GEOLOGY AT TUNGSTEN, NEVADA,
EMPHASIZING STRUCTURAL ASPECTS

A THESIS

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BY

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TABLE OF CONTENTS

ILLUSTRATIONS

TABLES

GEOLOGY AT TUNGSTEN, NEVADA,
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By John Middlebrook

ABSTRACT

Contact-metamorphic deposits containing scheelite are found at Tungsten, Pershing County, Nevada. Upper Triassic limestone beds were replaced by emanations from granodiorite stocks, forming tactite deposits bearing tungsten.

The tracing of all limestone beds to the contact would locate all possible deposits of tungsten. Tracing of the limestone necessitates a method of correlating the limestones displaced or partially exposed. Studies were made on limestone thin sections, heavy-minerals, specific gravities, and assays for CaO, MgO, insolubles, R_2O_3, and on hornfels, in order to find a reliable method of correlation.

The calcium percentage, apparently unique to each bed of limestone, seems to be a property that could be used for correlating displaced portions of the bed.

INTRODUCTION

Location

Tungsten is a mining community of approximately 200 population, located in the southeastern portion of the Eugene Mountains, Pershing County, Nevada. The town lies just eight miles northwest of U. S. Highway 40 and the Southern Pacific transcontinental line which parallels Highway 40. Mill City, located at the junction of the Tungsten road and U. S. Highway 40, serves as the main shipping point of tungsten products produced by the Nevada-Massachusetts Company. Winnemucca, the largest nearby town, lies 36 miles to the northeast of Tungsten while Lovelock is 53 miles to the south.

The area studied lies exclusively in T. 34 N., R. 34 E., and is centered in secs. 26, 27, 34, and 35, as shown on the U. S. Geological Survey Eugene Mountains quadrangle. Field investigations were restricted to an area bounded by Mill Creek on the north in secs. 11 and 12 and along the southwest trending ridge, across Pole Canyon in sec. 15, Olsen Canyon in sec. 21, and down the main canyon that ends at Millers Cabin in sec. 6, T. 33 N., R 34 E. The eastern boundary is the contact between the alluvium and the hills. This is an area of approximately 14 square miles. Mill Creek, Millers Cabin, and Florence Hill are not shown on plate 1.

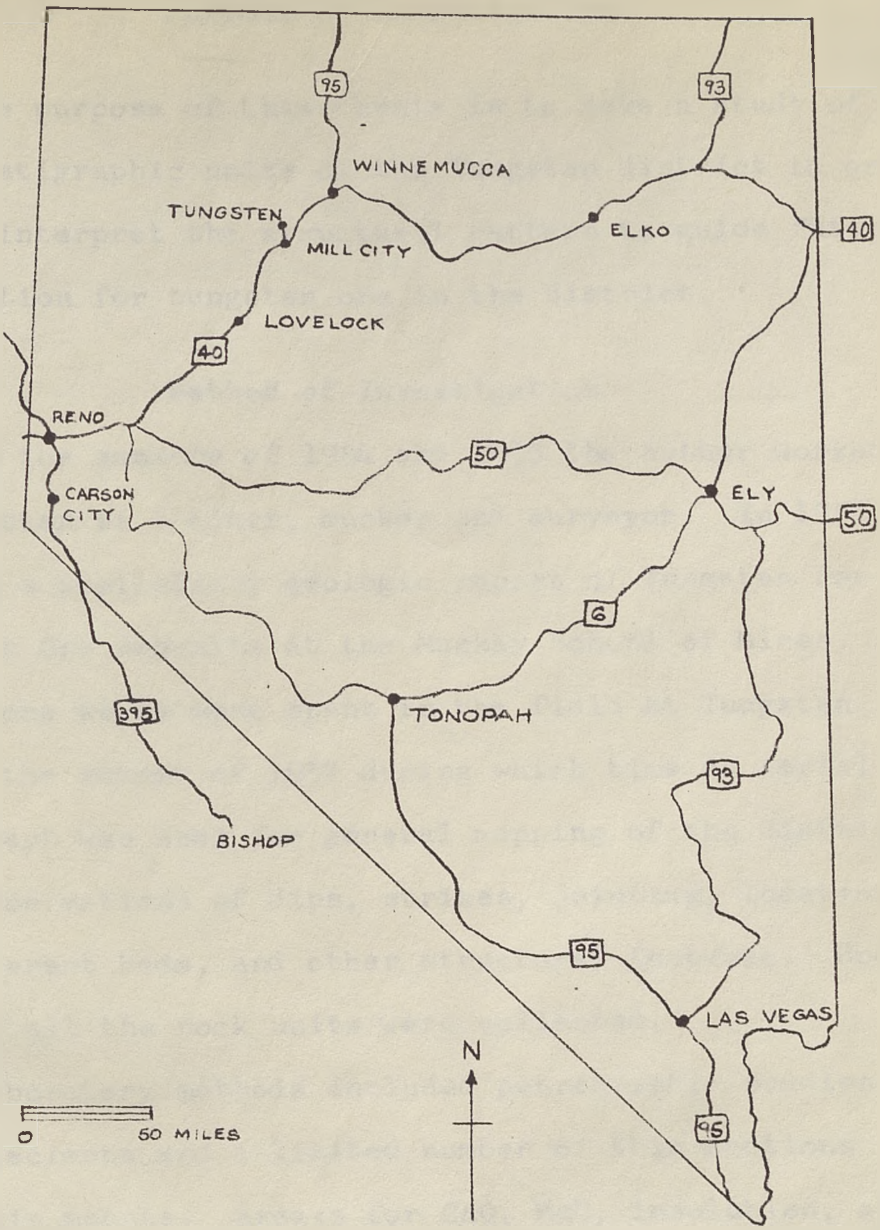

Fig. 1. Index map showing Tungsten, Nevada

Purpose of Investigation

The purpose of this thesis is to make a study of the stratigraphic units of the Tungsten district in order to try to interpret the structural pattern to guide future exploration for tungsten ore in the district.

Method of Investigation

In the summers of 1954 and 1955 the author worked at Tungsten as a miner, mucker and surveyor. In 1956 he made a preliminary geologic report of Tungsten for a class in Ore Deposits at the Mackay School of Mines. Eight more weeks were spent in the field at Tungsten during the summer of 1957 during which time an aerial photograph was used for general mapping of the district with observations of dips, strikes, jointing, location of different beds, and other structural features. Specimens of all the rock units were collected.

Laboratory methods included petrographic studies of hand specimens and a limited number of thin sections and grain mounts. Assays for CaO, MgO, insolubles, and R_2O_3 were made on 39 limestone samples. Specific gravity determinations and heavy-mineral separations were made on some limestone samples.

History

Scheelite deposits were discovered in Springer Gulch, a short distance from the present camp, in

1917. Wartime demand for tungsten advanced development so rapidly that by 1918 three companies, the Humboldt Corp., Pacific Tungsten Co., and Mill City Tungsten Co., were established and two mills were in operation. Activities ceased soon after the armistice because of falling tungsten prices. The mines remained idle until C. W. Poole leased the holdings of Pacific Tungsten Co. in 1924. In 1925 the Nevada-Massachusetts Co. acquired the properties of the Pacific Tungsten Co. and Mill City Tungsten Co., and in 1928 those of the Humboldt Corp. The Pacific Mill, which was soon enlarged to 260 tons per day capacity, operated until its destruction by fire on November 11, 1943. A new crushing plant was erected on the same site and started operations in July 1944. During 1941, a 1000-ton plant was installed to re-treat old tailings below the Pacific Mill. Work continued until exhaustion of the tailings dump in August 1944, after which the mill was remodeled to handle mine ore at the rate of 350-400 tons per day. Recently the plant was redesigned to handle 600 tons per day with heads averaging 0.3-0.4% WO_3.

There are four underground mines, the Sutton 1, Sutton 2, Stank, and Humboldt, which are 300, 800, 1300, and 1800 feet deep respectively. The Humboldt is probably the deepest tungsten mine in the United States. Approximately 10 open pits are located in the district.

Tungsten had its highest period of prosperity in its history during the years 1950 to 1956 when the

United States Government was stockpiling scheelite. During this time the payroll averaged 270 men. Since the drop in price from $63 to $15 per unit, only the Sutton 2 mine has been operated, along with one open pit and the mill. The personnel is now down to 70.

Previous Investigations

Many geological investigations have been made in the Tungsten district. The Nevada-Massachusetts Company had numerous mining and geological reports made on the various deposits before it consolidated all the mines and claims into one organization in 1925 and 1928. One rather comprehensive general geologic investigation was published by P. F. Kerr (1934). Two other men, M. R. Klepper and D. M. Lemmon of the United States Geological Survey, made studies and reports, umpublished to this date, on the Tungsten district. Klepper's report is available in the company files.

Much of this previous work has been verified by the author but there are many problems yet to be explained satisfactorily. It is in this direction that much of the field work has been repeated in an effort to find substantial clues that will give a better explanation of the problems encountered.

Acknowledgments

I extend my sincere appreciation to the Nevada-Massachusetts Company, Mr. Eldridge Nash, General Superintendent, and the rest of the staff, whose technical

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My expressed thanks and appreciation go to my advisor, Dr. Lon S. McGirk, Jr., for his continuous guidance, help, and encouragement, and also Dr. E. Richard Larson and the rest of the staff at the Mackay School of Mines, who took an active interest in the project by giving advice and making facilities available for the laboratory work.

GEOGRAPHY

The Eugene Mountain Range is part of the Basin and Range province and displays a typical structure of this province by having a steep western slope and a gentle eastern slope. The Tungsten district is located on the eastern slope just above an alluvial fan which extends down from two to four miles into the Humboldt River valley.

The lowermost hills rise out of the alluvium at an elevation of 4500 feet and in an average distance of two miles rise to heights of a little over 7000 feet. The hills on the eastern slope are well rounded, gently sloping, with few major conspicuous outcrops. It is possible to drive a jeep almost up to the summit of the range by following the ridge lines. Only along the higher ridge lines are major rock units prominently exposed. Most outcrops in the mining area of Tungsten are either on the crest of the hills, where they outcrop from a few inches up to five feet above the ground level, or along the washes. Rarely are outcrops found along slopes in exposures large enough to distinguish them from the float rock.

Weather in the district is typical of northern Nevada. Temperatures range from a low of 0° to 10°F in winter to the high 90°'s during the summer. The climate is arid with little rainfall during the year. Windstorms are common and transport much dust on occasion.

The Humboldt River flows continuously and forms the largest natural body of water in the district. A few springs flowing during the late summer were noted in Olsen and Springer Canyons, about a mile or more west of the main camp of Tungsten. Some water has been encountered while mining, but has never amounted to very much. Domestic and milling water is obtained from wells located four miles east of Tungsten along the west bank of the Humboldt River.

Vegetation is almost entirely sagebrush with some grassy meadows around 6500 feet elevation. A few willows and other lush types of vegetation are found along the streams that are fed by springs. These streams flow just a few hundred yards during the dry season and then go underground and occasionally reappear in the stream bed.

Wildlife is relatively abundant in this area and includes numerous types of common desert reptiles, rabbits, antelope, deer, abundant chukkars, some owls and buzzards, and other smaller birds. Field and kangaroo mice are often seen in the evenings. Cattle and sheep are sometimes herded to the higher elevations for green feed during the summer.

LITHOLOGY

Sediments

The local siltstone is a very fine-grained rock that is either light green or tan in color. Some areas contain lenses of coarser grained sandstone. Muscovite is a common accessory mineral. The rock tends to break along planes of deposition and has an irregular outline. The bedding planes reflect their state at time of burial, some with ripple marks and others with plain surfaces. There is no obvious banding and the lenses of sand and silt are essentially the same color. Texture and hardness are the only real distinguishing features. No thin section studies were made of this rock because it has no connection with the thesis problem. The siltstone will not effervesce with hydrochloric acid thus showing negligible carbonate content.

The most important sediment in the district is limestone. As will be explained later, the limestone beds are the host rock for the formation of tactite which contains scheelite.

Limestone in the district is essentially uniform in appearance. It is a massive dark blue, gray or black rock that has a fine-grained texture. Exposed areas are gray in color and sometimes have an elephant-hide texture where differential weathering has taken place. In many places the limestone does not outcrop above the surface of the ground but it can be located by a white powder residuum that is quite distinctive. In many places secondary white calcite stringers are found scattered throughout outcrops, with no apparent controlled orientation. These stringers are generally coarsely crystalline. Samples of limestone from the surface areas are usually porous, while similar rock from the mines is more dense and less porous. This may be attributed to weathering. The majority of limestone is massive while some is schistose.

A series of unique limestone beds, locally termed ribbon beds, consists of alternating layers of blue and brown limestone. These bands vary from a fraction of an inch to three or four inches in thickness.

Microscopic examination of six thin sections reveals that the limestones are composed essentially of calcite and carbon which accounts for the degree of dark color. Accessory minerals include wollastonite, clinozoisite, epidote, hematite, pyrite, muscovite, quartz, apatite, zircon, opal, and in one case, antigorite.

In studying the thin sections, it was observed that carbon was disseminated throughout the individual grains of calcite as well as bounding the edges of most of the grains. Carbon also formed as inclusions in the grains of epidote and clinozoisite.

Igneous Rocks

Granodiorite is the major igneous rock type in the Tungsten district. It is a light gray to tan rock that is medium-grained and hypidiomorphic in texture. Generally it is tan or gray when weathered and in one area in the eastern portion of the Olsen Stock it is lavender. Essential minerals are plagioclase, orthoclase, quartz, with biotite and hornblende as accessory minerals. Biotite phenocrysts are generally unaltered while the hornblende is decomposed. No thin sections were made as ample work was done on this granodiorite by Kerr (1934, pp. 30 - 32). There is no distinct cleavage or fracture and the weathered surface is decomposed and structurally very weak. It should be noted that all the granodiorite bodies tend to form the topographically low areas.

Quartz veins are associated with the intrusive. In the Olsen Stock a quartz vein is exposed for a distance of 200 feet and is two feet thick. Many quartz stringers are common throughout the stock.

Two types of dike rock are found in the district. Aplite, the commoner of the two, is fine-grained within limits and has a variable composition.. It may be considered to be of the same composition as the granodiorite in most cases. It is typically reddish-brown, caused by the disintegration of the ferromagnesian minerals. On a freshly broken surface, away from the zone of oxidation, it is gray to white.

The second type of dike rock is hornblende andesite. it is a black porphyry with an aphanitic matrix and phenocrysts of feldspar. Weathering does not alter the color or general appearance except where there may be some pyrite as an accessory mineral. The feldspar appears to be kaolinized. It is powdery and easy to scratch with a sharp point. No thin sections were made of the hornblende andesite which is the least common rock unit of the district.

Hornfels

The major rock unit of the district is a metamorphic type generally classified as hornfels.

Barth (1952, p. 272) defines hornfels as a hardened, sometimes flinty, rock that is generally so fine-grained that the mineral components are microscopic. The areal extent of hornfels is a product of many factors besides the size of the intrusion. The amount of cover and closure of the system, composition and texture of the country rock, and the amount of gases and hydrothermal emanations must be considered. The conductivity and the resultant rate of conduction of heat is so low that gases and vaporous emanations must become responsible for the transportation and transfer of heat into the country rock.

The degree of resultant metamorphism is referred to as the grade of metamorphism with high-grade metamorphism signifying the greatest alteration or change.

Many varieties of hornfels may be found in the Tungsten district. It may outcrop as a black-colored rock or else it may be a tan color, the latter predominating. Normally a bedded structure is distinctive with layers being black, brown, red, green or white. This banding is most distinct on a weathered surface and almost invisible on a fresh fracture. It is sometimes difficult to distinguish the bedding from the jointing that is present in the hornfels as the two generally coincide in direction. Thickness of the bands varies from 1/50 of an inch to two inches.

Hornfels is very brittle and fractures into blocky chunks. The edges are sharp and very uniform - not jagged in appearance. The jointed surfaces show dendritic growths of secondary minerals such as manganese and iron oxides, sometimes calcite and gypsum.

Internal remanent structures of bedding, cross-bedding, folds and ripple marks are found in the hornfels. Dr. Siemon Muller identified Monotis subcircularis (Gabb) (Kerr, 1934, p. 14), which is the most common fossil in the district. A few fossilized reeds were also found.

Microscopic examination of the hornfels shows it to consist essentially of quartz, biotite, and calcite, with the accessory minerals epidote, tremolite, plagioclase, zircon, apatite, hematite, ilmenite, and leucoxene. It is essentially a fine-grained, equigranular quartzose rock, banded by alternating layers of biotite which is incipiently- to well-developed. In some slides, calcite constitutes more than half the mineral content. These calc-hornfels may be distinguished from the quartzose hornfels with the microscope or by a test with acid.

A soft variety of hornfels has all the physical characteristics of the other types such as color, jointing, and general appearance, except that its hardness is comparable to that one would expect to find in a compact siltstone. The presence of "soft" hornfels zones within the regular hornfels may be due to faulting, or else they are in a zone that the permeating gases and solutions failed to reach.

Near the southwestern portion of the Olsen Stock, west of the Humboldt Mine, is a zone of spotted hornfels. It occurs in the normal hornfels with spots or lumps that are composed of biotite in most cases. This is the least common type of hornfels in the district.

Silicified Hornfels

Silicified hornfels is a rock unit found surrounding the intrusions and sometimes adjacent to the tactite beds. It is unique to the areas of higher-grade metamorphism. The rock appears on the weathered surface just as the regular hornfels, but is generally a shade lighter in color. A fresh fracture reveals a dense, massive, white or gray rock which has a sub-vitreous to greasy luster and aphanitic texture. Jointing and other types of fracturing are not as common in it and it is harder and tougher than the normal hornfels.

This rock is found in tabular lenses or beds intersecting adjacent beds at small acute angles. Mr. Nash, of the Nevada-Massachusetts Co., is working on the attitude of the silicified hornfels beds and its relationship to mineralization, but has reached no conclusions as to its effect on the tungsten deposits.

Zones of silicified hornfels probably represent replacement phenomena. It is not known whether this replacement is restricted to beds of certain mineral composition or if it is controlled by permeability or porosity of the beds. Sometimes small amounts of scheelite are found disseminated throughout these beds.

Tactite

Formation of white marble is the first change observed in the limestone as the proximity of its contact with granodiorite is approached. The marble is a fine-grained, saccharoidal rock that is generally speckled with light-tan andradite garnet. Garnet occurs in bands or disseminated evenly throughout the marble. There are a few localities where the marble contains scheelite.

Hess (1919, p. 378) defined a tactite as

> "...a rock of more or less complex mineralogy formed by the contact metamorphism of limestone, dolomite, or other soluble rocks into which foreign matter from the intruding magma has been introduced by hot solutions or gases. It does not include the enclosing zone of tremolite, wollastonite, and calcite."

Skarn is another term that is sometimes used instead of tactite but is much more restricted in its definition.

It was defined by Beyschlag, et al, (1914, p. 377) as a garnet pyroxene rock that

> "...consists chiefly as salite, i.e., a variety of diopside, and garnet; with epidote, grammatite, vesuvianite, chondrodite, serpentine, quartz, calcite, etc., or more briefly, the usual contact minerals."

Tactite in the Tungsten District has a varied appearance depending on the mineral composition. Two types of tactite will be distinguished here as garnet and epidote tactites. Garnet tactite consists essentially of garnet and quartz with calcite, epidote, scheelite, powellite, pyrite, chalcopyrite, and molybdenite as accessory minerals. It is a brown, massive, saccharoidal rock that is very hard and tough.

Epidote tactite is easily distinguished by its green color, the intensity of which is controlled by the ratio of epidote to quartz and scheelite. Kerr (1934, pp. 22 - 30) gave a detailed account of the tactite mineralogy in the Tungsten District.

MODE OF MINERALIZATION

Tungsten deposits of the Tungsten District represent a classical illustration of a contact metamorphic mineral deposit. Here the vivid effects of an igneous mass intruding a sedimentary series and altering the original rocks by heat and metasomatism are exemplified. Metasomatism, as defined by Lindgren (1933, p. 91) is

> "...the process of practically simultaneous capillary solution and deposition by which a new mineral of partly or wholly differing chemical composition may grow in the body of an old mineral or mineral aggregate."

The difference between metamorphism and metasomatism must be kept in mind. Metamorphism means a change in mineral and structural composition by heat and pressure with some addition or subtraction of constituents of the original rock. Metasomatism means certain constituents of the original rock have been replaced by matter introduced from an outside source.

When the granodiorite intruded, it was accompanied by emanations of gases and solutions. These solutions carried much silica, iron, alumina, and some tungsten. New minerals from these gases and solutions replaced the previous mineral assemblage of the more easily altered limestone host rock. The resulting mineral assemblage was dependent upon the original composition of the limestone and the new materials that were introduced by the invading pneumatolytic or hydrothermal solutions.

Tungsten in solution, because of its high melting point and chemical affinity for silicon, is an end stage product of the cooling magma, according to Buddington (1933, pp. 371-385). Minerals of high silicon content are the last to solidify. Kerr (1946, p. 34) noticed that whenever abundant scheelite was deposited, regardless of whether it was associated with garnet or epidote tactite, it was associated with an abundant amount of quartz. From this he deduced that enough silica must have been present to more than satisfy the requirements of the calcareous host rock in forming the calc-silicate minerals including garnet and epidote. The excess silica formed quartz.

Economic deposits of scheelite are restricted to the tactite zones. Some scheelite has been found in silicified hornfels as widely scattered grains, in granodiorite, and in limestone near the tactite beds. It is extremely important to know where the limestone beds are located and where they contact the granodiorite so that the resulting tactite can be explored and perhaps developed into a scheelite mine

GEOLOGIC STRUCTURE

Regional Attitude and Distribution

The hornfels and limestone beds are a conformable series which strikes N 20° E and dips eastward in most of the district except in the zone east of the Stank Fault. Two distinct groups, the Western and Tungsten beds, are evident. The Western beds, larger of the two groups, are located about one and one-half miles west of Tungsten and extend from the vicinity of Millers Cabin in the south to Mill Creek in the north. This group is discontinuous along its strike for the seven and one-half miles and the dip changes from easterly in the south to westerly in the north. The 450-foot thickness of limestones extends north from Millers Cabin and trends N 20° E up to the point where it crosses Olsen Canyon. Here these beds are deflected eastward with a resulting strike of N 40° E. Due west of Tungsten these beds have a 60° dip eastward.

The Tungsten group is the series shown on the general geology map. It contains at least six distinct limestone beds, some of which may be traced for a distance of one and one-half to two miles southward along the strike until they are lost in the alluvium. North of Tungsten these beds are disturbed by three granodiorite stocks and their last fragments to the north are seen at the mouth of Pole Canyon. These beds range in surface width from 2 to 30 feet. Individual beds may vary considerably in width along its strike.

The thickness of the hornfels between the two limestone groups has been computed to be 4100 to 4200 feet. The thickness of the sediments that contain all the limestone of the Tungsten group is 7800 feet.

Beds of hornfels and limestone that lie on the east side of the Stank Fault dip westward, averaging about 75°. The dip is not consistent, but undulates. This may account for the fact that thin section work shows a few beds overturned with nearly vertical dips in the vicinity south of the Sutton One mine.

The General Geology map shows the size and distribution of the three granodiorite stocks. Aplite and hornblende andesite dikes radiate in all directions from these stocks. The abundance and distribution of the dikes as well as their relatively small size makes their depiction on the map impracticable.

Tactite and marble, along with silicified and spotted hornfels, are found near the intrusions. The tactite lies along the same strike as the limestone beds except where it has been disturbed by faulting.

Structure Penecontemporaneous with Deposition

Much of the primary structure is still evident in the hornfels beds. Most common in the Tungsten district is banding that can be distinguished readily and is useful in determining the attitude of the beds. If it were not for this banding, caused by deposition of different-sized particles, determination of strike and dip in the field would be greatly hampered.

Graded bedding, where particles of a sediment grade from coarse to fine size perpendicularly to the bedding, seems to be common. It is a microscopic feature and not reliable for field work in all cases. The coarse particles, mainly quartz, are on the bottom and the finer particles grade upward and eventually grade into a zone of biotite. In the field, the biotite forms a darker band on a weathered surface and it is sometimes possible to denote the attitude of a bed by observing which portion of the biotite zone is more intensely colored. The darker color represents the side of deposition.

Cross-bedding seems more restricted in its distribution and was found in one area one mile south of Tungsten. Shrock (1948, p. 242) defines cross-bedding, or cross-lamination as follows:

> "Cross-lamination is the designation now generally used for that structure, commonly present in granular sedimentary rocks, which consists of tabular, irregularly lenticular, or wedge-shaped bodies lying essentially parallel to the general stratification which themselves show a pronounced laminated structure in which the laminae are steeply inclined (as much as 33°) to the general bedding."

The individual cross-beds are quite small, being approximately one inch long and a half-inch thick.

Associated closely with the cross-bedding are ripple marks. These ripple marks are symmetrical with a wave length of two inches and an amplitude of 0.3 inches.

Shrock (1948, p. 93) attributed the formation of symmetrical ripple marks to wave action, not current action. This structure may be used to determine the attitude of the beds in many cases. The sharp apex and concave trough of the ripple mark face the side of deposition or top side of the bed.

The last type of structure found within hornfels beds is folding penecontemporaneous with deposition. These folds are quite small, with an amplitude of one or two feet. A typical example may be seen in O'Bern Gulch just west of the South Sutton open-pit waste dump.

Effects of Intrusion

The sediments were somewhat disturbed by the granodiorite intrusion. A vast amount of faulting with large displacements could be expected if the intrusion had been viscous enough to be pushed up bodily through the overlying sediments. This is not the case in the Tungsten district. Most faulting in the beds caused by the intrusion occurs within a zone of approximately 500 feet surrounding each granodiorite intrusive. The granodiorite stoped its way, assimilating the sediments, as it approached the surface.

On the road passing the Uncle Sam workings and crossing the Olsen Stock toward the Florence workings there is a hornfels pendant containing some tactite located a few hundred yards north of the Uncle Sam workings (Plate I, coordinates 10500 N, 8500 E). In the wash adjacent to the north side of this pendant xenoliths of hornfels, up to five feet long, can be observed in the granodiorite. This pendant is a root of the overlying sediments that were part of the original capping extending over the Uncle Sam area. A tactite bed contained in the pendant has the same strike as the beds in the Uncle Sam area.

Isostatic effects must have played a major role in the local faulting surrounding the intrusive. The intrusive stoped its way through the sediments with the hydrostatic force of the molten mass quite close to the static weight of the hornfels. This must be particularly so if the sediments were assimilated by the intruding magma. Tests on samples of hornfels and granodiorite show the specific gravity of granodiorite as 2.64 and that of hornfels as 2.66. The specific gravity of molten granodiorite could be considered even lower than that of the solidified rock because of the presence of volatiles.

If the isostatic force of the magma was less than the combined weight and frictional force required to shear the rock, displacement would take place. The granodiorite intruded with steep hanging walls of 70 to 75 degrees. Resultant faulting would follow Hartmann's Law, with the fault plane forming an acute angle with the direction of the compressive force component. The buoyant effect of the magma being less, the block would slide down. A dike could intrude this weakened zone.

An action such as described above may account for, in part, the complete change in attitude of hornfels and tactite near the intrusion. New orientation of dip and strike may be attributed to the force of gravity, flow direction of the magma, or an obstruction forcing the blocks in different directions when movement took place.

No detailed studies were made of this by the author but it poses an interesting problem. The north end of the Sutton Two mine area is a good example of this phenomenon.

Faulting

There are four periods of faulting that can be distinguished. Of these faulting periods three can be distinctly recognized and the fourth has indirect evidence for its existence, as will be shown.

The first evidence of faulting in the sediments can be seen in the displacements sometimes present in the penecontemporaneous folds following original deposition of the sediments. These displacements, in the order of a few inches, occurred during sedimentation or previous to lithification. Pre-lithification faults are of no importance as a major structural feature and do not alter the general attitudes of the beds which contain them.

Faulting may have occurred during the period of time following lithification of the sediments and preceding the intrusion. Difficulty in determining faulting is encountered here because of the associated effects of the intrusion. It is highly probable that any faulting preceding the intrusion would have formed channelways for the emanations from the intrusion and in the course of time become completely obliterated. Here again we encounter a mechanism that would explain the genesis of the silicified hornfels. Another indication of pre-intrusive faulting can be found where the displacement of tactites shows no zone of brecciation or other indication of movement at all.

The faulting due directly to the intrusion of the granodiorite is the next period considered. The main evidence of this period of faulting is the skewed attitudes of tactite blocks near the zones of intrusion. This particular faulting has economic importance as it displaces the valuable tactite beds containing scheelite.

The post-intrusive faulting represents the last period and is readily recognized in the field by off-set beds and associated evidence as drag-folding, breccia, slickensides, and general zones of weakness within adjacent rocks. Contraction faults were observed on the granodiorite stock.

The most abundant faulting in this district is cross-faulting. Limestone beds serve as useful markers for recognizing this type of faulting as they form the key horizons, while hornfels beds are too similar in appearance to readily establish cross-faulting. Off-sets caused by this faulting of limestone are readily recognized but it is difficult to aline the segments of beds because the magnitude of displacement is by no means consistent. It will be necessary to correlate the segments of limestone beds in order to make a complete structural picture of the area. Limestone beds were observed to be weathered to some distance below the surface, thus making simple correlation by thickness and distance between the individual beds unreliable.

The Stank Fault is the most significant post-intrusive fault in the entire Tungsten district. It is defined on the surface by a major change in dip of the hornfels and limestone units. Beds on the east side of the fault dip westward and the beds on the west side dip eastward as if the fault zone coincided with the axial plane of a syncline. The fault zone, in someplaces several hundred feet in width as denoted by the first undisturbed outcrops on either side of the zone, can be traced for approximately 9000 feet on a strike averaging N 25° W. The fault zone is exposed in the Stank mine, the Yellow scheelite workings, and the George pit. The dip of the fault, measured in the George pit, is 62° westerly. How consistent the dip is, is not known. The direction of movement as shown by drag folding and displacement of beds indicates reverse faulting.

Quantitative measurement of the Stank Fault, if possible, would be of great importance to the district to determine displacement of tactite and limestone beds. This information would certainly be of importance in future exploration.

Small normal faults have been observed south of Tungsten about two miles. These faults strike parallel to the beds and form little ridges in the alluvium in the area northeast of Millers Cabin. The ridges may extend for several hundred feet and rise 50 or more feet above the alluvium.

Jointing

Jointing is predominantly in the hornfels series throughout the district. There were three main directions of jointing observed, and these formed in directions resembling cubic cleavage. Of these three directions, one always predominated while the other two showed minor development. It was this main jointing pattern that was measured and plotted on overlay No. 2 of Plate I. In some outcrops jointing was not distinct, and the rock showed parting in many directions. Jointing may be used as an indication of the amount of disturbance caused by the intrusion. Intrusive disturbances here again seem to be restricted to a small zone surrounding the stocks.

A few joint-planes are coated with quartz and epidote. No relation between the distribution of these fillings and their proximity to igneous activity has been found. It would be interesting to determine if there is any correlation between these two factors.

GEOLOGIC HISTORY

The first known sediments were deposited in this area during the Upper Triassic. These consisted of shallow, cyclic, marine deposits of relatively fine-grained sand and siltstone along with limestone. The carbonaceous nature of the limestone shows that much organic material must have been present during its deposition.

Structures such as wave ripple marks, cross-bedding, and graded bedding were formed during sedimentation. These features were buried by subsequent deposits, lithified, and thus preserved. Post-lithification faulting then occurred.

As the intrusion stoped its way upward, quantities of heated gases and solutions permeated in all directions to metamorphose the siltstone into hornfels. Metasomatism took place in the more susceptible limestone and transformed areas immediately adjacent to the contacts into tactite that graded outward to white marble and finally into the original limestone. Local faulting around the intrusion took place during intrusion. As the granodiorite cooled off, and the end stages of mineralization took place, some contraction faults formed, in some instances allowing quartz to enter and fill them as veins during the end stage activities of the intrusion. Aplite dikes followed the zones of weakness and formed an intricate pattern of intrusion. These dikes are found as far away from the stocks as

4500 feet. Hornblende andesite dikes intruded the district at a later date.

Cross-faulting occurred and movement on the Stank Fault took place subsequent to all intrusive activity. An aplite dike can be seen displaced in the George Pit.

Erosion was taking place at the same time with some differential weathering forming the topographically low areas in the granodiorite. Creep in the hornfels beds caused the voids left by the eroded limestone to be closed by hornfels.

CORRELATION OF LIMESTONE

Necessity for Correlation

It has been explained how the limestone beds were host to the metasomatic processes associated with the intrusion of the granodiorite which resulted in economic deposits of scheelite. Even though scheelite has been found in dikes, granodiorite, quartz veins, and silicified hornfels, the only deposits of any commercial importance are in the tactite beds.

All of the possible scheelite deposits would be found if all of the limestone beds in the district could be traced to where they contact the granodiorite. Faulting and incompleteness of exposure are two major factors which limit tracing the limestones to the contacts.

The Nevada-Massachusetts Co. has used bulldozers to scrape away shallow overburden and expose the rock for exploration and mapping. This method has been effective in exposing some tactites and limestones buried under shallow overburden.

The previous method of correlating limestone beds followed this procedure. A reference bed is measured for thickness and distance to the adjacent limestone bed in either direction from the reference bed at right angles to its strike. This measurement assumes uniformity in thickness and distance between the two limestone beds. Correlation becomes difficult, if not impossible, if this sequence is disrupted by faulting or is poorly exposed. Some other means of correlating the limestone beds is therefore desirable to strengthen the method described above. The remainder of this paper is devoted to this problem.

Methods of Correlation Studied

Fossils are not suitable for correlating beds in this area because they are rare, distorted, and poorly preserved. It is interesting to note, however, that Monotis subcircularis (Gabb) has been found south of the Sutton 1 mine between the Sutton and Mill beds. They are also found in the Uncle Sam area, and a few were found, very poorly preserved, on the saddle just west of Florence Hill, in a slaty hornfels. This could denote a key horizon for the eastern part of the Tungsten district but it would be contrary to the general attitude of the hornfels beds.

Hornfels were studied to see if there were enough differences to distinguish any of the beds from one another so that one horizon might be used as a marker bed. Again, the hornfels beds did not have enough noticeable differences to provide a key horizon.

Thus, stratigraphic position of beds in sequence seemed to be the next logical line of attack in obtaining the structural picture. Incomplete exposures and lack of a good type area discouraged this idea. Such procedure would have also called for correlation of the limestone, which is the problem now at hand.

The next logical step in correlation was to make a complete study of the limestone itself. Thin sections were examined to see if there were any noticeable differences in the textures or mineralogical compositions of the individual beds. No differences were observed. Thirty-nine different specimens were used to make CaO, MgO, insolubles, and R_2O_3 assays. The procedure followed in making the assays is an abbreviated form of that outlined in Hamilton and Simpson (1952, pp. 335 - 348). Results of the analyses were very encouraging.

It was necessary to answer two fundamental questions concerning the limestone composition before it could be used as a basis of correlation. Would any of the chemical constituents remain constant within the individual bed and would they differ enough within a series to distinguish individual members of that series?

Samples were taken at irregular intervals along the strike of the pairs of Sutton and Mill beds. These are the most nearly continuous limestone exposures of the Tungsten group.

Calcium seemed to be the constituent most applicable for correlating purposes. Compositions of the beds listed on the following page show a maximum difference in CaO content to be 3.6% within a bed. Sample YB4 is the one exception not consistent with the others taken from the Young bed. The limestone assay sheet shows YB4 to have a high insoluble content indicating the possibility of being partially replaced.

DATA STUDIED FOR CORRELATION OF LIMESTONE BEDS

Sample Number	Weight of Heavy-Mineral 5 gram Sample	CaO %	Specific Gravity	
		MILL BEDS		
7H	trace	51.7	2.627	Hanging Wall Bed
10	0.0060 gm	49.6	2.657	
13	0.0050	51.6	2.686	
7	0.0038	41.9	2.703	Foot Wall Bed
9	0.0065	38.9	2.630	
		SOUTH SUTTON BEDS		
19	0.0025	48.6	2.622	Hanging Wall Bed
45	0.0047	49.8	2.616	
20	0.0000	37.4	2.628	Foot Wall Bed
21-1	0.0065	41.0	2.645	
73	0.1750	40.1	2.650	
		YOUNG BED		
143YB	0.256	46.4		
YB4	0.124	32.7		
YB5		43.1		
		EXTENSION OF YOUNG BED		
141a	0.267	41.5		
141c	0.043	43.7		
146d	0.0075	43.4		
		DURNAM BED		
15a		40.6		
16a		42.4		

Black limestone lenses in portions of the tactite beds could probably be used for valid correlation. The presence of dark carbonaceous material indicates the rock has not been subjected to metamorphism.

Limitations of using calcium assays must be examined. As illustrated above, in sample YB4, care must be taken in sampling not to use samples of limestone partially replaced. Effects of weathering upon the calcium content of the limestone have not been studied. Some investigation should be done here.

Efforts were made to see if some field method could be worked out to obtain more rapid results so that extensive assaying would not be necessary and to strengthen calcium assay correlations.

Specific gravities of the limestones are tabulated with the other data on the Mill and Sutton beds. There proved to be no correlation between calcium content and specific gravity.

Heavy-mineral separations were made. Weighing and comparing the results of these weights with calcium assays again produced negative results.

Grain mounts were made of the heavy-minerals to see if any one mineral unique to one bed could be found or if any noticeable ratio between the different heavy-minerals existed. Subsequent observation showed that no unique mineral or ratio existed.

The remainder of the assays were taken on fragments of limestone and tactite beds between the Stank and Humboldt mines. Results are plotted on the assay map.

Calcium assays seem to indicate a reliable method of correlating limestone beds in this district. It must be remembered that these results cannot be taken as conclusive, because an insufficient number of samples was taken to be representative of the whole district. This method would have to be followed on a larger scale and with a more precise method of sampling, in order to correlate the limestone beds. Following of this procedure would show how the beds are aligned and would give sufficient information for accurate determination of displacements.

LIMESTONE ASSAY SHEET

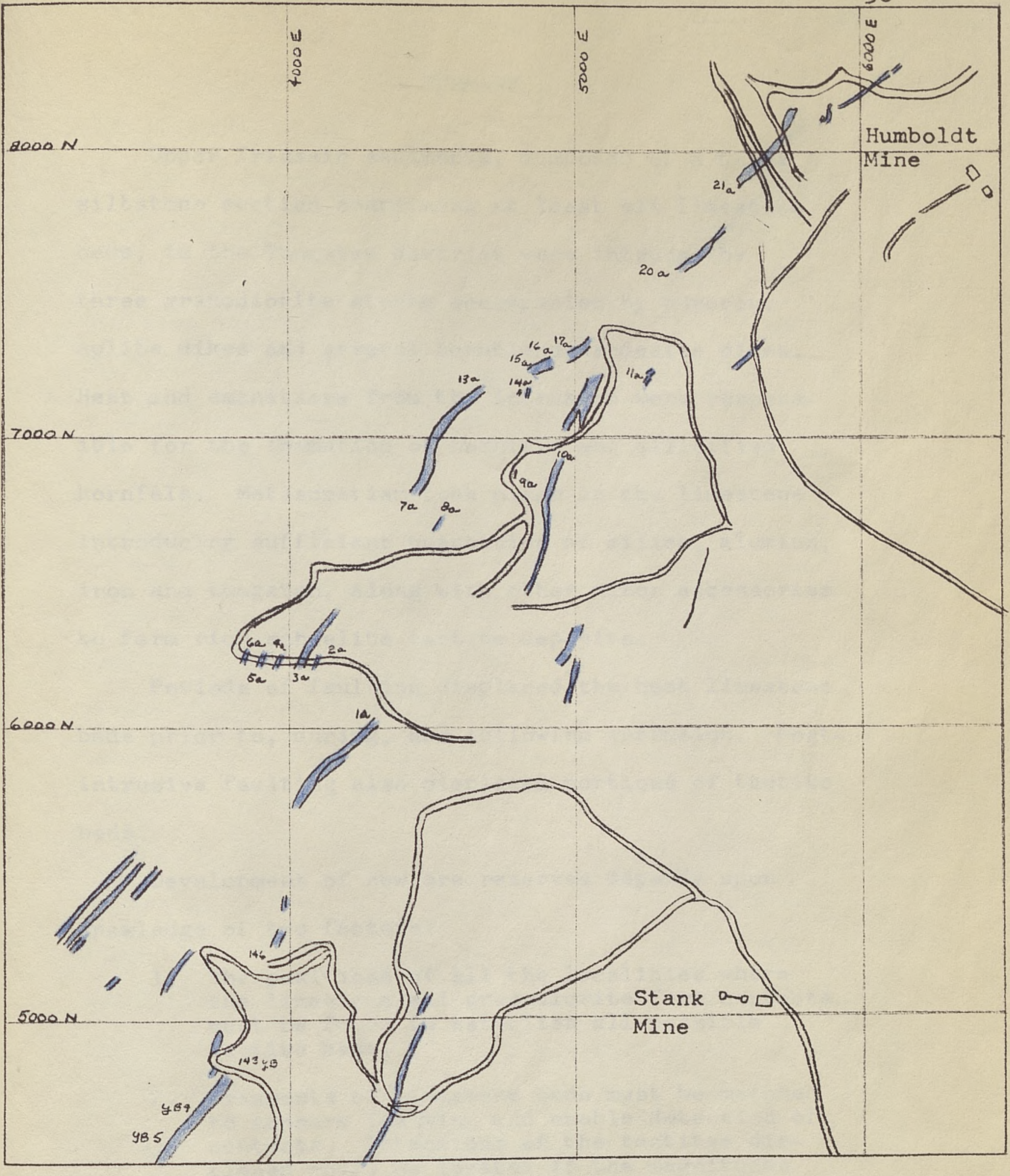
Sample	Insoluble	R_2O_3	% CaO	% MgO
1a	11.4	2.09	48.9	0
2a	57.1	5.62	24.8	0
3a	34.5	5.93	34.4	0
4a	17.4	4.00	43.6	0
5a	26.1	15.6	31.5	0
6a	24.6	1.72	30.6	0
8a	55.5	3.48	17.4	0
9a	15.4	2.10	33.3	0.0002
12a	11.3	1.10	35.1	0.0012
14a	23.6	0.85	30.6	0.0002
15a	13.8	2.22	40.6	2.97
16a	14.2	1.65	42.4	2.06
17a	32.6	6.37	34.0	0.0002
21a	10.4	0.91	32.3	0
Stank 1200	21.0	1.56	42.4	0
143YB	13.5	1.43	46.4	0
YB4	37.5	1.88	32.7	0
YB5	12.7	1.60	43.1	3.30
141a	11.0	2.16	41.5	5.00
141 c	6.52	0.69	43.7	0
146d	19.3	2.03	43.4	0
7	15.8	6.81	41.9	0
7h	2.30	1.17	51.7	0
9	19.4	4.23	38.9	11.1*
10	5.03	2.28	49.6	0
13	4.53	0.81	51.6	0.44
19	8.35	2.60	48.6	0.16
20	21.2	6.80	37.4	0
21-1	20.2	3.70	41.0	0
45	5.39	2.32	49.8	0
73	23.1	4.11	40.1	0.22
81-d	15.8	3.60	41.4	0.16
114	37.3	9.15	29.0	0.18
114-s	9.00	1.58	48.0	0
114-122	15.2	3.40	42.9	0
120	27.5	5.30	36.5	0
122	21.9	3.46	39.8	0
154	45.4	9.36	25.5	0
Ribbon bed	33.0	12.3	29.1	0

*Erroneous results were obtained on this assay. Computations show total composition of the sample exceeds 100% by a large margin.

COORDINATES OF LIMESTONE SAMPLES ASSAYED

Sample	Coordinates	
1a	4300 East	6030 North
2a	4100	6210
3a	4050	6210
4a	3940	6210
5a	3880	6220
6a	3820	6240
8a	4530	6730
9a	4440	6860
14a	4840	7160
15a	4830	7230
16a	4820	7280
21a	5560	7900
Stank 1200	Stank 1200' level - face of "High Grade" drift, August 1957.	
143YB	3750	4800
YB4	3650	4680
YB5	3560	4590
141a	3700	4950
141c	3700	4950
146e	3890	3250
7	7850	2500
7h	7850	2500
9	8050	3550
10	8200	3900
13	7800	1700
19	6600	2000
20	6550	2000
21-1	6550	2000
45	6400	1650
73	6800	3200
81-d	6700	3400
114	3400	3100
114-s	3300	2900
114-122	4000	3200
120	3150	4400
122	3000	4300
154	4000	6450
Ribbon Bed	3700	6000

The coordinates of Plate I and Assay Map are the same and correspond to those now being used by the Nevada-Massachusetts Co.



Scale 1 in. = 500 ft.

ASSAY MAP

Roads ═══

Limestone ▬

Reproduced from Nevada-Massachusetts Co.
Surface Geology Map

Fig. 2

SUMMARY

Upper Triassic sediments, composed of a thick siltstone section containing at least six limestone beds, in the Tungsten district were intruded by three granodiorite stocks accompanied by numerous aplite dikes and several hornblende andesite dikes. Heat and emanations from the intrusion were responsible for the formation of hornfels and silicified hornfels. Metasomatism took place in the limestone introducing sufficient quantities of silica, alumina, iron and tungsten, along with other minor accessories to form rich scheelite tactite deposits.

Periods of faulting displaced the host limestone beds prior to, during, and following intrusion. Post-intrusive faulting also displaced portions of tactite beds.

Development of new ore reserves depends upon knowledge of two factors:

1. The positions of all the localities where the limestone and granodiorite form contacts must be found to establish all possible tactite beds.
2. Fragments of limestone beds must be matched to measure faulting and enable detection of contacts. Extensions of the tactites displaced could be located if the magnitudes and directions of faulting were known.

Poor exposures of all the limestone beds make definite correlation among them difficult. A study of the hornfels beds disclosed no criteria for matching limestone beds. Properties of the limestone were studied to determine if any features were unique to a limestone bed so that any of its parts, even if not consecutively exposed along its strike, could be correlated. Heavy-minerals, specific gravities, thin sections, and CaO assays were studied. CaO assays on the strike of the same limestone bed gave similar results. This fact was consistent for several individual beds and indicated a basis of correlation.

More work should be done to determine the limitations of this method. Variations of calcium content in a specific bed must be learned and compared with those in adjacent beds to discover if any overlap exists. Frequency of sampling required would be dependent upon the variation in calcium content. This method of correlation is ideal as long as the variation in calcium does not affect the total calcium content in a limestone bed enough to overlap into the values of calcium of an adjacent bed. If a certain amount of overlap does exist cross-sections of the stratigraphy could be made with assay values plotted and then compared. This applies the same principle used in correlating data from different drill holes.

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