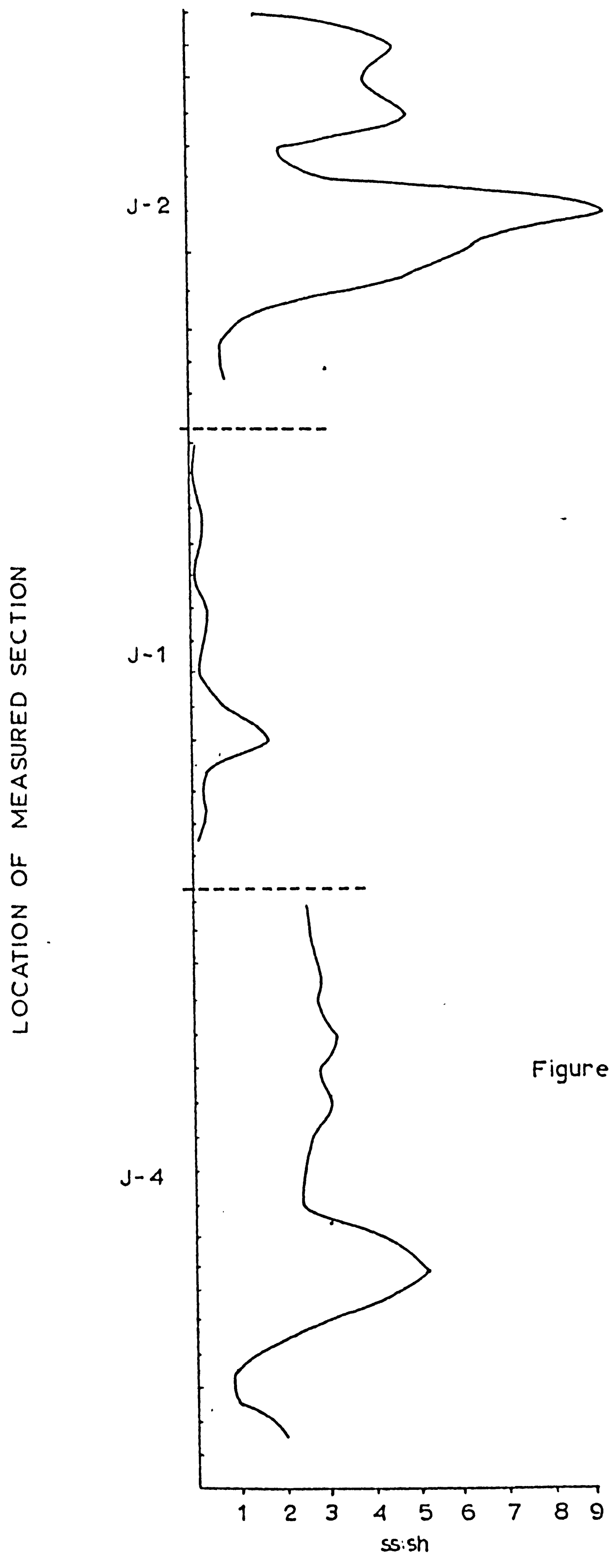


Figure 6. Moving average of sandstone:shale ratios per 25 foot interval in groups of three.

General Geology--Igneous Rocks

The igneous rocks occur in two stocks and in numerous dikes and sills. The Southern Stock is the largest and has radiating from it two phases of basic rock as dikes. These two dike phases were probably intruded at different times along similar planes of weakness. It has been demonstrated thet the Northern Stock is responsible for the intrusion of sills of syenitic composition. These syenitic sills are intercalated with the sedimentary rocks of the upper Shields River Valley area.

A second sill phase which has no demonstrable source at present is exposed in the Davey Butte Anticline(Figure 4). These rocks are identified as malignites by Simms(1964, oral communication). These rocks are presently being studied by Mr. F. E. Simms, Department of Geology, University of Cin Cincinnati.

The sills of syenitic composition are stratigraphically higher than the basic sills, and are principally exposed on the east flank of the Davey Butte Anticline.

PART II

PROPERTIES OF SEDIMENTS

Mineral Composition

Locations of all datum points are shown in Figure 7. The data resulting from the field and laboratory study are presented in table form in Figures 8,9,10,11,12. A general discussion of each tabulated feature follows. In the discussion of the mineralic features, with the exception of insoluble residues, per cent is by point count.

Quartz is a major component in all the sandstones. Quartz is always in excess of 20 per cent in any thin section, and in several it exceeded 50 per cent. Quartz occurs as sand size and smaller grains, and is abundant in the silt and fine silt sizes.

Feldspar is always a minor constituent although it may account for as much as 17 per cent of a thin section. The average range of feldspar content is two to eight per cent. The upper one-half of the measured strata show an increasing amount of feldspar. Both plagioclase and orthoclase are present. Plagioclase is the more abundant and contributes an estimated 80 percent of the total feldspar.

Identification of the sodic plagioclase and orthoclase was made by staining control slides to check the determination on unstained thin sections. The staining procedure made use of sodium rhodizonate and sodium cobaltinitrite. In this test the sodium rhodizonate complexes with the calcium of the plagioclase and the sodium cobaltinitrite complexes with the potassium of the orthoclase, producing red and yellow stains respectively. Broadness of the albite twin lamellae in the polysynthetically twinned plagioclase also indicates a calcic member.

Quartz and feldspar are characteristically corroded with calcite filling the corroded portions in all the thin sections of sandstones examined(Figures 13, 14). Quartz and feldspar are the only grains seen to be corroded. In some thin sections adjacent quartz and limestone grains are touching. The boundary between the two is quite irregular and indistinct, and calcite patches show a decrease in size and number as the center of the quartz grain is approached. This relationship is not seen in all the thin sections.

In figures 8-12 the group termed Lithic Fragments includes red and black lithic fragments of siltstone, limestone and dolomite, "clastic calcite", and polycrystalline quartz. In this investigation any particle made up of more than one, optically discontinuous, discrete grain of quartz, whether primary or sedimentary, is termed polycrystalline quartz; which thus includes quartzite, sandstone, siltstone, and chert fragments. Among the lithic fragments were some whose affinities were not known or whose characteristics excluded them from other groups. These fragments were highly altered, fine grained, brownish-grey to greyish-brown lithic material, which may be equivelant to what other workers have termed "andesitic debris".

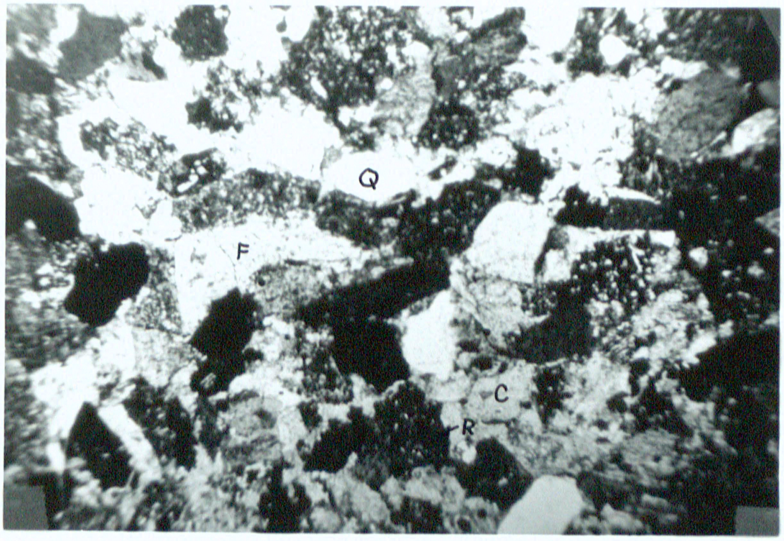


Figure 13. Photomicrograph. Q=quartz, F=feldspar, R=rock, C=calcite matrix

Figure14. This photomicrograph shows much lithic material and magmetite. Note the horizontal banding of the opaque rock and magnetite fragments parallel to the beding.

Variation in the red and black lithic material was estimated in hand specimens separately and is shown graphic-lly in Figures 8, 9, 10, 11, 12. On a megascopic scale the red and black lithic fragments are a striking feature of the Fort Union sandstones in this area. The red and black frag-ments are easily observable in a hand specimen.

In general variation in the clay mineral content is one of decreasing amounts of chlorite and increasing illite and montmorillonite as progressively older strata are examined. These variations are shown graphically in Figures 8, 9, 10, 11, 12, 15, 16, 17, 18, 19,20, 21. Mixed layer material components are variable but tend to increase in the older strata along with the illite and montmorillonite. Kaolinite is a very minor constituent in all the rocks investigated. Only one sample was found bearing abundant well crystallized kaolinite(J-4-83). A few grains of, what may be, glauconite were found in the thin section analyses.

The crystallinity of all the clay minerals is extremely poor. In some cases it was difficult to observe (002) reflect-ions on the x-ray diffractograms. Only rarely was it possible to observe higher reflections than the (002). Also an attempt to obtain b-axis dimensions for the contained chlorites failed, due to the lack of these higher order reflections. The b-axis parameter can be used for estimation of the ferrous iron content of chlorites for the general formula

$(Mg_{6-x-y}Fe_yAl_x)(Si_{4-x}Al_x)O_{10}(OH)_8$ (Brindley and McEwan, 1953). Even with lengthy and careful extraction processes reflections beyond about 45^{0} 2θ were unobtainable.

Swelling properties of the montmorillonites in ethylene glycol saturated atmospheres were not always uniform. However, more highly crystalline montmorillonites were obtained from the lower stratigraphic units (approximately the lower 500 feet.).

The cement of the sandstones is almost totally composed of sparry calcite. Each grain is completely enclosed in a matrix of clear crystalline calcite. Some of the cementing is due to the clays, and silica and pyrite. The clay minerals are intimately intermixed with the clacite cement.

Silica cement was first suspected when attempts at disaggragation of the sandstones for sieve analyses and separation of the heavy minerals were made. Incomplete disaggregations and contamination of the heavy mineral separates were encountered. Verification of the silica cement was obtained in thin section. The silica is present in the form of chalcedony, identified by its microfibrous texture in plane polarized light, and by a mosaic of grey, black and white fan-shaped masses in polarized light. The chalcedony present is very similar in appearance to that figured by Carozzi (1960, p. 12.). The amount of silica cement is very minor.

Large amounts of contamination of the heavy minerals separates were also caused by aggregates of quartz, feldspar, and lithic material around subhedral to anhedral pyrite grains.

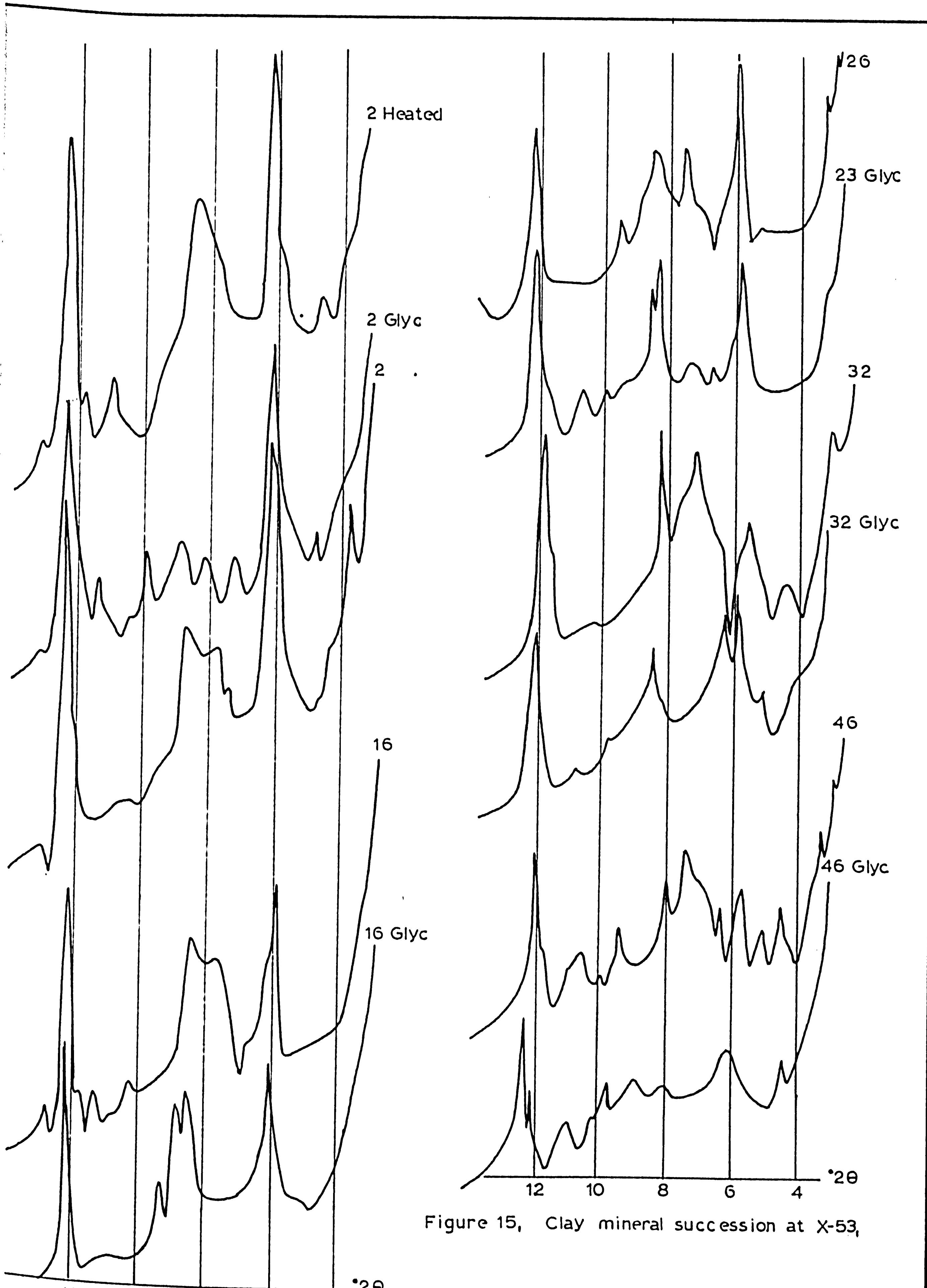


Figure 15, Clay mineral succession at X-53,

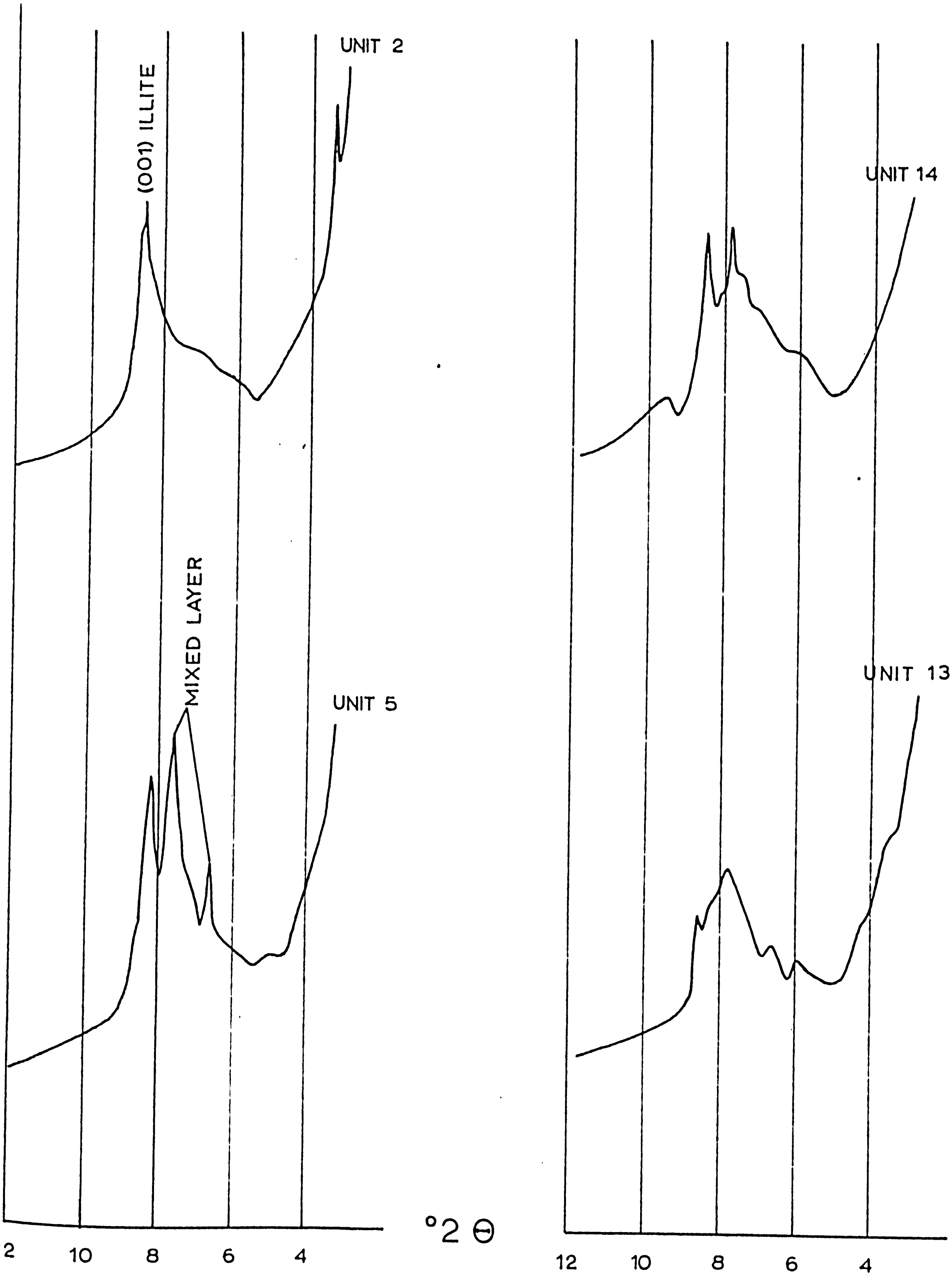


Figure 15. Clay mineral succession in section X-21. All samples unglycolated.

Figure 17. Clay mineral succession at X-13.

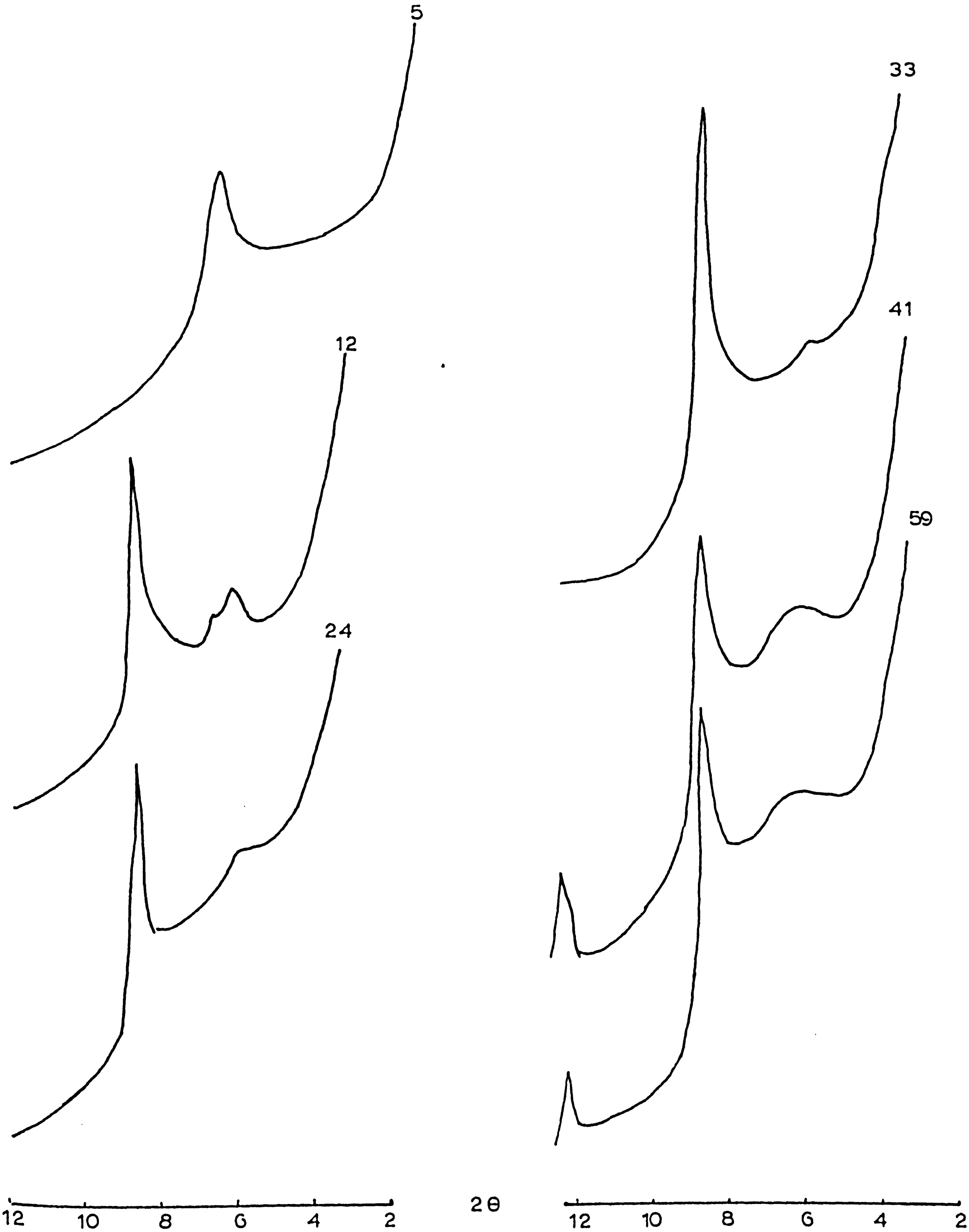


FIGURE 18. Clay mineral succession at X-5.

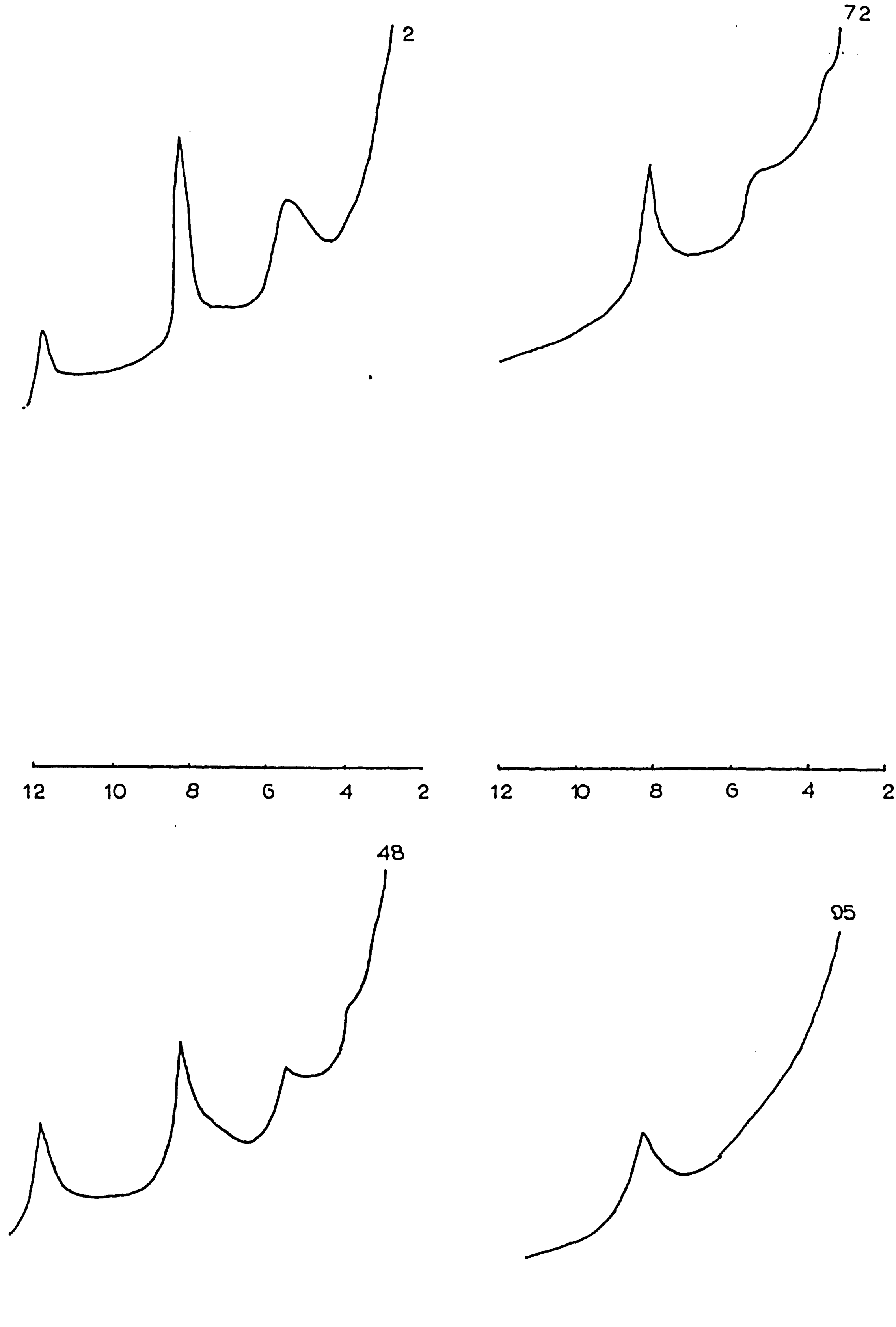


FIGURE 19. Clay mineral succession in J-2 (unglycolated, 2θ values)

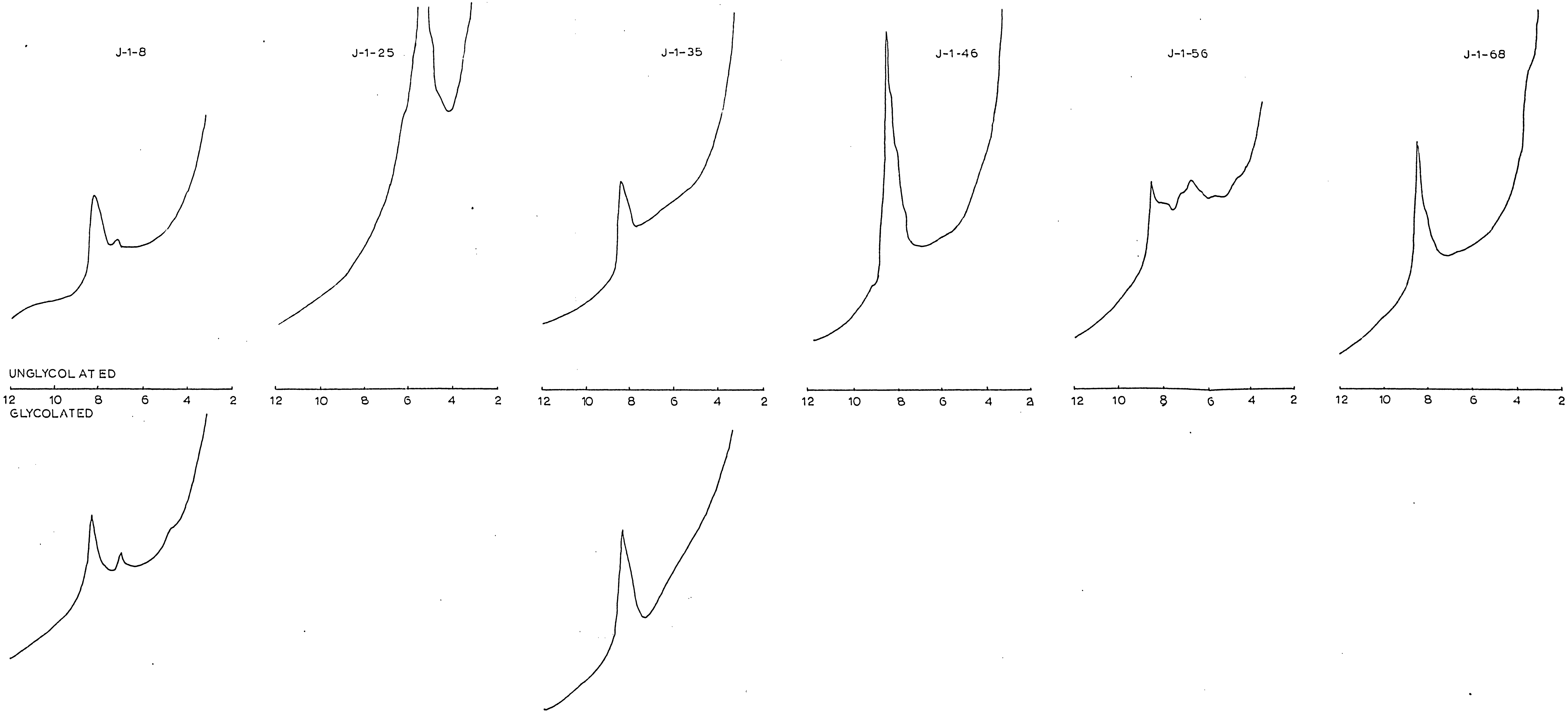
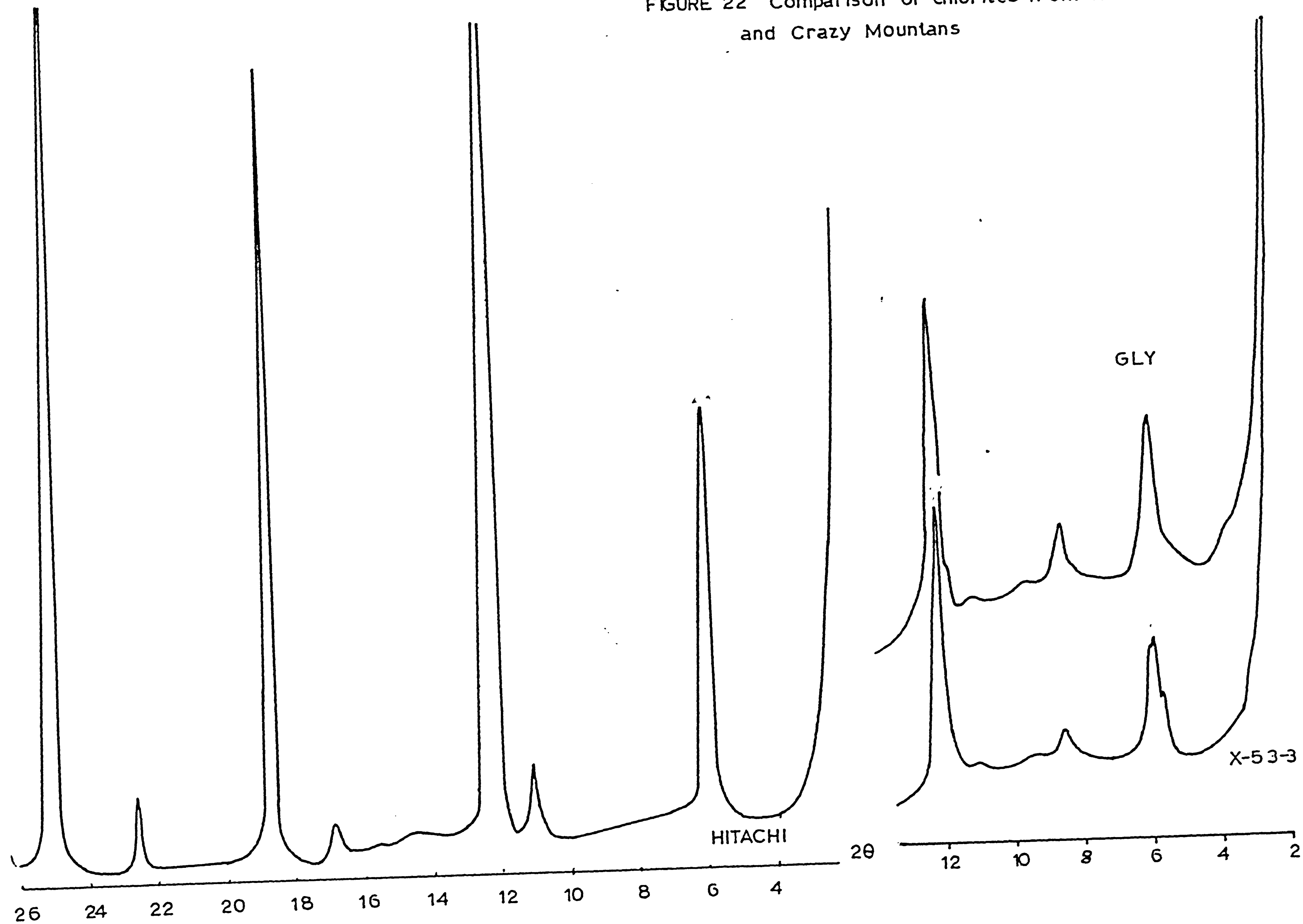


FIGURE 20. Clay mineral succession in J-1(2θ values).

The calcite cement of the sandstones is particularly interesting because of its intimate association with the corrosion effects of the quartz and feldspar grains. The corrosion of quartz and feldspar grains and their repalcement by calcite is representative of the "deep burial" stage in the diagenesis of sandstones proposed by Dapples(1959).

Sandstone compositions are portrayed in Figure 22, along with the calculated outcrop patterns of the measured sections, based on the geometric projection of the measured rocks on a topographic base map.

FIGURE 22 Comparison of chlorites from Hitachi Mine and Crazy Mountans



Mineralogy of the Sediments--Discussion

Quartz is seen to be abundant while feldspar is minor; indicating a source for these rocks poor in feldspar. Most of the rock fragments observed are of sedimentary origin. A high degree of rounding for some of the quartz grains along with a high degree of angularity for most of the other quartz grains indicates several sources for these grains. Rounded quartz grains were never observed to be corroded and replaced by calcite while angular quartz is almost always corroded and replaced by calcite. Feldspar is always corroded and replaced by calcite.

Another factor speaking for a source rock of sedimentary origin is the occurence of sporadic conglomeratic lenses. These were never observed to contain igneous or metamorphic fragments. The conglomeratic lenses were predominately composed of limestone and highly indurated siltstone fragments. Lithic fragments are always well rounded and, in general, do not occur in size grades smaller than 250 μ.

Holms and Hearn(1942), Weaver(1958), and others have shown that the clay minerals present in a fluviatile environment largely reflect the composition of the soils in the source areas from which they were derived. Differential flocculation and settling of clay minerals would not occur in fresh water environments, and a general mixing of the variously derived clay minerals would occur in the depositional site. Lateral variations would primarily be controled by the source areas.

Illite, montmorillonite, mixed layer material, and glauconite are all indicative of a marine environment. Chlorite is known to occur in both marine and fresh water environments. Kaolinite is indicative of a fresh water or brackish water environment(Grim, 1952).

Montmorillonite forms from the alteration of volcanic ash falling into a marine environment. It is the interaction of the salts in the saline water with the glassy material of the volcanic ash which results in the devitrification of the glass. The devitrification process liberates silica in exchange for other ions present in the saline water and eventually results in the formation of an expandable phyllosilicate structure. This mineral is common in the Cretaceous-Tertiary marine volcanic deposits of the Rocky Mountain region.

Illite may be formed from montmorillonite by the exchange of the interlayer cations in the originally expandable structure for potassium ions. The addition of the potassium ion to the phyllosilicate structure then destroys the expandable nature, because the clay mineral layers are very tightly held together through the strong ionic bonding of the potassium ion.

Intermediate between the complete change of montmorillonite to illite is mixed layer material. Mixed layering is the interlamination of illitic and montmorillonitic units. The mixed layer material may be randomly or regularly interstratified. A regular mixed layer clay mineral would, upon x-ray diffraction analysis, exhibit an intergal series of reflections, just as any single component clay mineral would, However, these reflections would have a d-value intermediate between the component clay minerals, This new d-value is dependent upon the original d-values of the component clay minerals and the amount of each present in the mixed layer structure. A randomly mixed layer mineral would result in t a non-intergal series of reflections. It would exhibit the characteristic reflections for each of the clay mineral components present in the mixed layer structure.

Little is known about the mode of occurence of chlorite. It is present in both marine and fresh water sediments in a variety of forms. Chlorite is abundant in limestones, dolomites and evaporites, along with illite and mixed layer minerals. Chlorite tends to be preserved in these rocks due to the high concebtrations of Mg^{2+} and Ca^{2+} ions, which are available to the chlorite in the regrading process.

The chlorites in the rocks studied are interesting because they are especially abundant in the upper 200 feet of the measured sections and generally absent in the lower 1000 feet. They appear to be in part authigenic or at least partially recrystallized, though achieving any high degree of crystallinity.

The chlorite is generally in brownish to olive, extremely fine grained masses, which are almost isotropic. Carozzi(1960) describes the alteration of finely comminuted biotite to chlorite having this same appearence. Occasional biotite flakes and booklets are present in the sandstones. However, the scarcity of large biotite flakes and the presence of the fine grained chlorite indicates that the biotite was exposed to an extreme process of tituration. Some large flakes of chlorite were observed. These, too, are assumed to be diagenetic products of the alteration of biotite.

Data obtained early in this study from a General Electric XRD-5 x-ray diffractometer and chart recorder indicated a basal (001) reflection of 14.7A for these chlorites. A search of the literature provided only one reported occurence of a chlorite with a 14.7A basal spacing(Sato and Sudo, 1959). The chlorite was described from the Hitachi Mine, Japan. The rocks in which the chlorite described by Sato and Sudo occurs are associated with contact hydrothermal and regional metamorphism(Jenks, oral communication).

Comparison of the Fort Union chlorite was made with that from the Hitachi Mine and was found to have the same reflections in the 2θ region smaller than 45°. Comparison of the chlorites at higher values was not possible due to the lower crystallinity of the Fort Union material.

Film comparison of these two minerals(Table 2) indicates a (001) reflection at 14.3A. Closer inspection of this film reveals a diffuse line at approximately 28.5A. This data indicates that the material has, in both cases, a unit cell of about 28A in height($d = \underline{c} \cos \theta$). These data then indicate that the minerals belong to the space group C2/c which is related to a c-glide in the (010) plane(McMurchy, 1934). The C2/c space group gives an identical projection of the electron density on the a-b plane as the unit cell 14.2A in height. The 14.2A unit cell would be in the C2/m space group with a (010) mirror plane.

Detailed crystallogrphic data are lacking and these data can be held only as indications untill further work is done.

The material identified tentatively as glauconite has apparently been derived from pre-existing rocks. Known rocks containing glauconite in the surrounding areas are limestones in the Wolsey shale and Park shale, both of Cambrian age.

Glauconite is a diagenetic product formed under extremely local reducing conditions in marine environments(Hadding, 1932; Hendricks, and Ross, 1941; Grim, 1952).

Two possible explanations are possible for the presence of kaolinite. As stated earlier, kaolinite commonly occurs in fresh to slightly brackish water enviromments, The rocks in this area are of fresh water fluviatile origin. Therefore, the kaolinite would be expected to occur if it were present in the source area, or if the conditions for its formation from pre-existing materials were present either at the source or depositional site. Kaolinite is commonly formed through the weathering of feldspars, particularly orthoclase. Lacustrine environments, through which an appreciablemovement of water occurs, and with consequent removal of alkalies and alkaline earths, would be expected to show a development of kaolinite (Grim, 1952, p. 354). Therefore, in lakes where lime is accumulating, the formation of kaolinite would be blocked and where there is no accumulation of lime, there would be a diagenetic development of kaolinite. Kaolinite is generally absent in carbonate rocks because of the large quantities of alkalis. Kaolinite is very poorly orgainized in porous media(Grim, oral communication).

All the clay minerals were in a general state of low crystallinity. Mesozoic rocks are abundant in surrounding areas and they, too, would contain rather poorly crystalline material when compared with the clay minerals from the Paleozoic rocks, because the clay minerals have not had enough time for complete regrading and reorganization. The weathering of these rocks in the processes of soil forming prior to incorporation in the Fort Union rocks would also tend to further decrease the crystallinity. However, this is probably an apparent reduction, because the hydraulic force which moved the sand and silt grains was strong enough to remove most of the clay minerals, due to their much finer size.

This gradual change in kinds of clay minerals could be accomplished through the folding, faulting, and warping of the strata on the edges of the Crazy Mountain Basin. Erosion of the rocks would expose increasingly olderrocks as it progressed. It has been illustrated by many authors that the predominant clay minerals in Paleozoic rocks are illite and mixed layer minerals, and that montmorillonite is predominant in the mesozoic rocks. These factors accompanied by the formation of chlorite from biotite derived from the igneous rocks would then account for the clay mineral variations.

The Fort Union rocks illustrate the gradual erosion of Mesozoic and Paleozoic strata from the Precambrian rocks, and finally the derivation of debris from source areas in which igneous and metamorphic rocks were abundant.

The relationship of silica and calcite in these rocks is an interesting one. Three possible explanations may be tendered: 1) the quartz and feldspar grains were corroded before deposition, and the calcite merely filled in the old corroded surfaces; 2) both pre-depositional and post-depositional corrosion occured; 3) the grains were corroded in situ.

The first possibility is enticing because it discretely moves the mechanism away from the area studied, and only the effect can be observed and the cause mildly speculated upon. However, certain data indicate that choices 2 or 3 may be better for the state of the feldspar and quartz. In some instances calcite has replaced the central portion of a quartz grain and in others there is wholesale replacement of polysynthetically twinned plagioclase by calcite.

Carozzi(1960) describes the progressive replacement of quartz and feldspar by the expansion of calcite inclusions and by the increase in number of calcite inclusions. Grains which appear to be detrital calcite are usually 100 per cent replaced feldspar and perhaps quartz. The case for primary calcite cement is strengthened by these factors plus the abundance of limestone fragments. Reorganization of these fragments in place would produce the abundant calcite cement observed in the rocks. The solutions which reorganized the calcite could also be partially responsible for the corrosion of the quartz and feldspar. Pressure solution is not indicated due to the lack of sutured boundries and overgrowths or penetration of grains.

Dapples(1959) proposed a model for the diagenesis of a sub-greywacke sediment.

1) Very minor rounding associated with the depositional stage.

2) During the intermediate stage initiation of calcite cementation occurs. Calcareous concretions are developed at this stage along with some secondary chert in fresh water sediments.

3) "The stage of deep burial is indicated principally by the introduction of carbonates, corroding grains of quartz and replacing clay matrix"(Dapples, 1959). Recrystallization of clay minerals, and the apparent introduction of authigenic muscovite also occurs in this stage.

These general diagnostic relationships are illustrated in Figure 23. Chertification is a process distinctive of

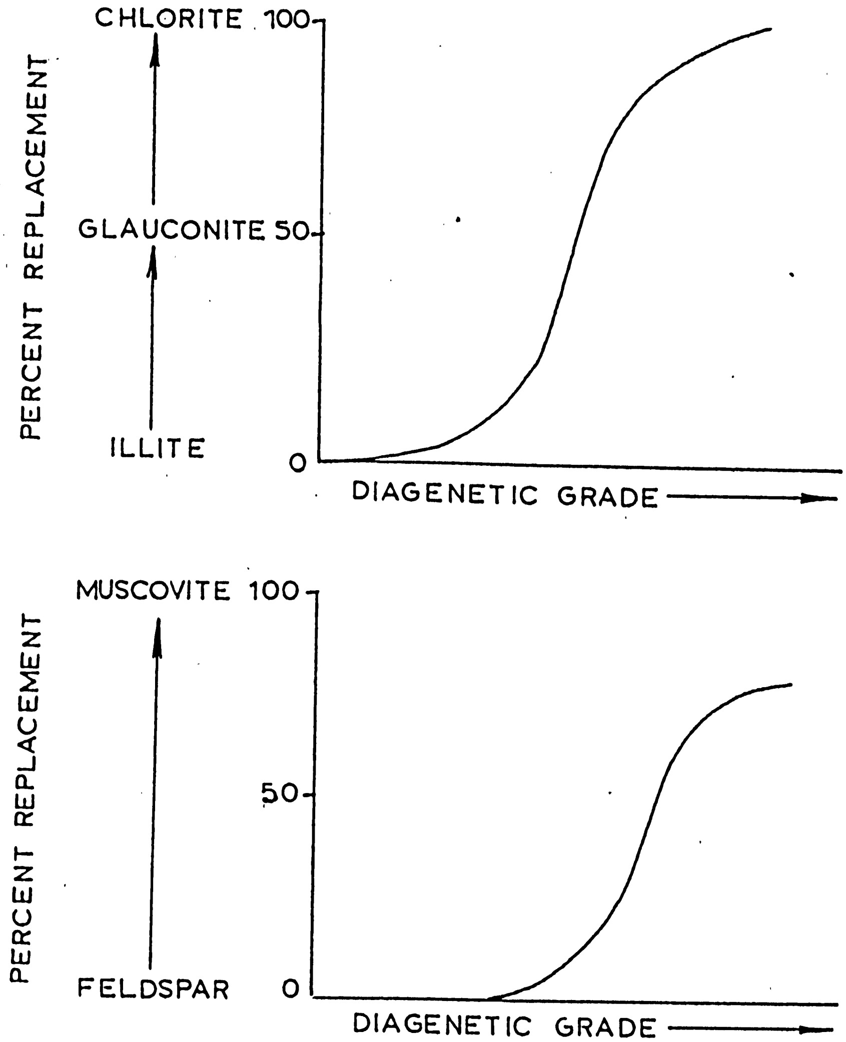


Figure 24. Diagramatic relationships in a subgreywacke sandstone illustrating the modification of the mineralic content with increasing diagenetic grade. (After Dapples, 1959).

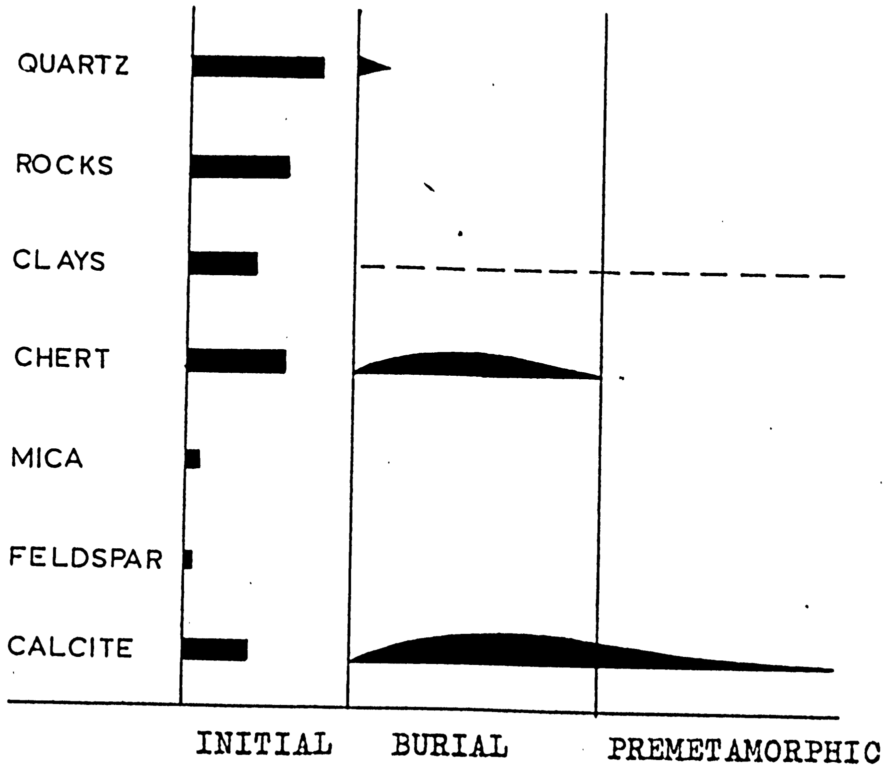


Figure 25. General diagrametic representation of mineral paragenesis in Frontier (First Wall Creek) in Wind River Basin, Wyo. Distribution of proportion of minerals in the detrital fraction is indicated by relative lengths of the bars in the initial stage. During burial and premetamorphic stages the relative order and magnitude is indicated by the length and taper of the wedge. (From Dapples, 1959).

the intermediate stages of diagenesis, especially so in sediments deposited in fresh water. Extreme calcification is indicative of a saline environment.

It is not intended, at present, to suggest that any of the sediments are of marine origin. The inverse relationships of calcite and quartz are not fully understood, but some relation between solubility and pH is implied.

Krauskopf(1959) presents a summary of the solubility of amorphous silica with respect to temperature(Figure 27) and with respect to pH(Figure 26). Krauskopf further lists and discusses factors influencing the solubility of silica as follows: 1) the form of silica, 2) occurence of amorphous silica in a supersaturated solution, 3) concentration, 4) the presence of other ions in the solutions, 5) the presence of other solids in the solutions, and 6) the presence of organisms.

The factors having the greatest effect are: temperature, pH, and the form of silica. The other factors mainly affect the rate at which the equilibrium solution is attained. The effect of temperature and pH are already summarized. Amorphous silica gell is most soluble(50-80 ppm, at 25° C.), opal is next and the crystalline forms of silica even less. Quartz is least soluble of the silica polymorphs(7-14 ppm, at 25° C.).

Upon disolving, silica forms monomeric silicic acid (H_4SiO_4), which is the stable product as long as undersaturated or saturated conditions are maintained. Supersaturated

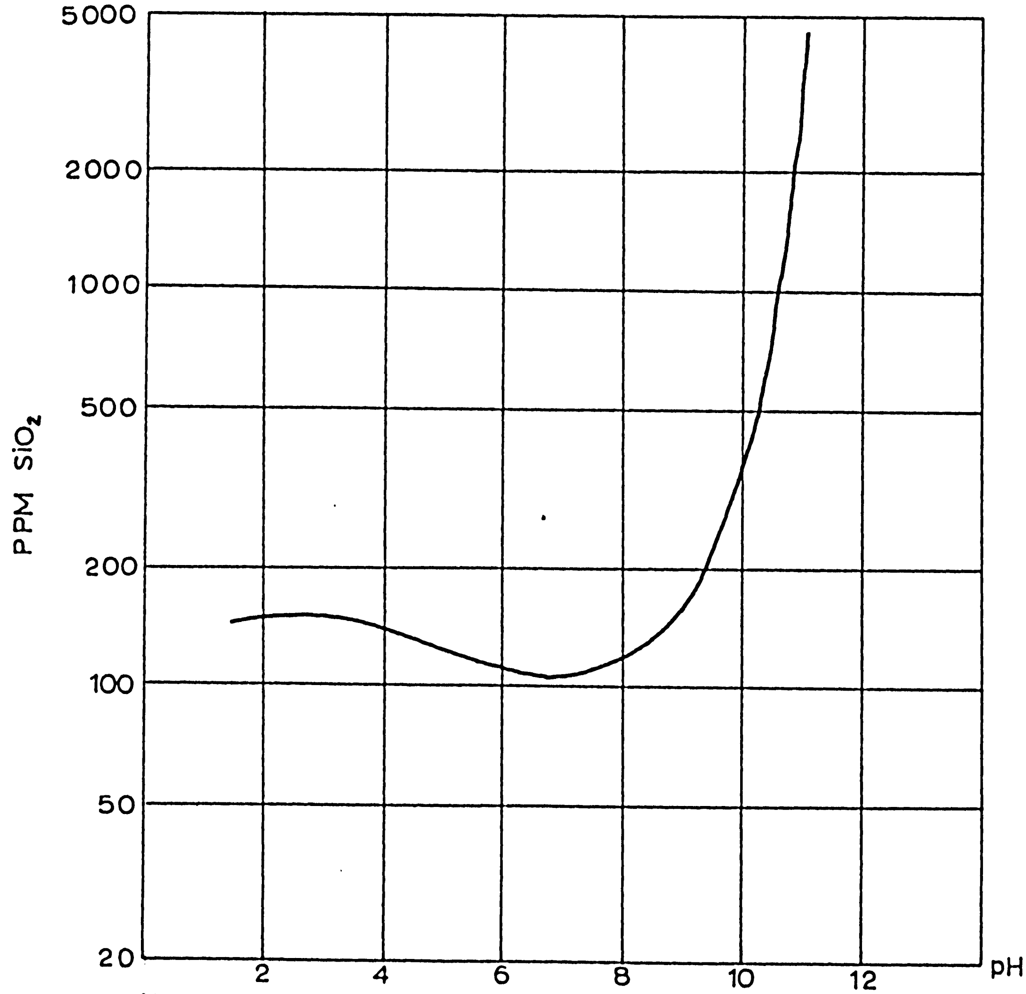


Figure 26. Change of solubility of silica with pH. Temperature approximately 25°C. (After Krauskopf, 1959)

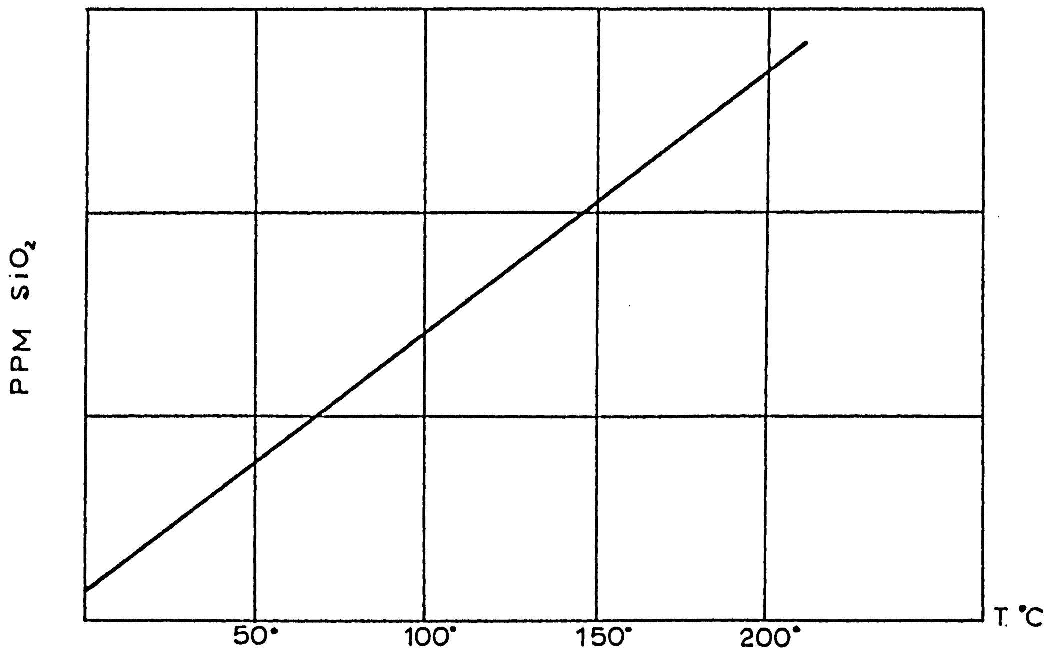


Figure 27. Solubility of amorphous silica (After Krauskopf, 1959)

solutions precipitate colloidal silica in an effort to maintain saturated equilibrium conditions with respect to temperature. The effects of pressure in combination with temperature were not discussed by Krauskopf.

Calcite, on the oter hand, is more soluble in cold waters of low pH and less soluble in warm waters of high pH. Thus, the antipathetic relationship of calcite and quartz is established.

From the data of Dapples(1959) and Krauskopf(1959), it may be surmised that the presence of calcite and temperatures in the range of 25-150° C. are sufficient to effect the solution of quartz and the deposition of calcite. The presence of moderate heat not only increases the solubility of silica but also the rate at which it goes into solution. At values of pH greater than 9.0 further increases in the solubility of quartz would occur, and the antipathetic relationship of calcite and quartz would be enhanced.

Textures and Structures

Grain size of the sediments is rather small. Average grain size of the sandstones is in the 250-500 micron range with occasional pebbles as large as about 2 centimeters. in the longest dimension. True conglomerates were not observed. Conglomeratic patches were randomly distributed in the sandstone, but generally occured at the base of scour and channel fillings. Size grades larger than 2000 microns were predominately composed of rounded siltstone and limestone fragments, set in a matrix of sandstone and silt sized material, and cemented by calcite. The rocks at localities X-53 and X-21 are,on the average, coarser than those in the strata at J-2, J-1, X-13, and X-5, and these are coarser than the strata at J-4(Figures 8-12).

Bedding in the sediments is generally medium to thick (Ingram, 1954) with an approximate average for the entire measured sequence of between 2 and 3 feet. The beds are hard, and many splinter quite readily when struck with a hammer.

Internal stratification is not common in the sediments. Many of the sandstones are laminated. The laminations are often quite pronounced by interlaminations of magnetite and black lithic fragments(Figures 13, 14). The magnetite grains are the more common interlaminae.

Shales are uncommon in the strata studied. But when a shaly unit is examined closely, it can be seen that the bedding fissility is usually caused by thin compressed layers of carbonaceous material which allow the shale to part rather freely, parallel to the bedding.

Directional features include crossbedding(Figure 28), ripple marks(Figure 29), log orientations, and channels. A number of these features were measured and plotted on Figure 25. As can be seen, two specific trends are evident. At locality J-2, a southwesterly direction is indicated, and at locality J-3, a southeasterly trend is evident. Additional information was obtained from J-4, X-21, X-20, and X-18 (Figure 25). At present, these data have only local significance and more measurements over a wider area are necessary for a better indication of source directions. Such measurements are contemplated as a portion of more extended and detailed work in the northern Crazy Mountain Basin in the summer of 1964-1965.

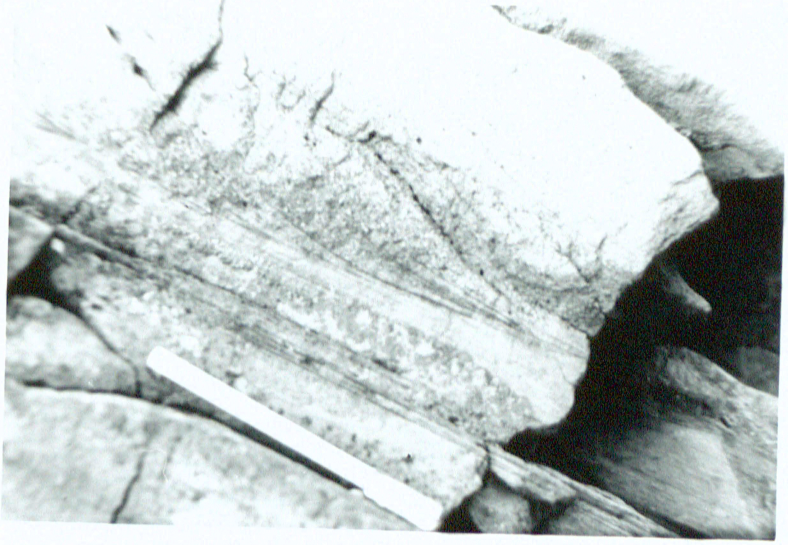


Figure 28. Crossbeding at locality X-18. The crossbeds are set off by cross laminae of black lithic fragments and magnetite. The direction of this crossbeding is plotted in Fig. 25.

Figure 29. Ripple marks at locality X-99. These are current ripples whose strike is NW-SE. This is plotted on Fig. 25.

Textures and Structures--Discussion

The general small grain size accompanied by large amounts of silt but relatively little clay size material indicates a moderately strong fluviatile environment for the sandstones. Variations in the hydraulic force did occur, as illustrated by conglomeratic lenses and very silty units. Interpretation of these siltstones wdll require more detailed imformation. The siltstones may represent a period of relative quiescense of the depositing streams, a still water facies of large streams or flood conditions.

Simpson(1937) visualized the environment of the Fort Union Group in the Crazy Mountains as a floodplain. This is supported by the excellent vertebrate fossile localities which are quarriable, freshly fractured bones, teeth missing from jaws, and association with fishes, aquatic reptiles, and fresh water molluscan fossils. This indicates that the remains were washed in and concentrated. Most of the mammals represented are thought to have had aboreal habits.

Non-laminated, non-fissile sediments would be indicative of a fluviatile environment in which settling time was short or interrupted. Clay material is also necessary for the production of fissility in indurated sediments(Grim, 1952).

The relatively minor occurence of crossbedding and channeling also tends to indicate a moderate or sluggish current, Channels are generally small, averaging one to two feet deep. Data on directional structures are still too incomplete for any real analysis. The sedimentological evidence tends to substantiate the evidence of Simpson(1937) for a floodplain environment.

Fossils

Fossils in the strata are fresh water and terrestrial forms. The preservation is rather poor, in general, and often fragmented, due to the coarseness of the rocks in which they are preserved.

Plants are particularly abundant as carbonaceous films and vein impressions. The following is a list of tentatively identified material which indicates a Paleocene age for these rocks:

Sequoia sp.
Metasequoia sp.
Taxodium sp.
Sassafrass sp.
Ulmus sp.
Betula sp.
Quercus greenlandica
Populus sp.

Animal fossils are rather rare and represented by pelecypods and gastropods. Of the invertebrates represented pelecypods are the most abundant. Generic identifications are offered:

Unio?
Viviperus?

Vertebrate animals are represented in the strata by only one fossil from locality J-4, an M_1 or M_2 of (?)Gidleyina silberlingi. Simpson(1937) reported (?)Gidleyina silberlingi as occuring 400 feet above the base of the Melville formation in Wheatland County, Montana, 20 miles to the northeast of Melville, along the road to Harlowtown, on the east flanks of the Crazy Mountains. This locality is 24 miles south-east of the locality herein d east of the locality herein reported. This indicates a late Paleocene age for the strata. It is on the basis of these plant fossils and the occurence of (?)*Gidleyina silberlingi* at the base of the measured sections that the entire sequence in the northern Crazy Mountains is correlated with the Melville formation of the Fort Union Group.

Conclusions

1) It is proposed that the stratigraphic terminology introduced by Stone and Calvert (1910) and Simpson (1937) be adhered to in this area. Other terminology is borrowed from separate basins in which different sources were active and with different conditions of sedimentation. The type localities of the Bear, Lebo and Melville are nearby for convenient reference.

2) The age of the rocks studied is Late Paleocene, as indicated by the fossil plants and the remains of Gidleyina silberlingi. The lithology is similar to the Melville formation. Therefore, the rocks studied are termed Late Paleocene, Melville formation.

3) Criteria for subdivision are based on the following: clay mineral content, and sandstone:shale ratios.

4) Corrosion of the quartz and feldspar appears to have occured at two times. Some of the quartz is corroded and some not. The non-corroded quartz usually has a high degree of roundness.

5) The sources of these rocks were pre-existing rocks which contributed much lithic material. The sources of supply were, in general, from the north, presumably from the Castle Mountains, and the Little and Big Belt Mountains.

6) Analysis of the clay minerals also indicated the progressive denudation of Mesozoic, Paleozoic and finaly Precambrian terrains, through uplift, erosion and supply of the material to the Crazy Mountain Basin to form the Fort Union.

References

Brindley, G.W. and McEwan, D.M.C., 1953, Structural mineralogy of clays, Ceramics--A Symposium, British Ceramic Society, p. 15-59.

Carozzi, A.V., 1960, Microscopic Sedimentary Petrography, John Wiley and Sons, New York, 485p.

Dapples, E.C., 1959, The behavior of silica in diagenesis, in Silica in Sediments, S.E.P.M. Spec. pub. no. 7, p. 36-54.

Grim, R.E., 1952, Clay Mineralogy, John Wiley and Sons, New York, 384 p.

Hadding, A., 1932, The pre-Quaternary rocks of Sweden, IV, glauconite and glauconite rocks, Medd. Lunds. Geol.-Mineral. Inst., v. 51.

Hendricks, S.B. and Ross, C.S., 1941, Chemical composition and genesis of glauconite and celadonite, Am. Mineral., v. 26, p. 683-708.

Holms, R.S. and Hearn, W.E., 1942, Chemical and physical properties of some of the important alluvial soils of the Mississippi Drainage Basin, U. S. Dept. Agr. Tech. Bull. 833.

Ingram, R. L., 1954, Terminology for the thickness of stratification and parting units in sedimentary rocks, Geol. Soc. America Bull, v. 65, p. 937-938.

Klemme, R., 1949, Geology of the Castle Mountains Area, Montana, unpubl. Ph. D. thesis, Princeton Univ.

Krauskopf, K.B., 1959, The geochemistry of silica in sedimentary environments, in Silica in Sediments, S.E.P.M. Spec. pub. no. 7., p. 4-19.

McMannis, W.J., 1955, Geology of the Bridger Range, Montana, Geol. Soc. America Bull., v. 66, p. 1385-1430.

McMurchy, R.C., 1934, Crystal structure of chlorites, Z. fur Kristallog., v. 88, p. 420-432.

Roberts, A.E., 1963, The Livingston formation, U.S.Geol. Surv. Prof. Paper 475.

Sato, H. and Sudo, T., 1956, Chlorite from the Hitachi Mine, Miner. J., v. 1, p. 395-397.

Simpson, G.G., 1937, The Fort Union of the Crazy Mountain Field, Montana, and its mammalian fauna, U. S. Natl. Mus. Bull. 169,

Stone, R.W. and Calvert, W.R., 1910, Stratigraphic relations of the Livingston formation of Montana, Econ. Geol., v. 5, p. 551-557, 652-669, 741-764.

Tanner, W., 1949, Geology of the Sixteen Mile Creek Area, Montana, unpubl. Ph. D. thesis, Princeton Univ.

Weaver, C.E., 1958, Geologic interpretation of argillaceous sediments, Pts. 1 and 2, Am. Assoc. Petroleum Geologists Bull., v. 42, p. 254-271.

Weed, W. H., 1893, The Laramie and the overlying Livingston formation in Montana, U.S. Geol. Surv. Bull. 105, p. 10-41.

__________, 1894, Geology of the Livingston Folio, U.S. Geol. Surv. Geologic Folio 1.

__________, 1896, Coal resources of the Crazy Mountains area, U. S. Geol. Surv. Bull 112.

__________, 1899, Geology of the Little Belt Mountains Folio, U.S. Geol. Surv. Folio 56.

APPENDIX

Explanation of symbols used in graphical sections

<u>Thickness in Feet</u>-self explanatory

<u>Unit Number</u>-self explanatory

<u>Lithic Fragments</u>-In the rocks studied red and black lithic fragments are distinctive. The bars represent vertically the thickness in which the phemomena occurs and horizontally a visual approximation of their relative abundance. A dot represents only a trace. This convention is used throughout this paper.

<u>Soluble Material</u>-self explanatory

<u>Value of (001) Reflection of 10 A Material</u>-This was not analysed for all units. A horizontal line represents an analysis and indicates the proper value as taken from x-ray diffractograms.

<u>Clay Mineral Content</u>-Clay minerals were identified from x-ray diffractograms obtained on a G.E. XRD-5 diffractometer using CuK radiation at 40KV, 16 ma, TC=2, Ni filter, fast scan.

<u>Layer Properties</u>-These symbols are taken from Bouma, 1962. <u>Sedimentology of some Flysch Deposits</u>.

 Crossbedding

 Parallel lamination

 Curved lamination

 Channel, material within same size as without

Channel, material within finer than without

Channel, with basal conglomerate

Plant fragments oriented parallel to bedding

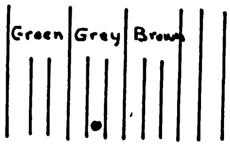
Plant fragments in all orientations

Nodules

Septaria

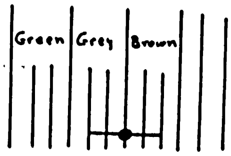
Texture-self explanatory.

Color-a dot represents a particular color:



medium grey.

A dot and a line —•— indicates a blend of two colors:



medium grey-brown.

Thin Section Analysis-The bar represents a 100 percent analysis and the symbols represent:

Quartz

Felfspar

Lithic Material

Matrix

Explanation of Figure 22

The triangular diagram represents a plot of the sandstone composition in four fields each having three components. These components are rock, quartz, feldspar, and matrix; and are represented respectively by the letters r, q, f, and m.

The upper triangle contains a plot of rock-feldspar-quartz; the lower left a plot of feldspar-rock-matrix; the lower right a plot of quart-matrix-rock; and the central triangle a plot of feldspar-quartz-matrix.

The various samples are represented by the following symbols within the triangular plots:

○ J-1-3
● J-1-19
△ J-1-48
▲ J-1-51
□ J-1-62
■ J-1-63
▽ J-1-72
▼ J-1-86
+ J-1-105
× J-1-112
♦ J-1-132
◊ J-1-143
† J-1-147
○ J-2-23
● J-2-27
□ J-2-36
■ J-2-53
△ J-2-63
▲ J-2-75
+ J-2-79
× J-2-85
● J-4-19
○ J-4-30
□ J-4-39
■ J-4-43
▲ J-4-50
△ J-4-69
× J-4-74
+ J-4-126
▽ J-4-147
○ X-13-4
● X-135
□ X-13-17
■ X-13-23
△ X-13-27
▲ X-13-29
† X-13-30
× X-13-54
○ X-5-3
● X-5-21
X
X
X
X

▲ X-5-32
△ X-5-45
□ X-5-58
○ X-21-1
□ X-21-3
△ X-21-10
\+ X-21-18
○ X-53-1
△ X-53-3
□ X-53-6
● X-53-28
▲ X-53-35
■ X-53-46

FIGURE 9. FORT UNION GROUP SECTIONS X-5(TOP) AND X-13(BOTTOM).

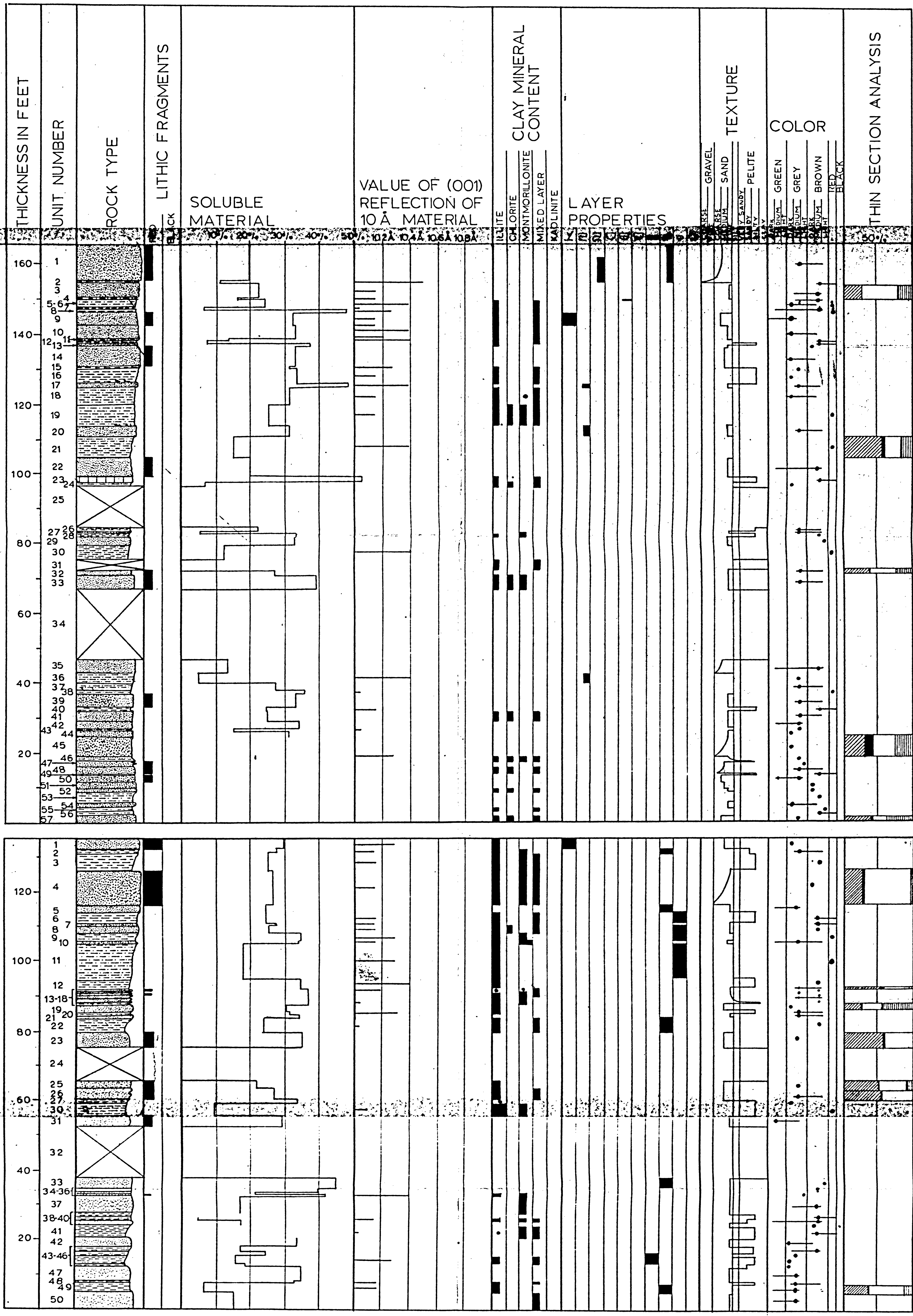
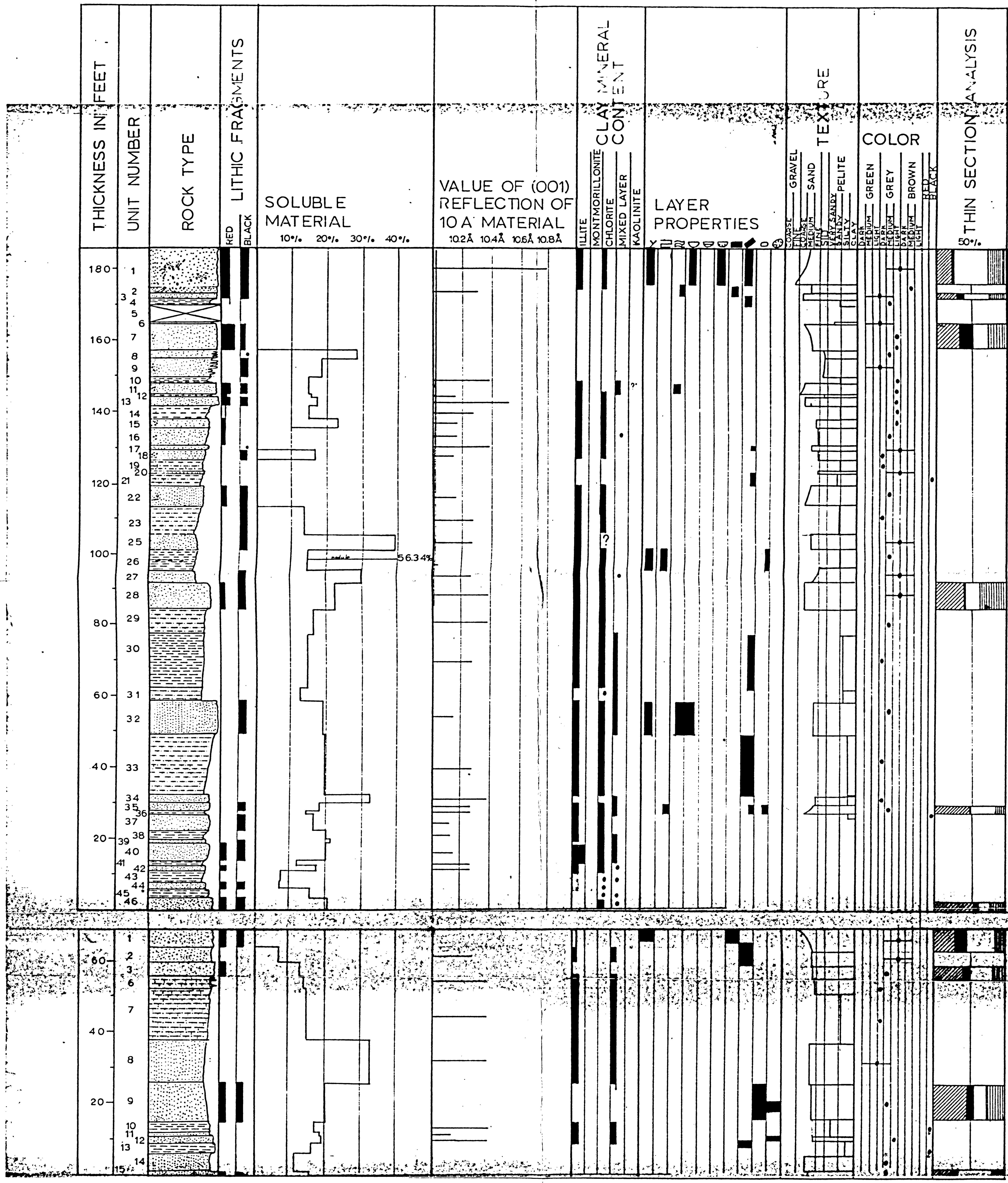


FIGURE 8. FORT UNION GROUP SECTIONS X-53(TOP) AND X-21(BOTTOM)



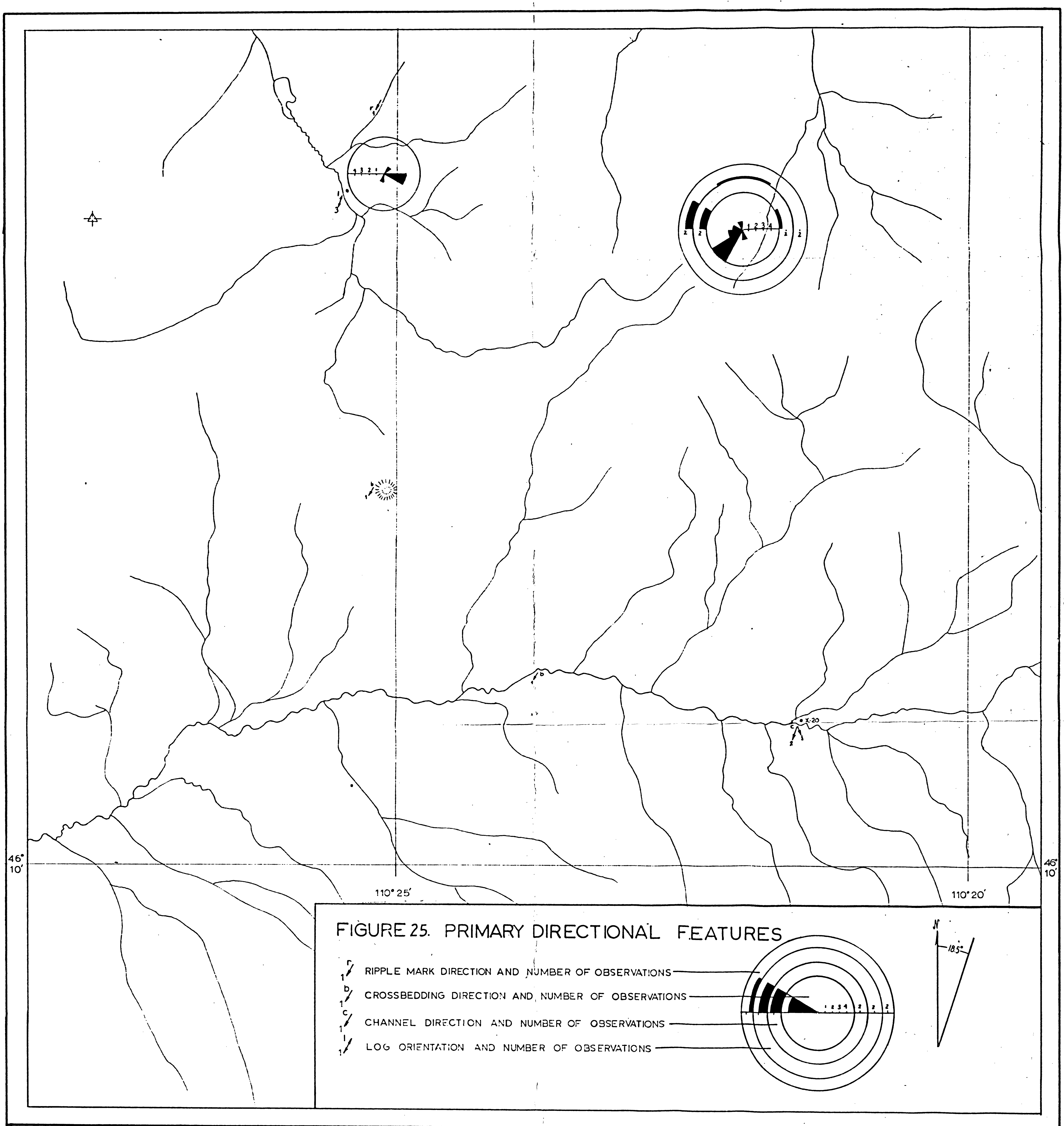


FIGURE 25. PRIMARY DIRECTIONAL FEATURES

FIGURE 10. FORT UNION GROUP SECTION J-2

FIGURE 11. FORT UNION GROUP SECTION J-1.

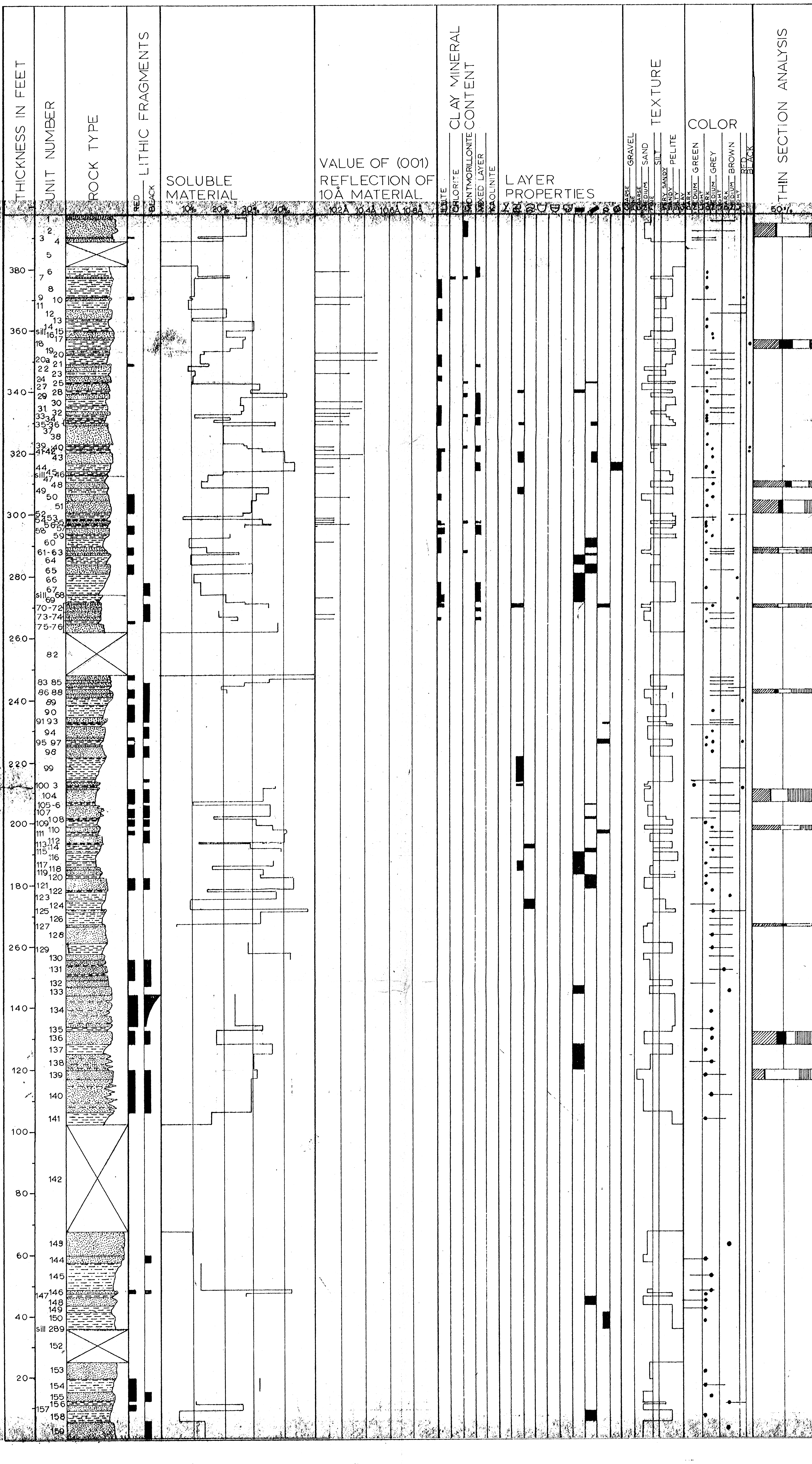


FIGURE 12. FORT UNION GROUP SECTION J-4.

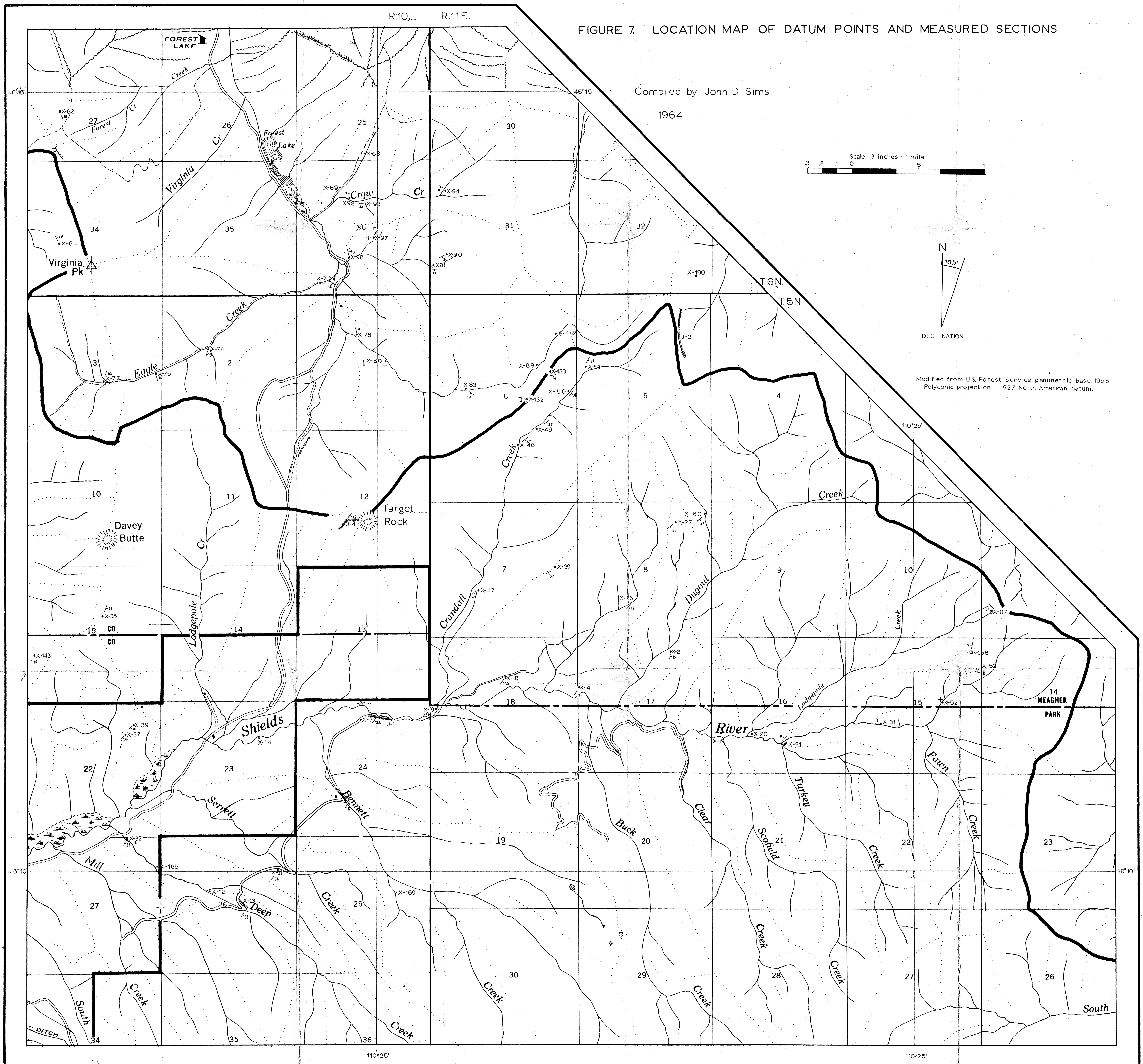


FIGURE 7. LOCATION MAP OF DATUM POINTS AND MEASURED SECTIONS

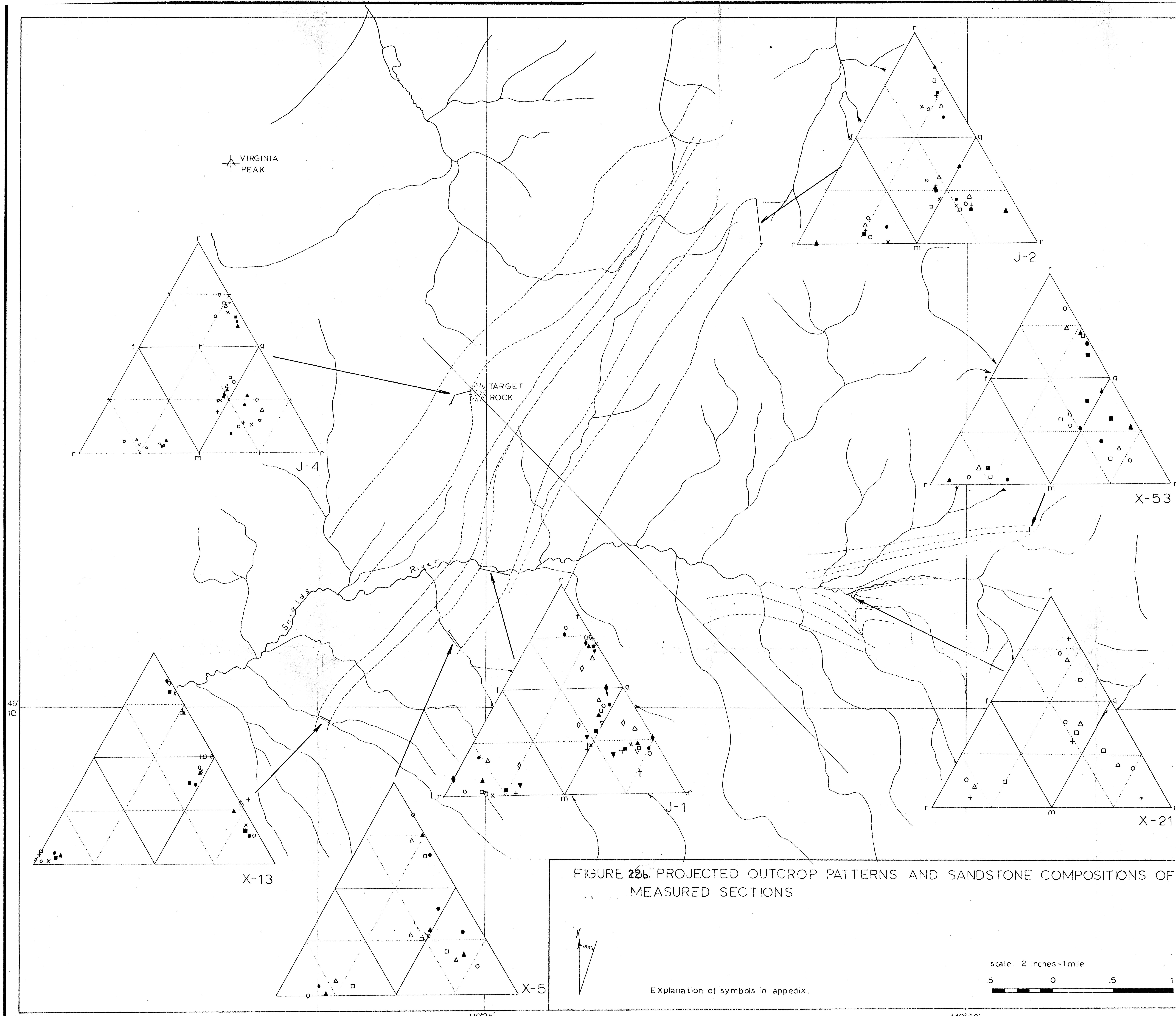


FIGURE 22b. PROJECTED OUTCROP PATTERNS AND SANDSTONE COMPOSITIONS OF MEASURED SECTIONS