THE RICE INSTITUTE

Geological and Geophysical Studies of a Portion of the Little Llano River Valley, Llano and San Saba Counties, Texas

by

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A THESIS SUBMITTED TO THE FACULTY IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF ARTS

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A geologic study of the Precambrian Valley Spring gneiss was made in the Babyhead-Wilberns Glen area in northern Llano County, Texas. Magnetic and gravity surveys were made over this and the surrounding areas to determine the relationships of the major rock units: Valley Spring gneiss, Packsaddle schist, associated granite intrusions, and Paleozoic sediments.

The area studied lies on the northeast flank of the northwest-trending Babyhead anticline, which forms the major structural control. The Valley Spring gneiss was mapped as four phases: felsic gneiss, mafic gneiss, feldspar-quartz-amphibole-pyroxene gneiss, and biotite-amphibole schist. Two meta-diabase dikes were also mapped. The composition of the Valley Spring gneiss, the constancy of its parallel bands, and its conformity and gradation into the metasedimentary Packsaddle schist indicate a parent rock composed primarily of impure sandstone. Preservation of original structures indicates a lack of mobilized constituents during metamorphism. The Valley Spring gneiss belongs to the quartz-feldspathic mineral assemblage in the staurolite-quartz subfacies of the almandine-amphibolite facies.

After metamorphism the area studied was folded and then intruded by granitic material. From middle Precambrian time to the present, the area studied has undergone only cycles of erosion, deposition, and mild uplift, except for faulting at the end of the Paleozoic.

The gravity survey indicates a synclinal body of schist trending northwest under the sediments and lying over the Valley Spring gneiss on the northeast flank of the Babyhead anticline. The magnetic survey indicates that the Packsaddle schist does not extend under the sediments to the east and that mineralization occurred along the llanite dike.
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INTRODUCTION

This thesis consists of a petrologic study of a portion of the Valley Spring gneiss of the Llano Uplift, Texas. The study has been carried out in an area regionally mapped by Paige (1912) but which has not been mapped in detail. The project was undertaken in conjunction with a study by Mr. Edward G. Lidiak of the overlying and related Packsaddle schist occurring to the north of this area. A gravity and a magnetic survey were made over the areas under study and the surrounding countryside for the purposes of better determining the relations of the different rock units, of investigating the usefulness of such surveys over basement complexes, and of educating the author and Mr. Lidiak.

Location

The area of geologic study of the gneiss is located in the northern part of the Llano Uplift (Central Mineral Region) of Texas (Figure 1). It lies approximately ten miles north of the Llano courthouse on State Highway 16, at Babyhead in northern Llano County. The area extends from Babyhead southward to the Mayes Chapel-Lone Grove Road and eastward to the Little Llano River between Wilberns Glen and the Mayes Chapel-Lone Grove Road.

The area of the geophysical surveys extends from State Highway 16 eastward to the road connecting Yates, Lominta, and Allen ranches to Lone Grove, and includes the area of
Topography and Climate

The Llano region consists of a basin formed in the Precambrian metamorphic and igneous complex and rimmed by a higher plateau of more resistant, outwardly dipping Paleozoic strata (mostly limestones). The Paleozoic rocks, in turn, are mantled by the flat-lying Cretaceous sediments of the Edwards Plateau.

Within the basin are isolated topographic highs, formed either as erosional remnants, such as Town Mountain, or by downfaulting, which brought the more resistant Cambrian sediments into a position where they acted as "relief preservers" during the uncovering and subsequent erosion of the less resistant Precambrian complex. Two forms were developed: the rounded or peaked erosional remnants and the flat-topped fault blocks. Average relief is approximately 500 to 700 feet; average elevation is approximately 950 feet above sea level.

In the Babyhead-Wilberns Glen area, the topography on the metamorphics is not the usual low rolling relief of the rest of the basin but rather sharp in comparison. Because the area lies near the edge of the uplift, it has not been subjected to as much erosion as the center of the uplift. Maximum relief in the area studied is 500 feet, ranging from 1050 feet to 1550 feet above sea level.
The Paleozoic sediments form a high scarp around the basin, with deep embayments formed by streams such as the Colorado River. The areas between the rivers are relatively flat.

In the area studied the Paleozoic scarp along the Little Llano River valley is sharpened not only by being formed of resistant limestone but also, at this locality, by being an obsequent fault line scarp. Where the limestone scarp turns eastward away from the valley in the southern part of the area, the scarp is somewhat more gentle and more irregular.

The drainage of the Llano area is controlled by the Colorado River through its major tributary in the Llano area, the Llano River. In the area studied, the Little Llano River, perennial and spring fed, is the controlling stream into which all of the area drains. Drainage is through intermittent streams except where faults occur, where the Paleozoic limestones form a scarp, or where a combination of these factors occur.

The climate is semi-arid but is sufficiently moist to permit the development of good grazing land, or to support a bountiful and varied, semi-arid flora and fauna. The land is used primarily for ranching.

Regional Geologic Setting and Previous Work

The Llano Uplift is the exposed southeastern end of the
northwest-trending Texas craton, the stable crustal element of the southwestern United States. The craton formed after the completion of the regional metamorphism of the rocks forming the Valley Spring gneiss-Packsaddle schist metamorphic complex approximately one billion years ago, in Middle Precambrian time (Flawn, 1956, p. 27). Through later orogeny and intrusion the craton was joined to the other stable shields to form a part of the hedeocraton supporting the North American continent. From evidence presented or summarized by Flawn (1956), the Texas craton has existed as a stable positive area since the middle Precambrian and has acted as the stable base for the subsequent orogenic activity in the southwestern United States. Thus, the southeastern margin of the Llano Uplift area is the buttress around which the Ouachita geosyncline was deflected and against which it was later collapsed during the late Paleozoic orogeny. This margin is also the locus of the Balcones fault zone and the associated igneous activity. The sediments lap onto the uplift and dip outward from it. The uplift forms the western stable margin of the depositional basin of the Gulf of Mexico, with Mesozoic and Cenozoic sediments dipping to the east and then south as their outcrop belts swing from north-south to east-west around the Uplift. (Figure 2.)

The lithology of the Llano Uplift consists primarily of metamorphic rocks and the granitic rocks intruded into them.
The metamorphic rocks consist of two major units:

Valley Spring gneiss - a somewhat massive, finely banded quartzo-feldspathic group of gneisses and schists of disputed origin,

Packsaddle schist - a generally dark colored, metasedimentary complex of mica and amphibolite schists;

and three minor units:

Red Mountain gneiss - meta-igneous rock in the southeastern part of the Llano Uplift,

Big Branch gneiss - meta-igneous rock in the southeastern part of the Llano Uplift,

Lost Creek gneiss - metamorphic rocks possibly formed under the influence of the Town Mountain granite in the northwestern part of the Llano Uplift between the towns of Mason and Fredonia (Ragland, 1960).

There are three major granitic rock types occurring in the uplift area which form the greater part of the intrusive, batholithic masses. According to Stenzel (1932, 1935), they are:

Town Mountain granite - major type

Oatman Creek granite

Sixmile granite

There is also a fourth granitic rock type which is important both because it is unusual and also because it has been suggested as most representative of the composition of the
parent magma for the various intrusive rock types of the area (Goldich, 1941). This fourth granite type is known as the opaline-quartz porphyry or llanite.

According to Paige (1912, p. 3) the Valley Spring gneiss in the Llano area is:

- dominantly light colored and pinkish toned
- and comprises feldspathic and quartzitic schists; quartzites, wollastonite bands, granular acidic gneisses and rare amphi-bolitic portions.

These rocks are primarily fine grained and generally finely, though indistinctly, banded and foliated. Although the Valley Spring gneiss has a definite structural trend and relationship to other units in the uplift, it is intensely internally folded, contorted, and broken. The unit as a whole is considerably more massive than the overlying Packsaddle schist and has greater and more distinct internal variation.

Paige (ibid., p. 3) believed the Valley Spring gneiss to be metasedimentary:

A study of areas occupied by this formation leaves the impression that a thick series of sediments of rather uniform composition has been subjected locally to intense granitic intrusion and metamorphism, in a zone where rock flowage and minor folding have been dominant.

However, he further states that there is evidence of intrusion prior to metamorphism.

Stenzel (1932, p. 143-144: 1934, p. 74), on the other
hand, feels that the Valley Spring gneiss is originally igneous and that its gradational relationship with the Packsaddle schist is caused by its intrusion into the schist during folding and metamorphism of the schist.

The Packsaddle schist is generally a dark, fine-grained, finely foliated, amphibolite schist with occasional quartzite and marble bands. Though the amphibolite schist is internally intensely contorted, the marble may be traced in a regular fashion so as to outline the structural pattern of the schist. For instance, near Oxford, in the southeastern part of the Llano quadrangle, the marble bands outline the plunging nose of an anticline. General agreement exists as to the sedimentary origin of the Packsaddle schist.

Stenzel (1932) has divided the intrusive granites of the Llano region into three major units. In order of increasing age they are:

- Six mile granite—gray, fine-grained biotite granite
- Oatman Creek granite—gray to pink, cataclastic granite
- Town Mountain granite—coarse-grained to porphyritic granite, typically with large flesh-colored feldspars.

Of these, the most important is the Town Mountain granite, which forms the major intrusive bodies of the region, such as the Wolf Mountain body, Granite Mountain body, Midway
sill, Enchanted Rock body, and the Lone Grove body (Buchanan Massif of Keppel, 1940). The Lone Grove body is of greatest importance in this study because it lies immediately southeast of the area under study and because its emplacement and the activity of its associated fluids seem to have influenced the geology of the area under study.

The Precambrian rocks briefly discussed above have the following major regional structural relationships:

1. The Valley Spring gneiss forms the core of two major northwest-trending anticlines, and the Packsaddle schist fills the synclines in between. In the thesis area gneiss and schist are generally gradational and concordant; to the southeast they may have a thrust fault relationship (Clabaugh, 1958, p. 1546). If the Valley Spring gneiss is considered to be of igneous origin, it is younger than, and intrusive into, the Packsaddle schist; if it is considered to be of sedimentary origin, it is older than, and underlying, the Packsaddle schist.

2. The granites tend to occupy the synclinal troughs. Because of this relationship, and because their associated pegmatites and aplites tend to follow foliation planes or joint patterns developed in the me-
amorphic rocks, the granites are considered to be post-metamorphic as to time of intrusion (or late metamorphic at the earliest).

3. The llanite is post-metamorphic.

Upon completion of metamorphism and intrusion, the region became a part of the Texas craton, was uplifted, and eroded. The Upper Cambrian seas invaded the region, covering 800 feet of topographic relief with the basal and continental Hickory sandstone member and overlying, gradational, marine limestones of the Cap Mountain and Lion Mountain members of the Riley formation. Above these were deposited the Welge sandstone, the Morgan Creek limestone, the Point Peak shale, and the San Saba limestone members of the Wilberns formation (Barnes, 1947). These sediments were followed, with minor unconformities by the remainder of the Paleozoic sequence.

At the end of Paleozoic time the region was uplifted and faulted as a result of the deformation of the Ouachita geosyncline adjacent to the uplift area, which acted as a stable buttress (Paige, 1912, p. 7). The area then underwent a long period of erosion - up to the time of the invasion of the Cretaceous seas and deposition of the Cretaceous limestones.

After Cretaceous time, little structural activity took place other than gradual epeirogenic uplift and gradual
retreat of the sea. Once exposed, the area was again attacked by erosion which has continued to this day.

In addition to the papers mentioned above, the following papers also describe some phase of the geology of Llano region and have bearing upon this study.

Paige (1910, 1911, 1912) carried out an excellent regional study, especially in the U.S.G.S. geologic folio of the Llano-Burnet quadrangles. The general relationships as determined by him are still valid, although the Paleozoic stratigraphy has been somewhat re-outlined.

Powers (1928) discussed the relationship of the Ouachita folding to the Llano Uplift and the Marathon Uplift.

Stenzel described the Wolf Mountain phacolith (1933) and the general structural relations of the Llano Uplift (1934). He (1935) also discussed the Precambrian unconformity.

Lidiak (1960) studied the Packsaddle schist north of the thesis area and found it conformable with the Valley Spring gneiss of the area under study.

Keppel (1940) outlined the concentric zoning of the granites in the region noted by Stenzel (1932). Hutchinson (1954, 1955, 1956) discussed the origin and development of the granites of the area. Especially important was his study of the Enchanted Rock batholith (1956). He found that the batholith was formed in a synclinal trough and felt its emplacement was due to the down-buckling of the syncline. He and Barnes further believed the Valley Spring
gneiss was originally sedimentary, in opposition to Stenzel and in agreement with Paige.

Sellards (1929, 1932) summarized the pre-Paleozoic and Paleozoic systems in Texas. However, Barnes, Cloud, and Bridge in various papers have reorganized and summarized the lower Paleozoic stratigraphy of the region, especially in Bridge, Barnes, and Cloud (1947), Cloud and Barnes, (1944), and Barnes, Cloud, et al. (1959). Plummer has outlined the overlying Carboniferous rocks (1949). The Cretaceous rocks are referred to in numerous papers but are not of direct concern to this study.

Barnes (1939, 1942 a, b) has outlined many of the economic uses of the Precambrian rocks - vermiculite, building stone, serpentine, etc.

Various guide books of the Geological Society of America (1940), Abilene Geological Society (1955), San Angelo Geological Society (1954), and West Texas Geological Society (1939) contain discussions of itineraries through the Llano area.

Various gravity and magnetic studies have been made in the Llano area by Barnes (1953, 1954 a, b, c), Barnes, Romberg, and Anderson (1954), and Romberg and Barnes (1949). Data from these papers were used in the surveys made in the thesis area, though none of them were concerned with this area. Flawn (1956) discussed a gravity survey made over various parts of the Texas craton, but none of the data were
directly available to the public, since it was primarily a private, commercial survey.

**Problems**

This study is concerned with the following problems of the Valley Spring gneiss:

1. The description of its mineralogy and petrography, and the subsequent delineation of its internal phases.
2. The petrologic and structural relationships among the internal phases of the gneiss and with its external associates, especially the Packsaddle schist and the intruding granites.
3. The external relationships as indicated by the gravity and magnetic surveys.
4. The origin of the gneiss and its relation to similar units in other parts of the region.
GEOLGY OF THE BABYHEAD-WILBERNS GLEN AREA

General

Upon leaving the low, broad valley formed on the Packsaddle schist one half mile north of Wilberns Glen, the Little Llano River flows southward through a narrower valley lying between the high Cambrian limestone fault scarp to the east and the equally high, steep knobs and ridges of Valley Spring gneiss to the west. At Carter's ranch the scarp swings eastward away from the fault, the valley opens into the Precambrian basin, and the steeply dipping gneiss begins its swing from north-northwest to west as it starts around the northern nose of the Babyhead anticline. The valley itself is fairly flat, being thinly covered by alluvium through which granite or gneiss may be seen. At Wilberns Glen is a small, remnant granite knob from the original Precambrian erosion surface (Figure 3).

Two major ridges of gneiss occur in the area. A major creek, flowing southeast, lies between them. The center part of the more southerly ridge is extended southward by the north-northeast trending occurrence of the llanite as it crosses this ridge.

The creek mentioned above shows evidence of structural movement along its course - either minor faulting, or slippage between foliation planes during the Precambrian fold-
Figure 3: Topographic development on the major rock types. View northwestward along the Little Llano River Valley. Limestone scarp on right and at rim in background; Pack-saddle schist in center where valley widens; Valley Spring gneiss in round knobs to left.
ing. The evidence consists of many breccia patches, commonly erratic strikes, topography (the presence of the creek) and displacement of the llanite. However, the llanite may have been intruded as discontinuous sheets, and local distortion may be sufficient to explain the breccia patches, so that only slippage on a foliation plane or possibly no movement at all took place.

Dips along the southern ridge are more erratic than along the northern one. Minor folding as well as faulting on the limb of a major fold is apparently the cause. One such minor fold is outlined on the southeastern end of this ridge. Intrusion has also played a greater part in deformation of this area than to the north, which may result from the closer proximity to the Lone Grove body of granite.

The high ridges end abruptly to the west and drop down to a low, fairly flat area which begins at Sawyer's ranch house and extends westward to State Highway 16. It is marked as alluvium on Plate I. The topographic break is caused by faulting seen in the creek east of the Sawyer ranch house.

The major creek flowing along the northeast edge of the area is an excellent example of stream control by faulting (east of Sawyer ranch house), jointing (along the Babyhead-Wilberns Glen road), and lithology (turn to the Little Llano River). Wright's Creek flowing south along the western edge of the area is not structurally controlled, while
the creek flowing east across the southern edge is parallel to the gneiss foliation.

Topography in the area studied is primarily structurally controlled. However, two other influences should be considered:

1. The influence of the surfaces developed by previous cycles of erosion; (pre-Hickory and pre-Cretaceous are the only ones of sufficient time to have greatly influenced topography).

2. The influence of the now-removed overburden in determining the drainage initiated upon retreat of the Cretaceous seas.

3. The influence of the resistance to weathering of different rock types.

Petrology

The Valley Spring gneiss in the area under study is formed primarily of quartzo-feldspathic schists or fine-banded gneisses with a few interbands of amphibolitic schists. Except where involved in minor folds, their dip is generally near vertical or slightly to the north or east. There is a noticeable decrease in the size and number of major schist and mafic gneiss phases as one moves away from the Packsaddle schist contact. At the Packsaddle schist contact bands of gneiss and schist alternate, the width and fre-
quency of the gneissic bands decreasing as one goes from gneiss to schist. Gradations between types of gneiss are of two kinds—either a series of alternate bands as at the Packsaddle contact or a gradual change of composition over a single zone. Commonly there is no gradation, one type occurring sharply against another.

Pegmatites and granite bodies are abundant and contain little ferromagnesian material other than minor boitite or magnetite. The pegmatite and aplite bodies generally follow the various joint sets. In the southeastern part of the area, this joint control is especially well illustrated. There the joints trend approximately east-west and north-south, and in both directions a granite dike may be found every 50 to 100 yards, forming a rough checkerboard pattern. Fine-grained granitic material also cuts the gneiss in thin veinlets and stringers throughout the area. Dike-gneiss contacts are generally sharp, but there commonly occur local swirls and gradations of the dike material into the country rock. Some distortion of the foliation also takes place along these contacts, but the gneiss is undisturbed beyond a few feet away. The dikes vary in width from a few inches to five feet at the maximum and may be traced for half a mile or more. (Figure 4).

The granite body contacts with gneiss are sharp and distinct in one place and obscure in another, even on the edges of the same granite body. In some places the contact
Figure 4: Fine-grained granite-mafic gneiss contact. Granite lighter colored, gneiss darker. Note sharp, straight contacts; chill border; stoping.
is so gradational that the gneiss and granite cannot be separated, the granite having acquired a slight lineation and the gneiss having taken on a somewhat coarser and more granitic texture and granitic composition. Most of the granite bodies tend to have a long direction which is oriented with the strike and foliation of the gneiss.

A llanite dike approximately follows the general structural trend but in detail is a cross cutting body. It dips steeply eastward and forms the crest of the high hills along the river and in the south-central part of the area and helps maintain their steep sides. At the small knob at the extreme northern end of the area it turns sharply west and southwest and runs to a point a mile west of Babyhead. The llanite at the turn seems to have undergone minor displacement. Various mineralizations occur along the llanite outcrop as do many small granite bodies such as the one associated with it at the turn from north to west.

Two basic dikes, each approximately two feet wide, trend roughly east-west across the area.

The Cambrian sediments bound the area to the east. Forming the lower slopes of the scarp is the ferruginous, non-calcareous, dark red, coarse-grained Hickory sandstone. In one outcrop in the Little Llano River at the base of the exposed Hickory is a dark pink, siliceous rock approximately one inch thick, and under this is a well cemented breccia (Fig.5) composed primarily of limestone with some fragments of granite.
Figure 5: Breccia and Hickory sandstone, Little Llano River fault. Hickory is dark rock on the right.
The breccia fragments are mostly angular, but some are rounded. The breccia is approximately one foot thick and is underlain by dark, thoroughly weathered, micaceous schist. Downstream are several outcrops of gneiss badly disturbed and broken; though the fragments have apparently not been moved, they seem to be slightly rounded and well altered. As all of these phenomena are along the major north-south fault, they are probably caused by it. However, the in-place fragments suggest an ancient outcrop surface, and it is possible that the breccia is a pre-Hickory conglomerate. These possibilities are interesting lines of future study of the pre-Hickory land surface, but it is assumed at this time that these features are related to the fault.

Above the Hickory sandstone lie the various scarp-forming, massive, coarsely crystalline, commonly glauconitic limestones of the Riley and Wilberns formations. Near the top of the scarp, where it begins to recede, lie the green shales and limestone lenticles of the Point Peak shale, and above this is the massive San Saba limestone. The Ellenburger, of Ordovician age, finally caps the plateau country away from the edge of the scarp.

In general the sediments dip eastward and northeastward, steeply near the scarp and much more gently eastward of it. In Wilberns Glen a small steep fold may be seen as well as evidence of minor faulting associated with the north-south fault along the valley.
Petrography

In general the igneous and metamorphic rocks of the area studied have free silica available and are, except for the pegmatites, fine- to medium-grained. No evidence of intrusion or metamorphism younger than pre-Hickory was found.

The following units were mapped and will be discussed:

1. Valley Spring gneiss
   Felsic gneisses
   Mafic gneisses
   Feldspar-quartz-amphibole-pyroxene gneiss
   Biotite-amphibolite schist
   Meta-igneous rocks.

2. Granitic intrusions
   Granitic bodies and pegmatite dikes
   Foliated granite dike
   Llanite


Valley Spring Gneiss  The Valley Spring gneiss is highly variable across strike but fairly constant along strike, some of the bands being traceable or correlatable across most of the area. However, the different types of gneiss seem to recur several times in no particularly regular fashion, so that structural complexity and the development of cover prevents positive correlation over much of the
area. Most of the bands, though seemingly constant in width and strike, are internally intensely folded and contorted.

The felsic and mafic phases are the two major types of gneiss in the area studied. These are general terms used to describe the various gneisses seen in the field and mapped on the basis of color and hand specimen analysis. Field delineation has corresponded well with compositional variation determined from optical studies.

The felsic gneisses are a widely diversified group containing both quartz-feldspar-mica gneisses and quartzites. All are fine-grained and finely foliated, though the foliations may be indistinct or not numerous. Commonly they appear sugary. The felsic gneisses are the most resistant to weathering of the different types of gneiss.

In the quartz-feldspar-mica gneisses color ranges from dark pink to white. Quartz, potassium feldspar, and plagioclase are the primary constituents, and muscovite, biotite, and dark opaque minerals (magnetite) generally occur as accessories. Calcite was found in two samples that were badly altered and lying in the fault zone near the Sawyer ranch house. One of these samples also contained minor hornblende. Zircon and sphene were found in only one thin section from this group of eight. The particular sample was near a pegmatite dike. Chlorite was found in one altered sample from the Sawyer ranch fault. One sample had augen-appearing schlieren of aligned muscovite and
quartz. An augen phase is also found consistently at the Valley Spring gneiss contact with the Packsaddle schist both in this area and along the western edge of the area studied by Mr. Lidiak.

The quartzites are generally cream colored to light gray and consist of 80% to 90% quartz with minor irregular altered feldspar. One sample contained minor garnet, pyroxene, muscovite, and biotite. Another sample contained zones of magnetite grains scattered through the quartz and minor feldspar.

The mafic gneisses are a variable group of feldspar-quartz-mica-amphibolite gneisses having a generally blue-gray to dark blue-gray color. All contain plagioclase, potassium feldspar (microcline) and quartz. All but one sample contains biotite. One sample contains muscovite, but does not contain either amphibole or pyroxene, as do the other samples in the group. Two samples contain epidote; and one, garnet. The following were found in minor amounts: dark opaques, calcite, sphene, zircon, monazite (in one sample), and apatite (every sample of the group). The mafic gneisses are somewhat coarser grained than the felsic group. The foliation is more discontinuous, but more closely spaced than the foliation of the felsic types of gneiss.

In general, the contact between the felsic gneiss and mafic gneiss is exceptionally sharp and straight (Figure 6).
There is little alteration along the contact. In the northern part of the area, a block of felsic gneiss is included in a band of mafic gneiss and the mafic gneiss is also seen to swirl into the felsic gneiss. Foliation strikes N70W through the whole complex (Figure 7). Except for banding and evenness of grain size, the same picture may be seen in the pegmatite sill and dike intrusions. These intrusions also have blocks of the neighboring country rock included in them. In this particular exposure, the mafic-gneiss is thought to have originally been an igneous intrusion formed prior to metamorphism. These observations also indicate little mobilization of material during metamorphism.

The feldspar-quartz-amphibole-pyroxene gneiss is a variant of the mafic gneiss. In the usual blue-gray matrix of the mafic gneiss are set pink feldspar grains and green, weathered hornblende grains. The rock serves as a useful marker in the field.

In thin section the rock consists primarily of plagioclase, microcline and quartz. Foliation is caused by alignment of hornblende, diopside, and actinolite grains. Laminae of diopside and actinolite occur next to laminae of hornblende and plagioclase. One explanation for this phenomenon is the preservation of the original textural and compositional variations of adjacent shale and limestone lenticles represented by the hornblende-plagioclase and diopside-actinolite assemblages respectively. As in the example of the pre-
Figure 6: Felsic and mafic gneiss types. Felsic gneiss to the left, mafic to the right. Note the conformity of the two phases and the development of the three major joint sets.
Figure 7: Inclusion of foliate gneiss in the mafic gneiss. Foliation indistinct, but passes through the inclusion from the mafic gneiss.
metamorphism inclusion mentioned above, lack of mobilization of rock constituents during metamorphism is indicated by the adjacent occurrences of the hornblende-plagioclase and the diopside-actinolite assemblages.

Thin layers of amphibolite-biotite schist occur throughout the area interbanded with the gneiss. In some cases they appear to be basic segregations formed during metamorphism (an exception to lack of mobilization mentioned above). In other cases they seem to represent original rock variation. One sample consists of a black, well-foliated schist composed primarily of amphibole with minor associated pyroxene and very little quartz, biotite, and dark opaques. The other sample has some quartz and plagioclase, much biotite and hornblende, and minor dark opaques and sphene. Two major bands of the second type of schist occur in the northern part of the area.

The meta-igneous rocks are of two types. The first, mapped as a separate unit, is a meta-diabase rock. It occurs as two, fine-grained, massive, dark gray dikes trending east-west across the center of the area studied. The rock is composed of plagioclase, hornblende, minor quartz, and dark opaque minerals. The extensive alteration of the hornblende and especially the clouded plagioclase (Wilcox and Poldervaart, 1958, pp. 1354-1357) indicate that the dikes have undergone metamorphism. The dikes, though approximately parallel to the trend of
the gneiss around them, cut across the gneiss bands to some extent. This discordance may indicate intrusion after major folding of the gneiss. The alteration of the dikes might then be attributed to continuation of metamorphism after folding.

The second meta-igneous rock was found at only one locality, in a prospect pit near the ilanite dike outcrop on the west slope of the Little Llano River Valley opposite Wilberns Glen. It is of interest because it illustrates garnets growing and excluding plagioclase, hornblende, and dark opaque minerals. Because of this feature, and because of the presence of andalusite, it is felt that the rock was metamorphosed by the heat from the ilanite intrusion.

**Granitic Intrusions** The granites of the area are pink, massive, and medium grained. They are composed of quartz, microcline, plagioclase, biotite, hornblende, dark opaque minerals and sphene. Structural and contact relations with the gneiss have already been discussed (p. 16).

The pegmatite and aplite dikes are associated with the granites and have the same composition. The pegmatites exhibit graphic intergrowth texture and are very coarse grained. The pegmatites exhibit zoning along the contacts (Figure 8). There is a fine grained chill zone of approximately \( \frac{1}{8} \) inch thickness, an intermediate zone of very coarse-grained pink feldspar, and a center which is some-
Figure 8: Zoning in pegmatite.
what finer grained. One explanation of the zoning might be multiple intrusion. However, it is possible that the finer grained center developed because volatiles escaping into the country rock or the surface caused an increase in viscosity of the still fluid center, and smaller crystals would result. Crystals in the outer zones are more nearly euhedral than the crystals in the central zone.

Beginning near the Sawyer ranch house and trending east, a coarse-grained pink and black dike or sill with coarsely foliated granite texture crops out. Foliation is caused by aligned biotite. Microcline is the major feldspar, but some plagioclase with rare, faint, zoned grains is present. Quartz and biotite are present in major quantities. The only other minerals present are dark opaque minerals and zircon in pleochroic halos in the biotite. The unit is thought to be a granitic dike which has undergone some alteration. The alteration was caused either by the dike's intrusion during the last stages of the Valley Spring gneiss metamorphism, or by alteration by later intruding pegmatites. The foliation of the rock indicates a somewhat different history from the rest of the granitic intrusions in the area.

The llanite dike has been analyzed both petrographically (Iddings, 1904; Lidiak, 1960) and chemically (Goldich, 1941; Iddings, 1904). There are apparently two phases in the area under study. The normal occurrence for this
area is a light orange-brown, massive, well fractured rock with coarse, equant, blue quartz phenocrysts in the fine-grained ground-mass. The other phase is commonly found near the contact with the gneiss. Here the llanite has a dark gray ground-mass with orange-brown feldspar phenocrysts and blue quartz phenocrysts. This second type is the one described by Iddings as the ordinary case, but it is found less commonly than the first in the area studied. The magnetic survey indicates a zone of high magnetite concentration along the ridge northeast of Babyhead corresponding to the llanite. It is assumed that the magnetite was introduced as a part of a zone of mineralization induced by the llanite but is not an actual part of the llanite body, because nowhere else has this rock produced a high anomaly. A second zone of mineralization associated with the llanite occurs on the west side of the northernmost knob in the area, where the dike turns from north to west. Here the mineralization is rich in copper.

Sediments  The Cambrian Hickory sandstone overlies the Precambrian basement complex. It is a massive, poorly bedded, dark reddish brown, poorly sorted, coarse- (containing pebbles) to fine-grained sandstone cemented with iron oxide. In an area of faulting, it is light yellow-brown to tan, cemented with silica, and fractured, with silica filling the fractures and forming a network of raised ridges. It grades upward into the Cap Mountain limestone. (Bridge,
Barnes, and Cloud, 1947).

Metamorphic Facies

From a consideration of the mineralogical and petrological characteristics of the various metamorphic rock types of the area under study the most suitable facies classification is the staurolite-quartz subfacies of the almandine-amphibolite facies (Fyfe, Turner, and Verhoogen, 1958, pp. 228-230). This subfacies is the lower grade unit of the facies. The general occurrence of this rank of rock is "... in the high grade zones of progressive regional metamorphism of the Barrovian type - from the middle of the garnet zone through the zones of staurolite, kyanite, and sillimanite" (ibid., 1958, p. 228). The pressures in this facies range from 3,000 to 12,000 bars partial pressure of water, load and water pressures generally being equal (ibid., p. 201). The presence of hydrosilicates suggests the high water pressures. Maximum temperature for the facies is approximately 700°C; for this subfacies it is probably somewhat less (ibid., p. 229).

The mineral assemblages of the staurolite-quartz subfacies are listed by Fyfe, Turner, and Verhoogen (1958, pp. 229-230). Most of these assemblages are represented by the mineral assemblages of the different phases of the Valley Spring gneiss. However, the major rock type in the area belongs to the quartzo-feldspathic assemblage, as is expected.
Those resembling other assemblages (except the biotite-amphibole schists) seem to result from variations in original composition around the quartzo-feldspathic composition, rather than being distinctly different assemblages.

One noticeable variation from the ideal assemblage is the greater number of pyroxene (diopside and augite) occurrences as compared with the epidote occurrences, or as compared with the occurrence of epidote in the ideal assemblages. A partial explanation is the gradation between an ideal quartzo-feldspathic rock type and an ideal calcareous rock type. However, some influence may also be attributed to conditions of metamorphism. According to Fyfe, Turner, and Verhoogen, epidote is unstable over slightly lower load pressures than are normal for this facies (1958, p. 229). Lidiak (1960) found diopside and high-calcium plagioclases in some of the pelitic schists of the Packsaddle schist adjacent to this area. He attributed this to lower load pressures. It seems to the writer that the two units, the Valley Spring gneiss and the Packsaddle schist, are intergradational and related, and that they underwent metamorphism together. If the variation of the Valley Spring gneiss assemblages from the ideal assemblages could be attributed to the same mechanism, lower load pressures, one more indication of the gradational relationship of the two units would be established. Fyfe, Turner, and Verhoogen (1958, p. 229) state:
Coexistence of medium plagioclase and an epidote mineral is highly characteristic of this subfacies... The writers attribute it to high load pressure, perhaps augmented by non-hydrostatic stress. At lower pressures (hornblende hornfels facies) epidote seems to be unstable over the same range of temperature, and plagioclase of any composition may crystallize.

It is suggested that the lack of epidote in the Valley Spring gneiss was caused by lower load pressure as in the Packsaddle schist. The Valley Spring gneiss has a lower concentration of calcium than the Packsaddle schist, so that the pyroxene formed in place of the epidote consisted of both diopside and augite. The plagioclase formed would be less calcic than that of the Packsaddle schist.

The effect of lower load pressure on the epidote and pyroxene occurrences is not as noticeable in the Valley Spring gneiss as in the Packsaddle schist because:

1. The gneiss would not have been as sensitive to the effects of variation in load pressure. The gneiss is quartzitic and the schist is amphibolitic. Also the gneiss underlies the schist and would be always subject to its load.

2. The gneiss has less calcium available for the formation of epidote or calcic pyroxenes than the schist.

Although the metaquartzites do not show the characteristic minerals of the quartzo-feldspathic assemblage,
they may be assumed to belong to it because they are surrounded by rocks of that assemblage and rank. Furthermore, consisting almost entirely of pure quartz grains, the quartzites can hardly assume so varied a composition unless material is introduced. This, too, is evidence for little movement of material during metamorphism.

The metamorphic facies and subfacies of the Valley Spring gneiss and Packsaddle schist agree but differ as to compositional assemblage.

**Structural Geology**

The Valley Spring gneiss changes trend from north-northwest to west-northwest as it swings around the northwestern end of the Babyhead anticline. It occupies the core of the anticline, with the Packsaddle schist on its flanks. Upon this large structure a small northwest plunging anticline is developed in the southeastern part of the area. Many other small folds, too small to map, have been developed throughout the area. Most of them trend approximately paralleled to the trend of the gneiss. In addition the gneiss is often contorted and folded within each band, parallel to the banding.

The major fault of the area trends north-south along the Cambrian scarp. Its throw is shown to be no greater than 400 feet because Hickory sandstone is found on both sides, and its thickness in this part of the uplift is no
greater than 400 feet. Paige (1912, p. 7) states that the movement is all vertical, but to create the displacement shown horizontally by outcrop relations would take greater vertical displacement than 400 feet. Rather, some degree of slip faulting is proposed to act as a mechanism for shifting the eastern block to the south as well as down. This movement would give the horizontal displacement of the Packsaddle schist and the Cambrian scarp.

Another fault trending northeast-southwest occurs along a creek just east of the Sawyer ranch house and is indicated by:

1. The topographic break.
2. The occurrence of a thin bed of apparent Hickory sandstone (Figure 9).
3. The sudden changes of strike from N70W to N45E.
4. The occurrence of badly fractured zones.
5. The displacement of a dike and a schist body.

These features are exposed in the creek east of Sawyer's ranch house. The presence of the Hickory sandstone may be due to deposition in a low on the Precambrian land surface which is just now being exposed. If so, the throw is unknown, but is probably not too great. Otherwise, if Hickory sandstone is present only because of faulting, the minimum throw is 200 feet, inasmuch as the lowest surface
Figure 9: Hickory sandstone in the fault at Sawyer's ranch. Pencil and light-meter mark the thin bed of sandstone.
upon which it could have existed without faulting is approximately 200 feet above the creek. This calculated value is the difference between the creek elevation and that of the highest Precambrian surface between the creek and the nearest Hickory outcrop.

Many numerous small faults occur throughout the area. They have displacements of a few inches to a few feet and are not mappable. These faults may be either small thrust faults or small normal faults.

The jointing of the area is well developed. There are three major sets:

1. Parallel to the banding.
2. Perpendicular to the banding.
3. Horizontal.

Other cross-cutting sets are present, but they occur locally and are not continuous. Especially along the vertical joints there has been intrusion of pegmatites and also erosion.

Foliation is caused primarily by light-dark mineral separation into thin bands. It may also arise from parallel orientation of mica flakes and of other platy minerals.

Several kinds of lineation are present: orientation of mineral grains, crinkles in the foliation, orientation of small folds, and slickensides. The slickensides are in the direction of the petrofabric axes and indicate
movement along the surface of a foliation, bedding plane, or fault. The other lineations are in the \( b \) direction, i.e., parallel to the trend of the Babyhead anticline.

The folds and joints formed after metamorphism have exerted the major geologic control in the area from Precambrian time to the present.

**Origin and Development**

That the Valley Spring gneiss is primarily a sedimentary unit is suggested by:

1. Gradation into the Packsaddle schist, an established metasediment or metapelite - metasedimentary complex (Lidiak, 1960).

2. Conformity and concordance with the Packsaddle schist.

3. Preservation of original structures on a microscopic as well as a macrosopic scale.

4. Variation of rock types which can be said to reflect original variation in the parent rock because of the evidence for lack of mobilization of rock constituents.

5. Variation across strike and continuity
along strike which, with the preservation of other primary structures, implies preservation of original stratification.

The parent rock of the Valley Spring gneiss was probably a varying sequence of somewhat argillaceous and calcareous fine- to medium-grained sandstones. The parent sediments of the Packsaddle schist were deposited conformably and gradationally over the Valley Spring sediments.

The whole group of sediments underwent mild intrusion both before metamorphism of the complex and near the end of metamorphism. Although the metamorphism resulted in rocks of the high grade almandine-amphibolite facies, it caused little mobilization of constituents and little addition of material.

Folding and jointing followed metamorphism. Then intrusion of the Lone Grove granite body on the southeast of the area studied caused the emplacement of small numerous granite bodies, aplites, and pegmatites along joint planes and synclinal axes.

Cycles of erosion and deposition ensued, continuing with mild uplift to the present day.
GEOPHYSICAL STUDIES OF THE LITTLE LLANO RIVER VALLEY

General

Both a gravity survey and a magnetic survey were made over the same area. Approximately the same stations were occupied. Locations were determined from the following seven and one-half minute quadrangle sheets with a scale of 1:24,000: Cherokee, Indian Hills, Lone Grove, and Llano North. Stations were spaced one-fourth to one-half mile apart in the areas studied in geologic detail by the writer and Lidiak and one-half to three-fourths mile apart in the surrounding areas. Stations were located at the most accessible and accurately determined points of elevation for the gravity survey and at the most readily accessible points for the magnetic survey. Because of the lack of roads, and scarcity of straight trails and crossable hills, the stations necessarily have a haphazard pattern. The relatively random station distribution gives perhaps more evenly reliable contour maps, but accurate station-controlled profiles are hard to obtain.

The standard of comparison for these surveys is the commercial survey such as is carried out by Geophysical Associates International. Through such precautions as transit surveyed stations, accuracies of 0.1 to 0.01 milligals in gravity work and 2.0 gammas in magnetic
work are obtained. Such accuracy was neither obtained nor necessary in the surveys presented here. The primary error was introduced in the training of the survey party in geophysical methods.

Nevertheless, because of the strong anomalies, both gravity and magnetic, developed over basement complexes, and after due consultation with Geophysical Associates International, it is felt that the assumed accuracy of one milligal for the gravity survey and 100 gamma for the magnetic survey are sufficient to permit the use of the data to outline the schist and gneiss and allow some discussion of the schist-gneiss-granite-sediment relationships.

The commercial methods of data collection and interpretation developed and used by Gravity Meter Exploration Company (subsidiary of Geophysical Associates International) as well as those currently existing in the literature of geophysics were used or modified for use in working these surveys. The basic reference generally followed was Nettleton (1940). It is assumed, in this discussion, that the reader has a basic understanding of the principles involved.

Gravity Survey

The survey was made with a La Coste-Romberg gravimeter in June, 1959, and extended in September, 1959.
Densities were measured with a Jolly balance on dry samples (paraffin coated) and compared to those measured by Romberg and Barnes (1944) near Smoothingiron Mountain.

<table>
<thead>
<tr>
<th>Formation</th>
<th>Romberg and Barnes</th>
<th>Almy</th>
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<tbody>
<tr>
<td>Packsaddle schist</td>
<td>2.95 gm/cc</td>
<td>2.85 g/cc</td>
</tr>
<tr>
<td>Valley Spring gneiss</td>
<td>2.64 g/cc</td>
<td>2.55 g/cc</td>
</tr>
<tr>
<td>Granite</td>
<td>2.62 g/cc</td>
<td>2.50 g/cc</td>
</tr>
<tr>
<td>Sediment</td>
<td></td>
<td>2.45 g/cc</td>
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The differences can probably be ascribed to the fact that Romberg and Barnes measured density with pore spaces filled with water, whereas in the writer's samples the pore spaces were filled with air. The important factor is that the density contrasts are the same between rock samples of the corresponding units from different areas. The writer used an average value of 2.63 g/cc which gives an elevation factor (combined Bouguer and free air corrections) of .060 mgl./ft. (determined from tables supplied by Gravity Meter Exploration Co.). No topographic effects were noted in the observed map so that the use of this one factor seemed sufficient. Latitude correction data was taken from the international formula. Tidal effects were plotted from data supplied daily by La Coste-Romberg. Meter drift was checked by this data, frequent loop ties, and checking at established base stations. No terrain corrections were made.
In making the survey, a system of base loops was established, tied, and checked. The closure error in the loops was -0.15 mgl. and was distributed around the loops. Stations were then established between base stations and tied to the base stations. The areas within the large loops were then filled with stations which were tied to the loops. Because of lack of roads, some stations were established on foot. The meter required a battery to maintain its internal heat, and at those walked stations at which the battery became weak, the plotted values are indicated by a question mark. Because of their general agreement with surrounding stations, they have been used in contouring. Stations in parentheses were not contoured.

Abnormal errors have been introduced by the use of topographic maps for elevation and location of stations, and in the possible cooling of the meter. A third factor was the Wyoming earthquake of September 14, 1959. At station 207, its shock did not permit the meter weight arm to come to rest. The shock was recorded by La Coste-Romberg, and reading error was estimated by them to be 0.1 mgl. The only uncorrectable source of error of major consequence is the inaccurate elevations. An error in elevation causes an error in both free air and Bouguer corrections. Thus the maximum elevation error of 15 feet produces a maximum gravity error of
0.9 mg/l. Total error may be approximately 1.0 mg/l.

The map was contoured at an interval of 1.0 milligal, which is very close to maximum error. Because of the regular contour pattern and general agreement with geologic data, such an interval appeared justified.

The major density contrast is between the schist and the rest of the rock types, p. 37. Secondary contrasts exist between the remaining rock types but are not deemed sufficient to warrant more than qualitative discussion.

Upon looking at the observed gravity map, Plate II, one is immediately impressed by the amplitude, sharpness, and correlation with the schist outcrop of the gravity maximum in the north central part of the map (Plate V: to be used with the geophysical maps). Also, the general trend of the map is north or northwest, in agreement with the general trend of the rocks in the area.

The circular high at station 103 is supported by the surrounding stations, although its magnitude may not be as great as indicated. It corresponds to a small schist outcrop in the Valley Spring gneiss.

The effect of the sediments is noticeable in the gentle eastward decrease of gravity values on the east side of the map and the straight north-south trend there. The masking effect of the sediments on the schist anomaly is also apparent in the broadening of that anomaly where the schist disappears under the sediments in the northwest.
To the northeast, there may be an expression of Precambrian topography.

Near base station VIII a small negative reentrant into the schist anomaly corresponds to the outcrop of a small granite body that may extend under the sediments.

The northwest-southeast string of negative anomalies on the west side of the map are not currently explainable because of a lack of geologic detail. They may be due to intrusive bodies in the gneiss.

Presumably the outcrop of schist near Lone Grove produces no high anomaly because the schist is very thin over the intruding Lone Grove granite.

From a study of the schist anomaly, it is apparent that the schist extends under the sediments to the northwest and is somewhat asymmetrical in shape, the western side being steeper. Observed profiles AA' and BB' were drawn across the anomaly, from southwest to northeast. Calculations based on the formula for a horizontal cylinder,

$$g_z = 12.77 \sigma \left( \frac{R^2 Z}{Z^2 + X^2} \right)_{\text{kilo-feet}}$$

where $g_z =$ gravity in milligals  
$\sigma =$ density  
$R =$ radius of cylinder in kilo-feet  
$Z =$ depth to center of cylinder in kilo-feet  
$X =$ horizontal distance from projection of cylinder center on the surface to the point at which the gravity effect is being calculated, in kilo-feet, (Nettleton, 1940, pages 108-109).

were made on profile AA' (Plate III) using a two-dimensional
dot chart (Nettleton, 1940, pages 115-116). In conjunction with geologic control, the calculations (Plate III) indicate that the schist body is an asymmetrical syncline which:

1. Extends to a depth of 5000 feet.
2. Has a more gentle dip on the east flank which is broken by the Little Llano River fault.
3. Extends under the sediments to the northeast.

Profile BB' shows the broadening effect of the sediments on the schist anomaly. The above description fairly well fits Lidiak's hypothesis of structure of this schist body—a minor fold on the flank of the Babyhead anticline.

The effect of the non-infinite extent of the schist body was not considered in the calculations because:

1. The calculated profile was made approximately over the center of the schist body and over the highest part of the schist anomaly.
2. The uncorrected, calculated body agrees with the geologic data on the schist (Lidiak, 1960).
3. The calculations were made in order to corroborate the geologic evidence and did not need to be exact.
Magnetic Survey

The survey was made with a Ruska vertical (type V) magnetometer for field measurements and a Ruska vertical recording (type VR) magnetometer for recording diurnal and temperature variations. The same topographic maps used for the gravity survey were used to determine locations for the magnetometer survey. The temperature correction was small enough \((0.37{^\circ}C/1000\gamma)\) compared to the contour interval \((100\gamma)\) that it was ignored. The diurnal correction was obtained from the daily record made by the recording magnetometer. Latitude corrections were made from the tables for variation of the vertical component of the earth's magnetic field. The magnetic inclination is \(60.9^\circ\), and the vertical component varies from \(44,750\gamma\) in the south to \(44,770\gamma\) in the north. The tables and charts used are found in Vestine, et al., 1947, pp. 414-523. Sensitivity of the field instrument varied from \(10.32\gamma/\text{scale division}\) at the start of the survey to \(10.35\gamma/\text{scale division}\) four days later, a change of \(0.03\gamma/\text{scale division}\). Instrument drift is negligible.

The survey was started by selecting a spot in the shade and out of the range of any disrupting influences, such as stock or traffic, where the recording magneto-
meter could be placed. Once set up it was not moved
during the survey. The base selected was the Mayes
Chapel Cemetery. At the beginning of each day a photo-
graphic plate was placed in the recorder and the reading
and temperature of that instrument and the field instru-
ment noted. At the end of the day before removing the
plate, the same procedure was followed. Loops along the
major roads were established first and tied together, then
the interareas were surveyed. The survey was made in
September, 1959.

Because of lack of intervening sedimentary cover,
a magnetic survey on the basement rock encounters many
great magnetic contrasts. The range of values is from
1117 to 30257. A contour interval of 1007 was used.
The maximum range of error is approximately 357 so that
contouring is well within the limits of error.

The most striking feature on the observed magnetic
map is the sharp drop along the Valley Spring gneiss-
Lone Grove granite body contact in the southern part of
the map. The trend of the gneiss from north to west in
the center of the map is clearly illustrated. One inter-
esting problem is the loss of high magnetic relief (though
it is higher than the surrounding granite, schist, or
sediments) in the Valley Spring gneiss in the northwestern
part of the area.
The lack of character in the schist is in sharp contrast to its character in the gravity survey. The indistinct low occurring over the schist, and extending somewhat westward of it, is thought to represent the schist as well as the granite body which intruded into the schist syncline and moved westward along the Valley Spring contact (Lidiak, 1960).

A zone of mineralization along the llanite dike is in evidence in the west central part of the survey at stations 124-126.

The high under the sediments (which do not contain magnetite) is probably due to the existence of the Valley Spring gneiss in the basement and thus marks the eastward extent of the exposed body of Packsaddle schist. The effect of buried topography may also be indicated.

In contradiction to the conclusions of Nettleton and Elkins (1944, p. 74), the magnetic and gravity anomalies of two of the rock units, Valley Spring gneiss and Packsaddle schist, do not agree in sign and sharpness. Also, the mafic rock is not the most magnetic, although it is the most dense. Conversely, the granite and sediments have little expression in either survey - their magnetic and gravity expressions are similar.

The structural trends of the rock units, and their limits, especially for the schist, are well defined by these surveys. However, the surveys are not accurate
enough for the detailed work of locating small features. Such surveys as these are thus useful in delimiting major units in a basement complex (see Tuominen, 1957).
SUMMARY AND CONCLUSIONS

This study of the Valley Spring gneiss in the Babyhead-Wilberns Glen area sets forth the following conclusions:

1. The Valley Spring gneiss is originally an arenaceous sedimentary unit intruded by a few dikes and sills.

2. The gneiss, with the Packsaddle schist, was subjected to high rank regional metamorphism during which load pressure may have been lessened.

3. Prior to intrusion by the large granite bodies, the gneiss-schist complex was folded and jointed by primarily compressional forces. Small folds were formed, one of which occurs in the southeastern part of the area. The trend parallels that of the contemporaneous Babyhead anticline.

4. Intrusion of the granite was structurally controlled and modified the gneiss only locally as to petrology and structure.

5. Gravity data indicates that the schist is approximately 5000 feet thick, forms
an asymmetrical syncline, and extends northwestward under the sediment cover around Babyhead anticline.

6. Magnetic data indicates that the schist extends only a little way under the Cambrian deposits to the east, and that mineralization occurs along the ilanite dike.

7. Post-Paleozoic faulting occurred:
   a. Along the Little Llano River Valley. This fault may have a horizontal strike-slip component.
   b. Along the creek east of Sawyer’s ranch house.
   c. Perhaps along the creek between the two major ridges.

8. Topography is structurally controlled.

It is hoped that the data and ideas presented here may be extrapolated to the study of other parts of the Llano Uplift; that the geophysical methods may prove useful; and that the petrography of the Valley Spring gneiss will aid in its definition and the separation from it of any similar but non-equivalent units, so that the sequence of events may be established for the Precambrian of the region. An understanding of the stable areas such as the
Texas craton is fundamental to an understanding of the continents which they support and underlie.

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Additional information on the collecting and the interpreting of the geophysical data in this report are given in this section.

**Gravity Survey**

Meter: Null reading type, LaCoste-Romberg, no. 76. Meter factor + 0.0854 mgl/scale division; read to five places. Must be maintained at heat, 50°C, 24 hours a day. Heat supplied by 6 volt storage battery. Under these conditions meter drift is negligible.

Base loop: Thirteen stations. Established by taking readings in the pattern

\[1-2-1-2-3-2-3-4 \ldots\]

until the loop is completed. This survey contained four loops. Readings are then changed to milligals. They are grouped by three’s thus:

\[1 \underline{2} \underline{1} \underline{2} 3 \underline{2} 3 \ldots\]

and the difference between end values of each group is distributed among the stations of the group as error caused by meter and tidal drift. The difference between the differences of the two stations of overlapping groups is applied to a value
previously determined for the first station to obtain the value of the second. Base I was assigned a value of 500 mgl. in this area.

Station loops: Two hundred thirteen stations. Readings are taken at a base, then a sequence of stations and then another base or established station. In calculating the values of the stations, the base reading for a certain day is set equal to its established value. The station reading is changed to milligals in accordance to the ratio of base value to base reading times the meter factor. Tidal and meter drift is added depending on the amount of variation of drift with time. Elevation and latitude corrections are applied and the points plotted and contoured. In the area studied, the earth’s gravitational field varied from 979.40331 gals in the south to 979.41654 gals in the north, a variation of 132.3 milligals.

Magnetic survey

Meter: Ruska VR 2445—recording magnetometer.
Ruska V 2061 - field magnetometer. Both temperature compensated. No external energy requirements for field instrument. Meter factor changes with time and is checked every three or four days with a Helmholtz coil. Diurnal recorded on a photographic plate.

Base station: One required for every 50 miles for an accuracy of less than $10^{-7}$ (Nettleton, 1940, p. 194) if using recording instrument. Needed to record diurnal variation.

Meter station: Loops are run and tied: the first loop to the base, those thereafter to previous stations. Readings on both instruments are taken at the base station at the beginning and end of each day. Two readings and the temperature are taken at each station. Magnetic material must not be present on the operator nor within 35 yards of the instrument. Most stations in this survey were at least 50 yards from magnetic objects. The diurnal variation is read from the recorder plate in scale divisions. Station values are determined the same as gravity
values are: by proportion of the base and field meter reading to a determined value times the meter factor. Diurnal is added in the same way as the drift correction in gravity. The temperature and latitude corrections are applied and the values plotted and contoured.

**Interpretation:**

Both methods are potential field methods and, except for constants, may be treated theoretically in much the same way. Invaluable preliminary knowledge may be gained by directly comparing the geologic and geophysical maps. Anomalies may correspond to rock type, and then an indication to the solution of a major interpretational problem, source of the anomaly, will be in hand. To determine the quantitative aspects of an anomaly, computations on a theoretical body are made. This body is outlined according to the known or suspected geology, and then computations for a simple shape approximating the geologic body are made according to formulas such as listed in Nettleton (1940) or Cook (1950). In this study such anomalies as the llanite (stations 123-126) might be approximated by a thin vertical sheet of infinite extent.
Because of the infinite numbers of solutions to potential field problems, some geological knowledge is necessary for interpretation.