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ASSIMILATION IN THE COLD SPRINGS AREA OF THE WICHITA MOUNTAINS IGNEOUS COMPLEX, OKLAHOMA

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ABSTRACT. In the Wichita Mountains igneous complex, near the village of Cold Springs, is an area which clearly illustrates the assimilation of one igneous rock by another. This assimilation of an andesite by a granite and the resulting hybrid rocks have been studied and described in detail. The hybrid products of the assimilation have a variable composition ranging from granite to quartz-diorite. Conclusions as to the assimilation are clearly shown by a study of field relationships together with petrographic study and chemical analysis.

INTRODUCTION

In the vicinity of the village of Cold Springs, Kiowa County, Oklahoma (T. 4 N., R. 17 and 18 W.) there is an area of about six square miles of complex igneous geology consisting of intrusives and associated assimilation products. This forms a part of the igneous rocks of the Wichita Mountains.

Study of the Cold Springs area had as its objective the determination of the origin and emplacement of the igneous rocks and their age relationships. The problem was approached by three methods of investigation: (1) field mapping of boundaries of each igneous unit, study of field occurrences, contacts and relationships; (2) studies of thin sections; and (3) determination and comparison of heavy mineral content.

The field work was done during the school year of 1947-48 and in the summer of 1948. The field mapping was accomplished with the aid of aerial photographs from which overlay tracings of lineations and inferred outcrop patterns were made. All the quarries in the area were studied and specimens of the rocks were collected from selected localities.

Laboratory work consisted of gross examination of collected specimens and study of thin sections made from the same specimens. The heavy minerals of samples of the different rocks in the region were determined qualitatively and quantitatively for purposes of comparison and correlation.

The writer wishes to acknowledge his indebtedness to the Agriculture Adjustment Administration office in Hobart, Oklahoma, and to the Oklahoma Geological Survey in Norman, Oklahoma, for the loan of their aerial photographs covering the area. Particular thanks is due T. S. Burkhalter for making the chemical analyses and to G. E. McKinley, who ably assisted in the field work. The writer is especially indebted to Dr. C. A. Merritt, under whose direction this paper was written, for the guidance and advice so freely given in connection with all phases of the work, and to Dr. W. H. Twenhofel for criticism in preparing the paper for publication.

PREVIOUS WORK

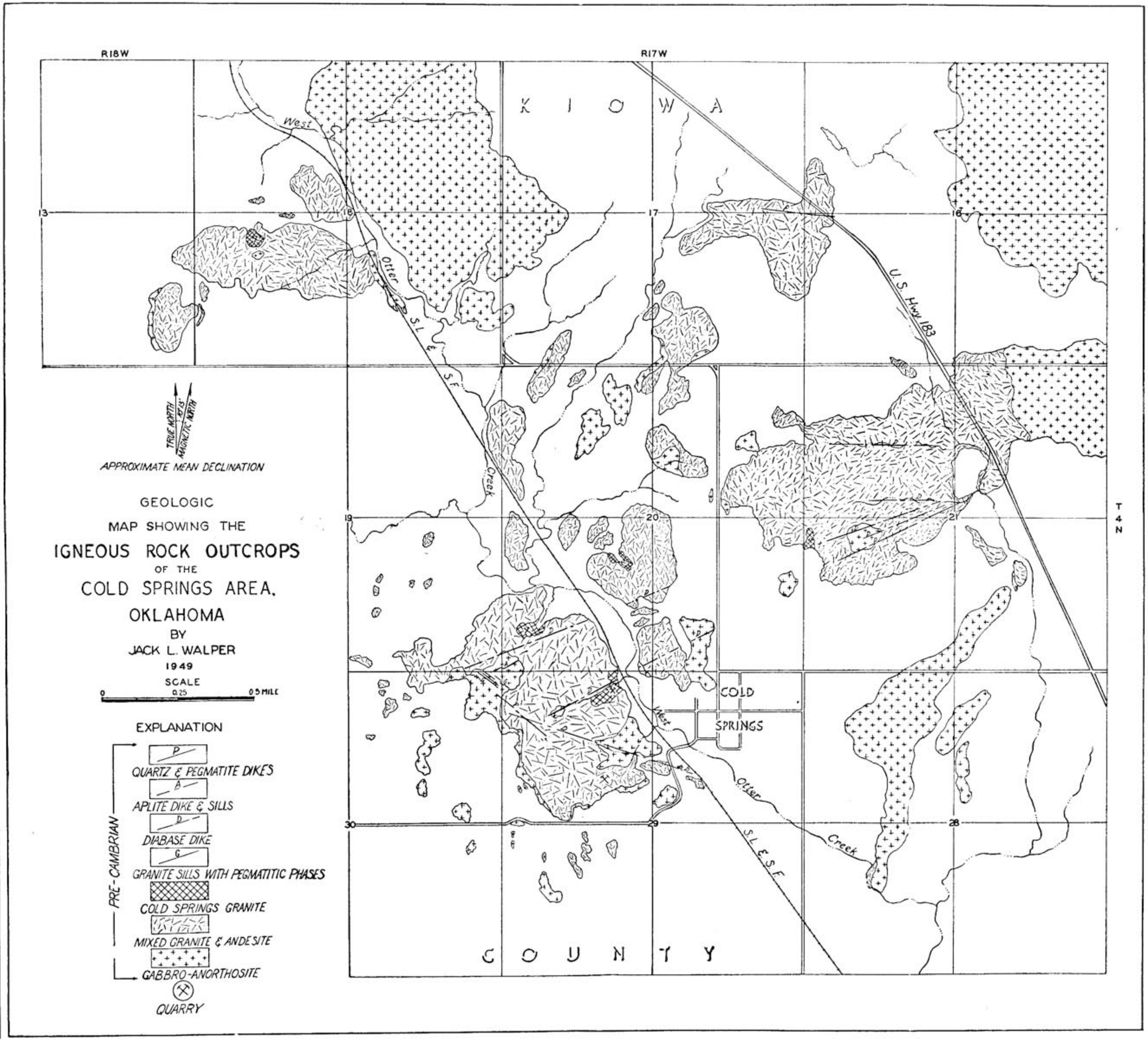
Early geological knowledge of the Wichita Mountains was obtained by various expeditions and geological surveys conducted at intervals during the latter part of the last century, among which were those of Shumard (1854), Comstock and Cummins (1889), Hill (1890, 1891), Vaughan (1899) and Bain (1900, 1904). Bain made a sketch map of the Wichita Mountain region and proposed the name Raggedy Mountains for the gabbro-anorthosite outcrops of the Roosevelt-Cold Springs area. Taff (1904) published a report and geological map of the Wichita and Arbuckle Mountain area.

More recent studies of portions of the igneous rocks of the Wichita Mountains have been made by Taylor (1911 and 1915), Hoffman (1930), Anderson (1946), Scull (1947), Polk (1948) and Schoonover (1948); but Taylor and Anderson are the only geologists whose studies consider the igneous petrology of the Cold Springs area. Taylor divides the rocks of the Wichita Mountains into four groups: (1) pre-Cambrian sedimentary rocks, (2) pre-Cambrian igneous rocks, (3) Paleozoic sandstones and limestones of Cambrian and Ordovician age, (4) horizontally bedded, red sandstones and shales of probable Permian age.

The pre-Cambrian igneous rocks of the Wichita Mountains consist chiefly of rhyolite, granite, quartz-monzonite, diorite and diabase. Taylor's (1915, p. 31) assigned age relationships of these rocks, reading from oldest to youngest, are: gabbro-anorthosite and Headquarters, Reformatory, Cold Springs, Lugert and Quanah granites. His second paper gives a detailed account of the dikes in the vicinity of Cold Springs.

TOPOGRAPHY AND VEGETATION

The type of rock controls the topography to a large extent. The resistant granites rise as rounded hills, moderately covered


R18W
R17W
K I O W A
C O U N T Y
13
18
17
16
19
20
21
30
29
28
T 4 N
West Otter Creek
S.L. & S.F.
U.S. Hwy 183
COLD SPRINGS
TRUE NORTH
MAGNETIC NORTH
APPROXIMATE MEAN DECLINATION
GEOLOGIC MAP SHOWING THE IGNEOUS ROCK OUTCROPS OF THE COLD SPRINGS AREA, OKLAHOMA
BY JACK L. WALPER
1949
SCALE
0
0.25
0.5 MILE
EXPLANATION
PRE-CAMBRIAN
QUARTZ & PEGMATITE DIKES
APLITE DIKE & SILLS
DIABASE DIKE
GRANITE SILLS WITH PEGMATITIC PHASES
COLD SPRINGS GRANITE
MIXED GRANITE & ANDESITE
GABBRO-ANORTHOSITE
QUARRY

by bush or grass, above a grassy plain underlain by Permian sediments. The weathered dikes of the area often give rise to drainage courses.

Most of the area is barren of trees and those present are found along the water-courses and around small springs. The rather sparse character of the vegetative covering is largely due to the present semi-arid climate.

GENERAL GEOLOGY

Following is a resume of the major geologic events affecting the entire mountain system:

A series of igneous bodies, beginning with basic and ending with acidic composition, invaded ancient pre-Cambrian sediments. The only remaining vestige of these sediments is the Meers quartzite (Taylor, 1915, p. 32; Hoffman, 1930, p. 48; Merritt, 1948) which occurs as isolated roof pendants in the gabbro-anorthosite and Lugert granite.

The pre-Cambrian igneous activity throughout the Wichita Mountain system was followed by erosion. It is possible that early and middle Paleozoic strata, beginning with the Reagan (upper Cambrian) sandstone, were deposited in the Cold Springs area over the eroded surface, as they are known to have been deposited in some other parts of the Wichita Mountains. This period of deposition was terminated by a mountain-building uplift which formed the Wichita Mountains and is believed (Powers, 1928) to have had its beginning in early Pennsylvanian time and probably extended into early Permian. During this orogeny the region was uplifted, folded and faulted. Erosion stripped the sediments from the igneous core. Following this erosion, the sediments composing the Permian Red Beds were deposited over the upturned edges of the sedimentary rocks and over large areas of the then exposed pre-Cambrian igneous rocks. Later orogeny may have slightly affected the area.

Taylor (1915, p. 71) has discussed the vertical joints of the area and states that the prevailing direction for the major joints is east-west and north-south. There is also a set of horizontal joints which imparts a distinct sheet structure to the rocks (plate 1A). This jointing is very obvious in the Roosevelt quarry (Sec. 18. T.4N., R.18W.).

THE IGNEOUS ROCKS

The igneous rocks of the Cold Springs area are of pre-Cambrian age and include large bodies of gabbro, anorthosite, andesite, and granite, and dikes of aplite, pegmatite and diabase. The anorthosite, which is a phase of the gabbro and grades into it insensibly, is discussed under the heading gabbro-anorthosite. The andesite is younger than the gabbro-anorthosite and has intrusive relationships with it; still younger than the andesite and intruded into it is the granite. The intrusion of the granite into the andesite has given rise to a series of hybrid rocks of varying composition, among which are quartz-diorite and granodiorite. A series of aplite, pegmatite and dense diabase dikes penetrate the larger igneous bodies.

The map accompanying this paper shows the irregular nature of the exposures. The rocks were mapped as two main types: the gabbro-anorthosite and the granite-andesite mixture. This latter is mainly an intrusion breccia but in places the andesite has been assimilated and formed a fairly even-grained, gray granitic type, which Taylor named the Cold Springs granite. Where possible, an effort was made to map separately the areas where this granite hybrid is present. This proved very difficult, owing to the similarity of the weathered surfaces and the intricate relationship of the various rock types in the area. The quarry sites where this granite is of commercial quality proved to be the only places where distinction could be made with any degree of accuracy.

Hand specimens and the corresponding thin sections of all rock types exposed in the Cold Springs area were studied. These were deposited with Dr. C. A. Merritt at the University of Oklahoma, Norman, Oklahoma. In order to be consistent with recent studies completed in other areas of the Wichita Mountains, the Johannsen (1939, vol. I, pp. 141-161) classification was used in the microscopic description and naming of the igneous rocks.

Gabbro-Anorthosite

The gabbro-anorthosite is the oldest igneous rock known in the Cold Springs area and has the most extensive distribution. It is present on top of the Roosevelt Quarry hill in section 18, T. 4 N., R. 18 W., as very small isolated outcrops and weathered boulders. The core of the hill forming the outcrop in sections 20 and 29, T. 4 N., R. 17 W. consists of this rock which outcrops at the top of the hill and again at its very base. The granite-andesite mixed rock forms a layer around the western side of the hill, resting upon the gabbro-anorthosite, The same conditions appear to exist on the hill in section 21, T. 4 N., R. 17 W.

The gabbro-anorthosite for the most part seems to weather much more readily than the other rocks of the area and the outcrops in places are strewn with cleavage particles of pyroxene crystals. This feature is well exhibited along the road into the quarry of the Oklahoma Granite and Monumental Company, just west of the village of Cold Springs. In several localities throughout the area the gabbro-anorthosite has a structure resembling schistosity. Taylor attributes this to local metamorphism but later investigators have ascribed it to magmatic flow.

A specimen of this rock, collected about one-eighth mile north from the SW corner of section 17, T. 4 N., R. 17 W. is considered to be fairly representative of the gabbro-anorthosite of the area. This rock varies a little in texture and grades from anorthosite to gabbro.

Megascopically, the fresh rock is medium- to coarse-grained, grayish-black in color and is composed almost entirely of dark-colored plagioclase feldspar showing bright cleavage surfaces. Most of the feldspar crystals are uniform in size and do not commonly exceed 4 mm. in diameter, although a few measure over an inch in diameter. These large crystals commonly resist weathering and in some cases form knobs on weathered surfaces. In many places knobs are not present but are replaced by spots of brown iron oxide.

Microscopically, the rock has an equigranular, holocrystalline, medium- to coarse-grained texture. From 85 to 90 per cent is composed of crystals of bytownite feldspar (Ab_{26} An_{74}), most of which exhibit albite twinning; some of the large crystals show schiller structure. The chief femic mineral is diallage which is in sufficient quantity to classify the rock as a gabbro. The accessories consist of magnetite, zoisite (non ferrian), olivine and calcite. In several places the feldspar seems to have been partly shattered and later cemented by the pyroxene, indicating the following order of crystallization; magnetite (first), plagioclase, olivine, and then pyroxene. The zoisite and calcite are of secondary origin. On the basis of the Johannsen system of classification this rock is placed in class II, order 3, family 12, and named diallage gabbro.

Andesite

This rock is present as sill-like bodies in numerous places, and everywhere it is intruded by a network of dikes and stringers of granite, forming an "intrusion-breccia" consisting of xenoliths of andesite included in a granite matrix. Near the margins of the sill-like masses in which this breccia occurs, the andesite is relatively pure. In more central portions the andesite grades into granitic types of rock, which are believed to represent syntectic products produced by the intrusion and assimilation of the original andesite by the granitic magma. In places where the andesite is present in the granite as large blocks, or is cut by granite dikes, and these have been exposed to erosion, the contact between the two rocks has been eroded to form depressions on the surface. These vary in depth up to three inches. A fairly good example of this is shown in plate 1B.

Near the margins of the andesite bodies the rock is found to be relatively free from alteration by the granite. It was from this uncontaminated marginal facies exposed in the quarry in the NW part of section 21, T. 4 N., R. 17 W. that the specimen studied in this section was collected. Other slides of this rock showing contact relationships with the gabbro-anorthosite and granite were studied, as well as slides from the Taylor Collection at the University of Oklahoma.

Megascopically, the andesite is a dark-gray to black, aphanitic rock, holocrystalline and almost coarse grained enough to be classed as phaneritic. It is completely crystalline and not dense. The weathered surface has a brownish-green tint and a somewhat pitted character. The surface tint is due partly to the weathering of minute biotite flakes.

Miscroscopically, the rock does not show any glassy, felty or hyalo-ophitic texture common to aphanitic rocks of this family. Its minerals, although smaller in size, exhibit the same hypidiomorphic granular texture of the phanerites of this type. It has an ophitic[1] texture. The laths of plagioclase are

[1] Albert Johannsen, 1939, vol. I, p. 45. The word is used as Zirkel first used it in 1866. It applies only to the crystal arrangement and does not imply that the minerals must be plagioclase and pyroxene.

from 0.2 to 1 mm. in length and are andesine (Ab_{53} An_{47}). They are twinned according to the albite and carlsbad laws, which are commonly combined. The mafic minerals are for the most part hornblende and biotite. Minor quantities of pyroxene are present, some of which have altered to hornblende and chlorite. The hornblende is pleochroic in shades of green and brown, and contains magnetite inclusions. It has altered to biotite and chlorite in some places. The lath-shaped biotite is about the same size as the hornblende and ranges from .05 to 0.4 mm. in diameter. Both these femic minerals contain feldspar and magnetite inclusions, giving a poikolitic texture. Interstitial quartz containing apatite inclusions is present. Accessory minerals are magnetite and apatite. The order of crystallization is magnetite (first), pyroxene, feldspar, hornblende, biotite, apatite and quartz.

The rock is assigned number 2212E and named hornblende andesite.

Granite

The granite in the Cold Springs area has been mapped as Lugert, a granite present in other parts of the Wichita Mountains, by Taylor, but the correlation has not been established. It is pink in color and generally present as large and small dikes and stringers cutting the andesite. In places it has been injected into the marginal zone of the andesite in a series of small dikes and sills, while in others it has been intruded along the contact of the andesite and gabbro-anorthosite as large sills, which project past the contact and cut into the gabbro. In many areas these sills exhibit a pegmatitic texture, as may be seen in the sill remnants on the northwest slope of the hill in the northeast corner section 30, T. 4 N., R. 17 W.

Contacts between the rocks in the marginal zones are very sharp and any evidence of assimilation is lacking. Here the andesite is the most plentiful, with stringers of granite forming a matrix around large blocks of andesite. Conversely, as the marginal zones are left and one approaches the central regions of the sills, the junction between the two rocks grade from sharp to shadowy, due, apparently, to more complete assimilation by the granite. Here one can see many partly digested xenoliths of the andesite in a gray Cold Springs granite which is in contrast with the pink granite. In the more central portions of the sill-masses of granite, the contacts with xenoliths of andesite become nearly obliterated and an occasional shadowy xenolith in the gray granite is all that can be seen of the original andesite.

Several samples of the marginal pink rock show it to be medium- to fine-grained, with a low mafic content. There are portions in the fillings between the angular fragments of andesite, which exhibit a pegmatitic phase.

Microscopic examinations were made of several slides. The pink rock has a hypidiomorphic granular texture and consists of orthoclase, quartz, plagioclase, hornblende, biotite, pyroxene and accessory magnetite, apatite, zircon and tourmaline. Chlorite, calcite, kaolinite, prehnite, leucoxene, hematite and limonite are present as secondary minerals. Orthoclase is the chief feldspar and occurs as subhedral crystals as well as in combination with plagioclase forming a perthite. A few lath-shaped crystals of plagioclase with albite-oligoclase composition are present; they are somewhat altered to kaolin, calcite and prehnite. Quartz occurs as cracked and shattered subhedral particles as well as fresh interstitial grains with apatite and tourmaline inclusions. The femic content varies a little and may be due to contamination of the granite by the andesite. Brown and green pleochroic hornblende is the principal femic mineral. Biotite and pyroxene are present and some alteration of these has produced chlorite. Accessories are mainly magnetite, apatite and zircon. The order of crystallization was probably magnetite (oldest), pyroxene, hornblende, biotite, plagioclase, accessories, orthoclase and quartz.

The rock number is 126 and the name is leuco-granite.

HYBRID ROCKS PRODUCED BY ASSIMILATION

Cold Springs Granite

A hybrid rock, known commercially as the Cold Springs granite, is found in several places throughout the Cold Springs region. An attempt was made to map the outcrop of this rock, but owing to its variable composition over small areas, its variable manner of weathering and its intimate relationship with the andesite and pink granite, this proved an exceedingly difficult task. Commercial quarries are the only places in which one can be certain of the type.

The main outcrops of the Cold Springs granite are the Roosevelt quarry, the Oklahoma Granite and Monumental

Company quarry, the Cold Springs Granite Company quarry, and a few small test quarries. The most important of these are: the lower of the two small quarries situated one-quarter of a mile south of the Oklahoma Granite and Monumental Company quarry and west of the village of Cold Springs; a boulder-blasting operation and small quarry located near center of section 20, T. 4 N., R. 17 W., on the west side of Otter Creek; the quarry farthest south of the two located on the east slope, near the south end of the large hill in section 21, T. 4 N., R. 17 W.; and the south-easterly one of the two quarries located just west of the highway in the NE corner, NW¼, section 21, T. 4 N., R. 17 W.

Taylor has adequately described this rock as a fine-grained gray hornblende-biotite granite of varying composition and texture. The light-gray surface upon close examination reveals specks of hornblende and biotite uniformly distributed through the fine-grained white and gray quartz and feldspar.

Microscopically, it contains varying quantities of orthoclase, albite, oligoclase, andesine, quartz, hornblende, biotite, magnetite, pyrite, apatite, sphene, and secondary chlorite, hematite, sericite and kaolin. Feldspar composes from 57.3 to 64.4 per cent of the rock. Both plagioclase and orthoclase are colorless or light-gray, and the plagioclase commonly penetrates or is completely enclosed by the orthoclase and quartz. The plagioclase ranges in composition from andesine (Ab_{53} An_{47}), which is badly altered to sericite, kaolin and prehnite, to oligoclase (Ab_{72} An_{28}). Taylor also reports albite. The oligoclase appears fresher than the more basic plagioclase and in some cases was identified as the plagioclase which forms the more acidic outer zone around the corroded more basic feldspar in the interior of the zoned crystals. Myrmekitic intergrowths are present along the edges of the plagioclase crystals but also form between the quartz and orthoclase. Brownish-green and green hornblende is present with green-to-black biotite. Accessories are mainly apatite, zircon, sphene, pyrite and sillimanite (?). The order of crystallization has been obscured by the injection of the granite magma. This interruption along with the deuteric or paulopost reactions in each of the magmas make the order of crystallization very difficult to determine.

The rock number is 226P and the name, due to the percentage of femic minerals and because Johannsen (1939, vol.

II, p. 124) prefers to omit the monzonitic types, is biotite-bearing hornblende granite.

Quartz-Diorite

Quartz-diorite is also a product of assimilation. Its man occurrences are (1) the railway right of way cut about one-half mile north of the village of Cold Springs, about 200 yards north of the Oklahoma Granite and Monumental Company's quarry, and (2) in the upper one of the two small quarries located south of the Oklahoma Granite and Monumental Company's quarry and west of the village of Cold Springs. In this last location it is associated with dikes and veins of granite. This rock represents the darkest and most basic assimilation product of the andesite by the granite.

This rock has a dark gray to black color with a mottling of lighter minerals. It has medium- to fine-grained equigranular texture and resembles the Cold Springs granite except that it is of much darker color.

In thin section the rock is hypidiomorphic granular and composed principally of feldspar, quartz, hornblende and biotite. The feldspar is a very basic andesine (Ab_{53} An_{47}) and occurs as laths exhibiting albite twinning lamellae. Many of the crystals have a zonal structure in which the outer zone is fresher and less corroded than the inner one. A part of the inner zone has a composition seemingly bordering on labradorite although this was not definitely established. The outer acidic zone in some of the specimens appeared to approach the composition of oligoclase when studied as crushed fragments in index oils. In some slides orthoclase feldspar is present as scattered crystals. Quartz occurs as subhedral crystals and rounded grains. Two ages of this mineral may be present. The older-appearing quartz occurs as fractured and shattered masses, whereas the younger, cleaner-looking material has been injected into the interstices between the feldspar crystals. In some cases there are feldspar fragments included in this supposedly later quartz. The femic minerals consist of hornblende, pyroxene and biotite. Hornblende was noted replacing pyroxene and also a dark brown biotite re-

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Plate 1A. Horizontal or sheet jointing visible in a quarry near Cold Springs. Section 29, T. 4 N., R. 17 W.

Plate 1B. Veins and stringers of granite cutting andesite. This is common throughout the area, but especially well exhibited in NW part of section 29.

Plate 1A

Plate 1B

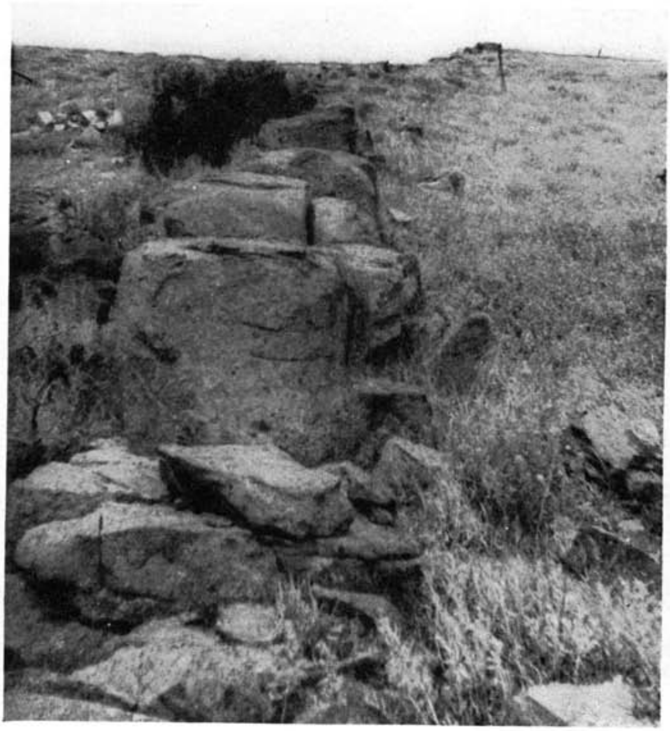

Plate 2A

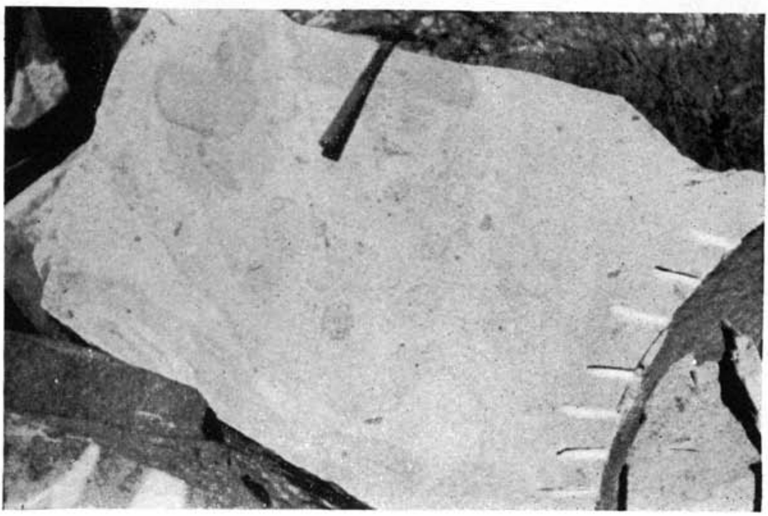

Plate 2B

placing hornblende. Early magnetite is commonly bordered or almost wholly replaced by hornblende and biotite. Some of the hornblende is twinned and the twinning lamellae are altering to chlorite; other hornblende is very much altered and eaten away, with chlorite the principal alteration product. Biotite ranges from fresh to slightly altered. The general appearance of the slides suggests paulopost reaction or exomorphic replacement.

The accessories are magnetite, apatite, zircon and sillimanite (?). The apatite is colorless and appears in a peculiar en echelon arrangement enclosed within the quartz. Some very fine needles of rutile may be present in some of the quartz crystals.

The rock is given number 228 and named tonalite or, more commonly, hornblende quartz-diorite.

Granodiorite

The granodiorite, also a product of the assimilation of the andesite by the granite, is intermediate in composition between the Cold Springs granite and the quartz-diorite, and grades imperceptibly into both. It is present in a small quarry on the east slope of the large hill in the west central part of section 21, T. 4 N., R. 17 W. In other quarries throughout the area where the Cold Springs granite is present, the granodiorite occurs as a phase of the Cold Springs granite.

Megascopically, this rock resembles the Cold Springs granite except for being of a slightly darker color. Microscopically, it is essentially the same as the Cold Springs granite, differing

Average Norms

Rock	Invading Gr.	Cold Springs Gr.	Grano-diorite	Quartz-diorite
Quartz	31.9	19.0	23.8	29.6
Orthoclase	49.7	36.2	25.4	3.2
Plagioclase	12.3	25.2	33.6	44.2
Hornblende	2.6	9.6	8.4	13.2
Biotite	2.1	7.3	7.5	7.1
Pyroxene	0.1	0.3	0.3	1.2
Magnetite	0.8	1.2	0.5	1.2
Apatite	Tr.	Tr.	Tr.	0.02
Zircon	Tr.	Tr.	Tr.	Tr.
Pyrite	—	Tr.	—	—

Plate 2A. Aplite dike in SW corner of section 20. It has resisted weathering and stands above the general surface.

Plate 2B. Flow lines and inclusions of andesite in Cold Springs granite. Small quarry west of Cold Springs.

only in the mineral percentages. It exhibits some of the same features as the quartz-diorite but is more acidic.

It is classified as number 227 and given the name biotite-bearing hornblende granodiorite.

DIKE ROCKS

Dikes of aplite, pegmatite, diabase, and quartz are common in the Cold Springs area. The aplite dikes are mostly very small and cannot be traced very far. The most prominent aplite dike is exposed on the top of the hill near the intersection of sections 19, 20, 29, and 30, T. 4 N., R. 17 W. It has resisted weathering better than the surrounding rocks and rises above the general surface (plate 2). This dike is vertical and is about three feet wide.

This flesh-colored, medium-grained rock has a xenomorphic granular texture in thin section. It is composed essentially of orthoclase and quartz with minor oligoclase and a few scattered crystals of hornblende. It is classed as a leuco-granite aplite and has the number 126.

The two best known pegmatitic dikes are in the central part of section 17, T. 4 N., R. 17 W., and on top of the hill in the central part of the NW¼ of section 29, T. 4 N., R. 17 W. Anderson (1946, p. 32) described the former, which penetrates the mixed granite-andesite. The latter is very similar and also cuts through the granite-andesite mixture, which makes up the greater portion of the hill where it occurs.

These dikes are composed essentially of quartz and orthoclase feldspar and crystals of the two minerals often are as large as 2 to 3 inches in diameter. The quartz is of the milky variety; locally it is graphically intergrown with the orthoclase.

Several diabase dikes have been found. These are usually highly weathered and produce a slight depression on the surface. This topographic expression is much more evident in aerial photographs than in the field and, consequently, it was from the photographs that many of the dikes were located and then examined in the field. Except in prospect pits, which are fairly numerous and usually located on dikes, the only field evidence of these dikes is the slight depression and particles of weathered rock fragments strewn about the surface along the "lead" of the dike. A typical example of this may be seen on the road into the Oklahoma Granite and Monumental Company's quarry just west of the village of Cold Springs.

The map shows the main dikes. They range in thickness from two to five feet and have a vertical or nearly vertical dip. Since these diabase dikes weather very readily to soil that usually supports vegetation, it is probable that some were overlooked in the field.

The diabase dikes vary in color from a dark greenish-brown to a reddish-black, and are composed of very fine-grained, dense rock. Thin section examination revealed two types: one type, generally of a more brownish color, is highly weathered, and mineral identification was not possible; the other is microporphyritic and consists of phenocrysts of labradorite in a ground mass of what appears to be small feldspar laths and very badly altered femic minerals.

On the basis of what mineral identification was possible the rock was called diabase with number 2312.

The rocks have been cut by small quartz veins and stringers of variable thickness and shape. These appear to follow fractures and cut through the older rocks in many of the quarries, and also are present in the diabase dikes where they are associated with calcite veins. In some of the prospect pits where this was noted, the quartz and calcite veins are in a series forming a composite unit.

HEAVY MINERALS

The heavy minerals consist mainly of hornblende, biotite and magnetite, and nothing conclusive could be determined from a study of slides made from the separated fractions.

ASSIMILATION AS SHOWN IN THE ROCKS OF THE COLD SPRINGS AREA

Because of the discontinous surface outcrops of the igneous rocks in the area covered, as well as limited subsurface information, it is not possible to determine accurately the forms of the intrusions of all the rocks. The field occurrences and petrographic studies of the rock types show the Cold Springs granite, granodiorite, and quartz-diorite are not differentiates in their present form from one magma but represent syntectic products produced by the intrusion into, and cross-assimilation of, the andesite by the granite. The term "cross-assimilation" is here used in the same sense set forth by Shand (1947, p. 67).

> It is clear that there are three processes by which foreign matter may be taken up by a liquid magma, namely:
> (1) Mechanical incorporation of solid particles without any chemical change;
> (2) Reactive solution and precipitation; involving the replacement of one solid phase by another solid phase;
> (3) Total dissolution, the solid phase disappearing altogether.
>
> It is very desirable that these three processes should receive distinctive and unequivocal names. Loosely speaking the term "incorporation" might be applied to all three of them, and "assimilation" to two; but much would be gained if we could agree to restrict "incorporation" to the first process, "assimilation" or perhaps "cross-assimilation" to the second and "dissolution" to the third.

Hence, cross-assimilation is the reactive solution and precipitation of a rock by a magma. This may result in profound changes in both the rock and the assimilating magma. There is a great deal of evidence that two of these geological processes, if not all three, have taken place in the igneous rocks of the present area.

The following is a review of the events taking place at the time of emplacement and also an attempt to establish evidence to substantiate the origin and emplacement of the igneous rocks in the Cold Springs area.

The gabbro-anorthosite is the oldest and most abundant rock and it is very probable that all outcrops of it are small parts of a large body which underlies the entire area. It is considered to be intrusive into pre-Cambrian sediments. There are no remnants of the original country rock in the Cold Springs area but it may be assumed that similar conditions took place here as in the Meers region several miles to the east, where some of the country rock remains. Merritt (1948) has stated that the gabbro magma intruded the original Meers sandstone and produced an unusual series of contact metamorphic rocks.

The size of the gabbro-anorthosite mass seems to be very large as Polk and McKinley found this rock extending far to the west. This extensive occurrence would support the idea that its outcrops in the report area are small parts of a batholith, sill, laccolith or lopolith; the exact form of the intrusion has not been proven to date.

Following the emplacement of the gabbro-anorthosite a more acidic magma was intruded into it, forming sill-like masses of andesite. The magma which formed this rock may represent a more acidic differentiate, at depth, of the gabbroic magma which formed the gabbro-anorthosite. From the remnants of the eroded surface outcrops, this intrusion seems to have formed, in most cases, thick lense-shaped or sill-like masses within the gabbro-anorthosite. The intrusion was accompanied by a contact border chilling which gave rise to a shell of solidified andesite around the sill-like masses.

At a relatively short interval of time after the intrusion of the andesite into the gabbro-anorthosite a granitic magma was injected into the andesite, but the intrusion was delayed long enough for the marginal zone of the andesite to become chilled. As a result of this chilling and early consolidation of the border facies, the peripheral shell of these sill-like masses was shattered and the granitic magma was injected into the resulting fractures. This magma engulfed the shattered fragments of the andesite, giving rise to an intrusion-breccia, with rounded to angular fragments of andesite cemented with granite. In the fractured marginal regions of the andesite bodies, the junction between the two rocks is very sharp indicating very little reaction. This chilled border phase, where the granite has formed a network of dikes and stringers in the andesite, would indicate that there was not sufficient heat in either of the rocks to cause cross-assimilation. Harker (1909, p. 357) has noted that the amount of mutual reaction depends upon high temperature in the solid invaded rock.

In the thick central part of the sill, owing to more prolonged flow and somewhat higher temperature, the acid magma has made greater inroads upon the earlier basic rock than it has in the thin part of the sill near the margin, and in places has totally destroyed it. This intrusion and cross-assimilation of the andesite by the granite has given rise to a series of hybrid rock types, varying in mineralogical composition and texture to such an extent that the differences are easily discernible in small exposures. The Cold Springs granite is an example of the rocks which make up this hybrid series, the quartz-diorite and granodiorite being other types intimately associated with it. Although only a minor part of the granite-andesite mixture, the Cold Springs granite is found as large bodies in the central regions of what is left of the andesite sills, which remain only as small hills. The mixture, which has undergone only fracturing and injection without assimilation, forms a crust around the outer part of the hills and grades inward, becoming increasingly more granitic, into the Cold Springs granite.

The texture and mineral composition of the Cold Springs granite varies a great deal in different parts of the Cold Springs area. It is usually a fine-grained, gray, hornblende biotite granite of a wide color and composition range. In some places it is very light in color and closely resembles the intruded pink granite except for a greater mafic content. In other places, and in some cases in the same locality but in a different part of the quarry, it is darker in color due to a much higher per cent of hornblende and biotite. In these quarries unassimilated fragments of gabbro-anorthosite surrounded by flow lines were noted as well as shadowy xenoliths of the original andesite. This indicates incomplete assimilation of the andesite by the granite. These partly assimilated xenoliths and the andesite breccia are strong field evidence that this hornblende biotite granite, termed the Cold Springs granite, has been formed as a result of the intrusion and cross-assimilation of the andesite by the granite.

The pegmatitic phase of the granite associated with the basic xenoliths of andesite tend to support Bowen's (1922, p. 513) experimental conclusions that basic inclusions in a granitic magma or the addition of a basic magma to a granitic one advances it on its normal course of differentiation. This advancement in differentiation of the granite would explain the pegmatite and aplite phases which occur in the small dikes or apophyses between the inclusions of andesite. The pegmatitic granite is usually near the contact and there is a gradation to a finer-grained granite towards the center of the dikes. Emmons (1926, p. 423) has pointed out this same phenomenon in a study of inclusions in igneous magmas in several localities in Canada.

Microscopic examination of the Cold Springs granite has revealed further evidence as to its origin. The zoned feldspars are not proof but suggest that assimilation may have taken place. The presence of myrmekite intergrowths in this assimilated rock adds to the evidence of re-solution and precipitation of the andesite by the granite. Sederholm (1916) has described like intergrowths and shown that they are the result of the assimilation of a basic rock by a granite. Hogbom (1899) has observed the solution of a diabase in a granite at Ragunda, Sweden, and has pointed out not only the occurrence of a network of veins and dikes of granite cutting the diabase, a condition similar to one in the field of the present report area, but also the chemical and structural inconstancy of a series of intermediate rocks produced as a result of the assimilation.

Krieger (1932, p. 355) in a study of the zinc-lead deposits at Pecos, New Mexico, has also recognized that assimilation has taken place between a basic rock and granite. Besides field evidence he states as some of the petrographic evidence, the presence of myrmekite, the corroded centers of the zoned plagioclase feldspar crystals, and the replacement of hornblende by a deep brown biotite.

The thin section slides made from the syntectic rocks of the Cold Springs area exhibit many of these same features. This array of evidence strongly supports the conclusion that the Cold Springs granite and the other syntectic rocks, identified as quartz-diorite and grano-diorite, are the result of cross-assimilation.

In addition to the foregoing evidence, the chemical composition of the rocks concerned tends further to support the fact that they are cross-assimilation products. The hybrid rock should have a composition which can be calculated from the analysis of the two component rocks, taken in the proper ratio. The following table gives the SiO_2 and the CaO percentages of the rocks along with the calculated mixture:

Rock	SiO_2	CaO
Granite	74.0	0.9
Andesite	48.3	6.7
Calculated mixture	61.6	3.7
Cold Springs granite	61.6	3.2

A mixture of the granite and andesite in the proportions of 51.6 to 48.3 would give the SiO_2 percentage of the hybrid rock, or, in this case, the Cold Springs granite. It would also give 3.7 per cent of CaO. This calculated percentage is not much greater than that actually found in the hybrid rock. This slight difference may be accounted for by unequal diffusion as has been pointed out by Harker (1909, p. 358) in a similar case of assimilation occuring in the British Tertiary plutonic rocks of Skye.

Therefore it seems probable that the Cold Springs granite, as well as the other minor syntectic rocks, namely granodiorite and quartz-diorite, are cross-assimilation products which have been produced by the intrusion, reactive solution and replacement of the andesite by the granitic magma.

To get a series of intermediate rocks as a result of this cross-assimilation seems to be the normal thing. Hatch and Wells (1937, p. 267) state that intermediate rocks of monzonite, tonalite and quartz-diorite composition are formed by interaction between acid magma and basic xenoliths. Krieger (1932, p. 361) also found some minor varieties of rocks in the Pecos area.

Following the emplacement of this series of rocks the region was later fractured and cut by a series of aplite, pegmatite and diabase dikes and quartz veins. There was considerable hydrothermal action associated with the diabase dikes. The igneous activity of the area was terminated by the formation of a few narrow quartz and calcite veins within the diabase dikes.

References

Anderson, K. C., 1946. The occurrence and origin of pegmatites and miarolitic cavities in the Wichita Mountain system, Oklahoma, Master's thesis (unpub.), Dept. of Geology and Geography, University of Oklahoma.

Bain, H. F., 1900. Geology of the Wichita Mountains: Geol. Soc. America Bull., vol. 11, pp 127-144.

———, 1904. Reported ore deposits of the Wichita Mountains, Oklahoma. *In* Taff, J. A., Preliminary report on the geology of the Arbuckle and Wichita Mountains in Indian Territory and Oklahoma: U. S. Geol. Survey Prof. Paper 31, pp. 82-93.

Bowen, N. L., 1922. The behavior of inclusions in igneous magmas: Jour. Geology, vol. 30, pp. 513-570.

Comstock, T. B., and Cummins, W. F., 1889. A preliminary report on the geology of the central mineral region of Texas: Texas Geol. Survey 1st Ann. Report, pp. 319-328.

Emmons, R. C., 1926. Concerning inclusions in igneous magmas: Jour. Geology, vol. 34, pp. 422-428.

Harker, Alfred, 1909. The natural history of igneous rocks, The Macmillan Company, New York.

Hatch, F. H., and Wells, A. K., 1937. The petrology of the igneous rocks, 9th ed., George Allen and Unwin Ltd., London.

Hill, R. T., 1890. Classification and origin of the chief geographic features of the Texas region: Am. Geologist, vol. 5, pp. 68-80.

———, 1891. Notes on a reconnaissance of the Ouachita mountain system in Indian Territory: Am. Jour. Sci., 3d ser., vol 42, pp. 111-124.

Hoffman, M. G., 1930. Geology and petrology of the Wichita Mountains: Oklahoma Geol. Survey Bull. 52.

Högbom, A. G., 1899. Om Regundadalens Geologi: Sveriges geol. undersökning, ser. C., no. 182.

Johannsen, Albert, 1939. A descriptive petrography, 2d ed., vol. 1 and 2, The University of Chicago Press, Chicago.

Krieger, Philip, 1932. Geology of the zinc-lead deposit at Pecos, New Mexico: Econ. Geology, vol. 27, pp. 344-364.

Merritt, C. A., 1948. Meers quartzite: Oklahoma Acad. Sci. Proc., vol. 28, pp. 76-77.

Polk, T. R., 1948. A study of the igneous rocks of the Devils Canyon mountain group, Wichita Mountains, Oklahoma, Master's thesis (unpub.), School of Geology, University of Oklahoma.

Powers, Sidney, 1928. Age of the folding of the Oklahoma Mountains....: Geol. Soc. America Bull., vol. 39, pp. 1031-1072.

Schoonover, F. E., 1948. The igneous rocks of the Fort Sill Reservation, Oklahoma, Master's thesis (unpub.), Dept. of Geology, University of Oklahoma.

Scull, B. J., 1947. A further study of the igneous rocks in the Granite-Lugert Area, Oklahoma, Master's thesis (unpub.), Dept. of Geology and Geography, University of Oklahoma.

Sederholm, J. J., 1916. On synantetic minerals and related phenomena: Comm. geol. Finlande Bull. 48.

Shand, S. J., 1947. Eruptive rocks, 3d ed., John Wiley & Sons, Inc., New York.

Shumard, G. G., 1853-1854. Remarks upon the general geology of the country passed over by the exploring expedition to the sources of Red River. *In* Exploration of the Red River of Louisiana, in the year 1852: U. S. 32nd Congress, 2nd session, Senate Exec. Doc. No. 54 (1853), pp. 179-195; U. S. 33rd Congress, 1st session, Senate Exec. Doc. (1854); U. S. 33rd Congress, 1st session, House Doc. (1854), Appendix D, pp. 156-172.

Taff, J. A., 1928. Preliminary report on the geology of the Arbuckle and Wichita Mountains in Indian Territory and Oklahoma: Oklahoma Geol. Survey Bull. 12. (Republication of U. S. Geol. Survey Prof. Paper 31, 1904).

Taylor, C. H., 1911. Granites of Oklahoma. *In* Gould, C. N., *et al.*, Preliminary report on the structural material of Oklahoma: Oklahoma Geol. Survey Bull. 5.

———, 1915. Granites of Oklahoma: Oklahoma Geol. Survey Bull. 20.

Vaughan, T. W., 1899. Geologic notes on the Wichita Mountains, Oklahoma, and the Arbuckle Hills, Indian Territory: Am. Geologist, vol. 24, pp. 44-55.

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