University of Nevada
Reno

Geology and Tungsten Mineralization
of a Portion of the Ragged Top Mining District,
Pershing County, Nevada

A thesis submitted in partial fulfillment of the
requirements for the degree of Master of Science in Geology.

by

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ABSTRACT

The area surrounding the Ragged Top Mine in south-central Pershing County, Nevada, is underlain by Late Triassic-Jurassic sediments which are intruded by a Cretaceous granodiorite pluton. Tertiary volcanic rocks unconformably overlie both the granodiorite and the sediments. The sediments consist of a carbonate unit, probably correlative with the Dun Glen formation of the Auld Lang Syne group, and a black argillite unit correlative with an unnamed Post Dun-Glen unit.

Mineral assemblages typical of contact metamorphic alteration zones are developed at or near the intrusive-carbonate contact. Disseminated scheelite occurs in low grade concentrations in these alteration zones. Alteration can be divided into light and dark colored skarn assemblages with the bulk of the scheelite associated with the dark skarn.

Development of alteration and scheelite mineralization have been controlled by structure and stratigraphy. Where the intrusion was emplaced at an angle to sedimentary bedding, fluids emanating from the intrusion were allowed to migrate along bedding planes, enhancing the development of skarn and the emplacement of scheelite. Where sedimentary bedding paralleled the intrusive contact, the type of skarn and the amount of scheelite varied from layer to layer.
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INTRODUCTION

This paper is a study of the geology of a portion of the Ragged Top Mining District in Pershing County, Nevada. Geologic features associated with tungsten mineralization are emphasized.

Location

The Ragged Top District is in extreme south-central Pershing County and straddles the Trinity Mountain Range. An area of approximately 18 square kilometers in the northwest corner of the district is dealt with in this paper. This area is in Sections 35 and 36 of Township 26 N, Range 28 E, Sections 1, 2, 11, and 12 of Township 25 N, Range 28 E, Sections 6 and 7 of Township 25 N, Range 29 E, and Section 31 of Township 26 N, Range 29 E (taken from Lovelock AMS sheet, 1970). The nearest town is Lovelock, Nevada, 25 kilometers northeast of the district. Figure 1 illustrates the location of the Ragged Top District.

Accessibility

The area is easily reached from Reno, Nevada, by traveling about 130 kilometers northeast on Interstate Highway 80 to the Toulon exit. A well-traveled gravel road leads west from Interstate 80 at this point. Sixteen kilometers of travel on this road will lead through a low pass in the Trinity Mountains to the Ragged Top Mine. Untended dirt roads allow vehicular travel throughout much of the area surrounding the mine.

Purpose of Study

The purpose of this investigation is to examine and record the geologic features responsible for determining the nature, distribution,
Figure 1

Index map showing location of Ragged Top Mining District.
and extent of tungsten mineralization in a portion of the Ragged Top Mining District. Features related to the development of an economically exploitable concentration of tungsten are emphasized.

Methods of Study

A geologic map for an area of approximately 16 square kilometers was compiled at a scale of 1:5,000. Special care was taken to examine features influencing the location and configuration of alteration zones. Selected areas of these alteration zones and rocks surrounding them were irradiated with short wave ultra violet light to determine the distribution and extent of the tungsten-bearing mineral, scheelite. Specimens were collected and thin sections prepared and examined for all the rock types in the area.

Previous Work

Only brief descriptions of the Ragged Top District can be found in published literature. Kerr (1946), Hess and Larsen (1922), and Vanderburg (1936) summarize mining activity in the district and include geologic descriptions. Warner and others (1959) describe a particular skarn zone near the Ragged Top Mine with reference to the trace occurrence of beryllium in the area.

Mining History

The discovery of scheelite in "inconspicuous outcrops of contact metamorphosed limestone" by E. J. Mackedon in early 1916 is the earliest known mining related activity in the Ragged Top Mining District (Hess and Larsen, 1922, p. 289). This discovery resulted from prospecting activity generated in the area by a sudden rise in the price of
tungsten in late 1915 and by its close proximity to the St. Anthony Tungsten Mine. The St. Anthony Mine is about 10 kilometers southeast of the Ragged Top Mine and had been exploiting scheelite in "contact metamorphosed limestone" since 1908 (Hess and Larsen, 1922).

In April of 1916 the claims were sold to H. M. Byllesby and Co. of Chicago. They formed the Chicago-Nevada Tungsten Co. and began mining in the summer of 1916. A mill with a capacity of 50 tons per day was constructed 16 kilometers west of the mine at the Toulon siding on the Southern Pacific Railroad. The mill was in operation by the end of 1916 (Vanderburg, 1936). The construction of the ore haulage road and the method of hauling (six trailers full of ore behind a caterpillar tractor) were innovative enough to merit mention in a leading mining journal of the day (Mining and Engineering World, 1916 a,b).

The mine remained active only until early 1918. With the closing of the mine, the mill was sold to the Humboldt County Tungsten Mine and Mill Co. The mill was later reopened and became a shipping point for several tungsten mines in Nevada. The mill was owned at different times by both the Nevada-Massachusetts Co. and the Rare Metals Corp., both of which were important producers of tungsten in the 1930's and 40's (Minerals Yearbooks, 1931, 1937, 1946).

After the shutdown in 1918, the Ragged Top Mine remained inactive until the Nevada-Massachusetts Co. obtained the claims in 1931. That company did development work on the claims in 1931 but a slowdown in the tungsten market caused them to cease their Ragged Top operations (Minerals Yearbook, 1931). In 1940 and 1941 the Rare Metals Corp., under the direction of Ott Heizer, did "considerable work" at the
Ragged Top Mine. They may have processed ore from Ragged Top at the Toulon mill at that time but no specific reference to this has been found (Minerals Yearbook, 1940, 1941).

The next reported activity at the Ragged Top Mine was in 1953 and 1954 when J. F. De La Mare shipped small amounts of ore to a custom mill (Minerals Yearbook, 1953, 1954). The Cordero Mining Co. shipped a "few thousand tons" of ore from Ragged Top in the mid-1950's (M. Gomes, U. S. Bureau of Mines, Reno, Nevada, personal communication). This small scale mining was probably due to a U. S. government stockpiling program in effect from 1952 to 1955 (Tingley, 1963).

Reported mining activity at Ragged Top is virtually nonexistent for the twenty five years that have passed since the end of the government stockpiling program. An examination of Pershing County records reveals claim staking activity by individuals not associated with organized mining companies beginning in the late 1960's and continuing to 1979. The man who presently lays claim to the Ragged Top Mine, Jim Brown of Reno, Nevada, informed the author of this paper that "several thousand tons" of tungsten ore had been removed from the area in the 1970's.

A tungsten occurrence 3 kilometers north of the Ragged Top Mine is included in the area this paper deals with and has been exploited on a small scale in the 1970's. The amount of ore taken from here is unknown but it is probably in the neighborhood of tens or, at most, hundreds of tons.

Production

The production of the Ragged Top Mine in 1916 amounted to 75,475
pounds of tungsten concentrates averaging 60-70% WO₃ taken from 3,441 tons of ore (an average of about 0.7% WO₃). About half of this ore was processed at a mill in Eureka, Utah, and the other half was processed at the Toulon mill (Mineral Industry Yearbook, 1916).

No other specific information on the yearly production of the Ragged Top Mine has been found. An estimate of total production through 1944 has been placed at 12,000 to 20,000 tons of ore averaging 1.0% WO₃ (Johnson, 1978). Production since then has been sporadic and has involved several different operators. The present owner of claims staked at Ragged Top estimates that "over 100,000 tons of ore" have been removed from the vicinity of the Ragged Top Mine throughout the years. Mine workings present at the property do not prove the accuracy of that statement but they certainly allow the possibility of that much production. These workings include a "glory hole" (an open cut 15 meters deep and 20 X 30 meters around), 5 shafts (at least 3 of them over 30 meters deep), 5 adits, and evidence of surface excavation. Figure 2 is a picture of the glory hole, one of the shafts, and part of the surface excavation.
Figure 2

A view of the Ragged Top showing the Glory Hole, a headframe over a shaft, and surface excavation. The metallic structures in the middle ground are towers on a high tension electric line. View is looking west.
GEOLOGY

Regional Setting

The Ragged Top Mining District is in the Trinity Mountain Range of the Basin and Range physiographic province in extreme south-central Pershing County. It is one of the series of generally north-south to northeast trending, elongate mountain ranges that are characteristic of the Basin and Range province. Rocks in the Trinity Range include Triassic-Jurassic sediments that have been intruded by quartz monzonite and granodiorite intrusions during the Cretaceous era. These rocks are unconformably overlain by Tertiary volcanic rocks. These volcanic rocks include andesite, basalt, dacite, and rhyolite and range in age from Oligocene to Miocene (Johnson, 1978, Willden and Speed, 1974). At least a portion of the dacite volcanics in the Trinity Range were expelled from a caldera entirely within the Ragged Top Mining District (Willden and Speed, 1974).

General Summary

The area this paper is concerned with consists of about 18 square kilometers on the west flank of the Trinity Mountain Range and is in the northwest corner of the Ragged Top Mining District (Plate 1). Included in the area are the Ragged Top Tungsten Mine and several tungsten occurrences that have been exploited on a small scale.

Sediments exposed in the area consist of a 2-50+ meter thick section of white to medium gray, deformed and recrystallized carbonate overlain by poorly exposed, interbedded, black argillite, quartzite, and carbonate. These rocks have been assigned to the Late Triassic-Early Jurassic Auld Lang Syne group of sediments exposed over a large
part of northwestern Nevada (Johnson, 1978). The assignment was made on the basis of their lithology and sparse fossil content but stratigraphers have not been able to relate them to specific parts of the group (Burke and Silberling, 1974, p. 11).

A granodiorite pluton of Cretaceous age has intruded the Auld Lang Syne sediments. The surface exposure of this intrusion presently occupies an elliptical area of about 3.5 kilometers along the northeast trending long axis and 2.5 kilometers on the short axis of the ellipse (Plate 1). The pluton is in contact with the Auld Lang Syne rocks to the south and northeast. Occasional small isolated outcrops of carbonate rocks crop out within the boundaries of the pluton.

Tertiary volcanic rocks unconformably overlie the intrusion and the sediments in the northwestern and eastern parts of the area. A northeast trending, probably normal, fault has juxtaposed Tertiary volcanic rocks against the sediments and the intrusion in the southern part of the area. An east-west trending strike-slip fault borders the intrusion and the sediments in the northwestern part of the area. To the west, the intrusion disappears under alluvium.

Three different types of dike rocks are present within the area. Aplite dikes 1-100 centimeters in width and up to 50 meters long can be found throughout the intrusion. Steeply dipping, northeast trending, diabase dikes cut both the granodiorite and the Tertiary volcanics in the northern part of the area. Light colored felsic dikes cut the granodiorite in the western part of the area (Plate 1).
Sedimentary Rocks

Introduction

Two distinct stratigraphic units crop out in the Ragged Top area. Johnson (1978) lumped these rocks into "undivided Auld Lang Syne group" on a reconnaissance scale geologic map. Burke and Silberling (1974, p. E11), in a discussion of similar rocks throughout central and western Pershing County state that "Although the lithology and sparse fossil content of these strata indicate their relation to the group, it is presently impossible to refer many of them to specific parts of the group". The author of this paper believes there is enough evidence to support the assignment of the sediments at Ragged Top to formations in the Auld Lang Syne group.

Auld Lang Syne Group

Dun Glen Formation

A 50+ meter thick section of white to medium gray, deformed and recrystallized carbonate rock is exposed in the northeastern and southern parts of the area (with reference to the grid system on the geologic map, Plate 1, these exposures are located near 12,500 N, 11,500 E and 10,500 N, 10,500 E). Isolated outcrops of carbonate rock with similar lithology can also be found in several places throughout the area (for example, near 11,500 N, 12,000 E).

Extensive development of small scale folds, pervasive recrystallization, and the absence of the lower depositional contact have combined to cause difficulty in assigning a thickness to this rock unit. Exposures in the southern part of the area indicate a maximum thickness
of at least 50 meters. Tectonic forces have broken and scattered this rock unit in the northern part of the area so the thickness of the carbonate unit in this area is indeterminate.

Lower beds of the carbonate unit are in contact with intrusive igneous rocks. The top of the unit appears to be gradational with overlying beds of black argillite and quartzite. The relationship with the black argillite unit serves as the basis for determining whether the carbonate unit is overturned or right side up.

Texturally, the rock ranges from fine grained to coarsely crystalline. Outcrops consisting almost entirely of calcite crystals 1-2 centimeters long are present. Where this is the case bedding is poorly preserved. Where the rock is finer grained, bedding has been preserved and the unit can be seen to be medium bedded in some places and massive in others.

Most outcrops of the carbonate unit consist entirely of calcite crystals visible to the naked eye. No chemical analyses were made of the carbonate but based on visual examination, the rock is virtually 100% calcite.

In this author's opinion, it is probable that this carbonate rock unit correlates with the Upper-Triassic (Norian) Dun Glen formation as described by Burke and Silberling (1974) and Silberling and Wallace (1969). Silberling and Wallace (1969, p. 40) studied the Dun Glen in the Humboldt Range about 45 kilometers northeast of the Ragged Top area. They state the Dun Glen formation is a massive, medium to thick bedded limestone. It has a maximum thickness of 1,150 feet (354 meters) and it thins southwestwardly to 50 feet (16 meters) in the area they studied. They also state that it is a homogenous unit of dolomite or limestone.
within a thick sequence of "mainly fine-grained terrigenous clastic rocks". Allowing for the extensive recrystallization present in the carbonate unit at Ragged Top, Silberling and Wallace's lithologic description of the Dun Glen formation is similar to the Ragged Top carbonate. The thickness of this rock unit at Ragged Top is compatible with the thickness range established for the Dun Glen formation. The relationship of the Ragged Top carbonate to overlying strata is also similar to that displayed by the Dun Glen formation. Lastly, it is widely recognized that the Ragged Top sediments are a part of the Auld Lang Syne group. The Dun Glen formation is the only carbonate unit of substantial size within the Auld Lang Syne. For these reasons, this author feels that the Ragged Top carbonate correlates with the Dun Glen formation.

**Black Argillite**

A section of interbedded black argillite, quartzite, and limestone overlies the carbonate unit already discussed. The thickness of this section is indeterminate because of the disintegrated nature of its surface exposure. Commonly, this unit forms piles of angular pebble-sized fragments. Only rarely does it form a solid outcrop. The thickness of the unit is probably variable but near 10,500 N, 11,300 E (see Plate 1) it must be thicker than 20 meters. Outcrops display a thickness of 20 meters at this point. Surface debris from the black argillite unit surrounds these outcrops, suggesting the unit is greater than 20 meters thick at this point.

The few outcrops of this unit that do exist reveal thin beds (2mm-2cm thick) of black argillite sometimes found with thicker beds
of quartzite and limestone. A quartzite bed 1-2 meters thick can be followed for about 75 meters just northwest of 12,500 N, 12,500 E (Plate 1). The limestone beds are usually less than 1 meter thick and are most often found as discontinuous outcrops surrounded by argillite debris. The argillite fragments are usually black but are often stained orange-red on weathered surfaces.

In some places (for example 10,750 N, 11,500 E), discontinuous outcrops of light-colored calc-silicate hornfels are present among debris from this rock unit. These outcrops probably represent recrystallized beds that differed from most of the sediment in the argillite unit. Possibly they indicate sandy and limy strata within the finer grained sediment.

Silberling and Wallace (1969, p. 44) describe what they call an "unnamed lower unit of Post-Dun Glen Lower Mesozoic strata". The lithology of the "Black Argillite" unit at Ragged Top is similar to their description of this unnamed unit. If the carbonate unit of the Ragged Top area is indeed correlative with the Dun Glen formation then the stratigraphic position as well as the lithology of the "Black Argillite" unit would certainly allow for the correlation of this unit with the unnamed lower unit of Silberling and Wallace.

Silberling and Wallace (1969, p. 44) state that this unnamed rock unit is "lithologically similar, partly correlative, and probably genetically related to the Winnemucca and Raspberry formations". These formations are part of the Auld Lang Syne group and are described from exposures located in mountain ranges northeast of the Ragged Top area (Burke and Silberling, 1974). The unnamed rock unit is not
definitely placed in these formations because, according to Silberling and Wallace (1969), "These formations cannot be readily recognized away from their typical outcrops because, as defined, they are neither unique in lithologic composition nor bracketed by distinctive stratigraphic boundaries".

Igneous Rocks

**Cretaceous Intrusion**

An elliptical area approximately 3.5 kilometers along the northeast trending long axis and 2.5 kilometers along the short axis is occupied by a granodioritic pluton (see Plate 1). Smith and others (1971) obtained two K/Ar age dates from this pluton. Analysis of hornblende revealed an age of 88.0±6.0 million years while analysis of biotite (presumably from the same sample) yielded an age of 87.2±3.7 million years. This places the time of crystallization in the late Cretaceous.

In the northeastern and southern parts of the area the intrusion is in contact with the Auld Lang Syne sediments. To the northwest and east the intrusion is unconformably overlain by Tertiary volcanic flows and to the west it disappears under Quaternary valley fill.

The pluton forms a topographic depression compared to the surrounding Tertiary volcanic rocks. The intrusive rock forms a pediment surface over much of the area and is often covered by a thin veneer of relatively recent deposits of debris from rocks on the mountainous slopes found on three sides of it. The granodiorite has disintegrated to grus over most of its surface exposure. Outcrops have generally weathered to rounded boulders and cobbles. Mining-related pits and prospects provide places
to examine the mineralogy and structure of the intrusion.

Outcrops are moderately fractured. Fracture attitudes measured throughout the study area have not revealed a preferred orientation for these features (see Geologic Map, Plate 1).

The intrusive rock is medium-grained and non-porphyritic. Most of the specimens examined fall into the mineralogical composition range of granodiorite although two specimens, found at different localities but within five meters of the contact with sediments, were poor in potassic feldspar and would be classed as quartz diorite. A whole rock analysis obtained by Smith and others (1971) from a specimen of this pluton revealed that the chemical composition of the rock is also very close to that of a typical granodiorite. Table 1 demonstrates that similarity. Occasional variations from the typical mineralogy were observed. At a pit located near 10,800 N, 11,400 E (Plate 1) an exposure of the intrusion reveals a much greater percentage of hornblende and biotite. At this place, approximately 30% of the rock is hornblende and approximately 20% is biotite. This variation in composition, like the two examples of quartz diorite composition previously mentioned, occurs within a few meters of the contact of the intrusion and the sediments. Because these variations have only been observed near the contact, they are probably due to a difference in the chemical environment near the contact at the time of crystallization.

Part of the opaque minerals observed in thin section are pyrite. Many of the opaques are cube shaped and occasional pyrite crystals can be seen megascopically.
Table 1
Chemistry of Ragged Top granodiorite compared to typical granodiorite

<table>
<thead>
<tr>
<th>Oxide</th>
<th>Analysis of Ragged Top pluton (from Smith and others, 1971) (weight %)</th>
<th>Analysis of typical granodiorite (from Krauskopf, 1967) (weight %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>63.9</td>
<td>66.88</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>17.8</td>
<td>15.66</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>1.8</td>
<td>1.33</td>
</tr>
<tr>
<td>FeO</td>
<td>2.1</td>
<td>2.59</td>
</tr>
<tr>
<td>MgO</td>
<td>1.2</td>
<td>1.57</td>
</tr>
<tr>
<td>CaO</td>
<td>4.6</td>
<td>3.56</td>
</tr>
<tr>
<td>Na₂O</td>
<td>4.4</td>
<td>3.84</td>
</tr>
<tr>
<td>K₂O</td>
<td>2.2</td>
<td>3.07</td>
</tr>
<tr>
<td>TiO₂</td>
<td>0.56</td>
<td>0.57</td>
</tr>
<tr>
<td>P₂O₅</td>
<td>0.21</td>
<td>0.21</td>
</tr>
<tr>
<td>MnO</td>
<td>0.09</td>
<td>0.07</td>
</tr>
</tbody>
</table>

Table 2 illustrates the mineralogical composition of most of the specimens collected for this study. The mafic minerals referred to in the table are hornblende and biotite in approximately equal amounts. Trace amounts of muscovite, sphene, and opaque minerals were also observed.
Table 2

Mineralogical Composition of Ragged Top Pluton

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Volume %</th>
</tr>
</thead>
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<tr>
<td>K-feldspar</td>
<td>5-15</td>
</tr>
<tr>
<td>Plagioclase</td>
<td>50-60</td>
</tr>
<tr>
<td>Quartz</td>
<td>10-20</td>
</tr>
<tr>
<td>Mafic minerals</td>
<td>15-20</td>
</tr>
</tbody>
</table>
Aplite Dikes

Dikes as small as 1 centimeter wide and as large as 1 meter wide can be found in many places throughout the granodiorite intrusion. These dikes do not display any consistent orientation. They are light colored and fine-grained with a mineralogical composition of approximately 40% quartz, 40% microcline, 15% orthoclase, and 5% plagioclase.

The aplite dikes are considered to have been formed from residual fluids in the magma that formed the granodiorite. This late-crystallizing fluid probably filled fractures in the already hardened granodiorite. The random orientation of these dikes is similar to the random orientation of fractures in the granodiorite.

Diabase Dikes

A series of dikes trending north-south to northeast is present in the northern half of the area. They were emplaced after the crystallization of the Tertiary volcanic rocks in the northern part of the area and intrude both the Cretaceous intrusive and the Tertiary volcanics.

These dike rocks are dark brown and are sometimes porphyritic. The fine-grained groundmass consists largely of plagioclase with subordinate pyroxene (augite). The phenocrysts are always plagioclase. They are usually lath shaped and may be up to one centimeter long.

Felsic Dikes

A series of discontinuous outcrops consisting of light gray, fine-grained rhyolite defines two northeast trending dike sets in the western part of the area. These are represented by exposures at 10,500 N, 9,000 E and 12,500 N, 9,600 E (Plate 1).
This rock consists of approximately 50% orthoclase and 40% quartz with the remainder divided between plagioclase, biotite, and muscovite. This same rock type crops out near 12,000 N, 11,500 E (Plate 1). This outcrop is about 50 meters long and 25 meters wide and may represent a small plug related in lithology and time of emplacement to the Felsic dikes.

**Tertiary Volcanic Rocks**

Tertiary volcanic rocks occupy mountainous slopes on three sides of the pluton and sediments. These rocks consist of pyroclastics, andesite, dacite, rhyolite, welded tuff, and vitric tuff. The volcanics were not studied in detail because they are unrelated to the tungsten mineralization in the Ragged Top area. One feature of these rocks that should be mentioned is the presence of a caldera just south of the area with which this paper is concerned. Willden and Speed (1974) state that this caldera is a source for a portion of the dacite rocks in the Trinity Mountains. The jagged appearance this caldera imparts to the hills in the Ragged Top Mining District is responsible for the "Ragged Top" name.

**Quaternary Geology**

**Pediment Veneer**

The material mapped as "pediment veneer" on the geologic map (Plate 1) is debris derived from recent erosion of rocks on the mountainous slopes located north, south, and east of the area. This material is probably no more than a few meters thick but it effectively hides the bedrock geology at many places in the area.
Quaternary Alluvium

This designation on the geologic map was reserved for material deposited in drainage channels. It is often very similar in appearance to "pediment veneer" but can usually be differentiated by tracing drainage basins on aerial photographs. This material consists of detritus derived from the volcanics, granodiorite, and sediments of the Trinity Range.

Structural Geology

Regional Setting

The thesis area is on the western flank of the Trinity Mountain Range. The Trinity Range is one of a series of north-south to northeast trending, elongated mountain ranges characteristic of the Basin and Range province of western North America. Theories on the origin of Basin and Range structure have been proposed by geologists since the nineteenth century. Two of these theories will be briefly discussed in this paper.

Basin and Range structure is characterized by normal faults bounding elongate horsts and grabens. Roberts (1968) considers these features to be a result of crustal break-up due to geosynclinal sedimentation, uplift, and subsequent denudation. Normal faulting would be due to unstable crustal equilibrium resulting from the "unloading" of the area by erosion. More recently, Wright (1976) proposes an explanation based on the theories of global tectonics. He believes that crustal extension caused by westward movement of the Pacific Plate provides an explanation for features observed in the Basin and Range
province. Wright (1976) deals directly with the formation of strike-slip faults located in the southwestern part of the Great Basin as well as with the normal faults found throughout the Basin and Range.

**Structures Associated with the Emplacement of the Pluton**

**Deformation of Sediments**

The present day attitudes, configuration, and distribution of the Auld Lang Syne sediments can be attributed to a combination of deformation of the sediments prior to the intrusion of the granodiorite and to deformation of the sediments caused by the intrusion. These sediments have been folded, broken, and separated into isolated blocks along the boundaries of the pluton or resting on top of the pluton as roof pendants.

Two examples of steeply plunging folds with amplitudes on the order of 75-300 meters exist in the Ragged Top area. One of these is illustrated by the marble unit in Figure 3. This figure is a reproduction of a portion of Plate 1 at 12,700 N, 12,300 E. Although covered by alluvium, it is likely that the core of this vertically plunging fold is occupied by granodiorite. A subsurface interpretation of the geology shown in this figure is illustrated by the eastern portion of cross section D-D' (Plate 2). Another steeply plunging fold can be inferred by exposures near 10,500 N, 10,500 E. The core of this fold would be the granodiorite and black argillite at 10,300 N, 10,050 E. An interpretation of this fold can be seen on Plate 2 in the southeastern portion of cross section C-C'. The difference in attitudes displayed by the marble unit on C-C' can be explained by changes in attitude after the development of the steeply plunging fold. These changes could be due to forces associated with the emplacement of the
Figure 3

Reproduction of a portion of the Geologic map at 12,500 N, 12,250 E (Plate 1). Symbols are the same as on Plate 1.
pluton and deformation associated with the nearby major fault. A glance at the geologic map (Plate 1) reveals a variety of attitudes for the marble in this area, indicating extensive development of minor folds that partially disguise the gross structure.

Another style of deformation evident in the Ragged Top area is illustrated in Figure 3. Attitudes displayed by the "Black Argillite" rock unit (Ba on Plate 1 and Figure 3) in the southeastern and central parts of the figure reveal that the sediments have been broken and forced apart. This probably represents an intermediate step in the process that resulted in the separation of the sedimentary blocks throughout the area.

The folding discussed above could have developed prior to the emplacement of the granodiorite or it could have developed from forces associated with emplacement of the intrusion. The crystallization of the granodiorite in the core of the folds could be explained by prior sedimentary structure guiding the intrusion or by the sediments being forced to wrap around the intruding material. The occurrence of separate blocks of sediments surrounded by intrusive rock throughout the area indicates the intrusion had force enough to move the blocks of sediments. These forces could also be responsible for at least partial development of the folding.

Nature of the Intrusive-Sedimentary Contact

Due to the movement of the "blocks" of sediments when the intrusion was emplaced, the contact between the sediments and the intrusive rock has taken on several different configurations which are divisible into two broad categories. In the first of these the sedimentary bedding
planes parallel the plane formed by the intrusive-sedimentary contact and in the second the sedimentary beds form an angle with the contact. The importance of differentiating between these contact types relates to ore emplacement and is discussed in the section of this paper dealing with controls of alteration and mineralization.

The intrusive-sedimentary contact at 10,600 N, 10,600 E (Plate 1) is an example of sedimentary bedding paralleling the contact. In this situation only one surface of one sedimentary bed is in physical contact with the intrusion. The situation where sediments form an angle with the intrusive-sedimentary contact is best illustrated on cross section C-C' (Plate 2) by the southern (right side of cross section) exposure of marble. This example shows that when sediments form an angle with the contact several different sedimentary beds as well as bedding planes are in physical contact with the intrusion.

**Contact between Tertiary Volcanics and Mesozoic Rocks**

Although the contact between Tertiary volcanic rocks and the Mesozoic intrusive and sedimentary rocks has been affected by faulting after the deposition of the volcanics, the original depositional contact remains along the eastern, southwestern, and northwestern borders of the intrusion (Plate 1). The relationship can also be seen by examining erosional remnants of the Tertiary volcanics within the boundaries of the pluton. In all these places the volcanic rocks unconformably overlie the Mesozoic rocks. The basal member of the Tertiary volcanic series varies from white or red rhyolite in the northeast and northwest to a pyroclastic (white rhyolite fragments up to 2 cm in diameter in a red rhyolite matrix) in the east to a white
tuff (fragments of various type of volcanic rocks in a white, powdery matrix) in the southwest.

Cenozoic Faulting

Two major faults exist in the Ragged Top area. Both are high-angle faults that displace Mesozoic intrusive and sedimentary rocks as well as Tertiary volcanics. From this displacement, it is clear that the age of this faulting is after the deposition of the Tertiary volcanics. This makes the faulting Tertiary to Recent. The fault in the northern part of the area trends N 70° W while the fault in the south trends N 65° E.

Typical Basin and Range faults are high-angle, north to northeast trending faults of mid-Cenozoic to Recent age. The similarity in ages between the Ragged Top faults and Basin and Range faulting suggest that the same tectonic forces responsible for Basin and Range faulting are also responsible for the Ragged Top faults. The disparity in orientation between the faults in the thesis area and the north-northeast trend of typical Basin and Range faulting can be explained by the direction of shear stresses related to Basin and Range faulting and by an observation and conclusion made by Wright (1976). He states that,

"...the patterns of normal faulting, if observed in detail, tend to be highly irregular and thus difficult to analyse. The fault orientation must have been guided, in part, by lithologic and structural inhomogeneities, ranging from subhorizontal to vertical, that were acquired during a long history of sedimentation, deformation, and igneous activity."

The two faults strike in a direction compatible with shearing related to Basin and Range faulting and an examination of Plate 1 reveals the two faults could well be related to "structural inhomogeneities"
related to the contact between volcanic rocks and the Mesozoic rocks.

The northeasterly trending fault in the southern part of the area displays only dip-slip movement. Older Mesozoic rocks have been upthrown in relation to the Tertiary volcanic rocks. The northwesterly trending fault in the northern part of the area exhibits strike-slip movement as well as dip-slip. Diabase dikes located just north of the mapping area have been offset by this fault. Right-lateral movement of approximately 70 meters is indicated by these dikes. Dip-slip movement is indicated by the juxtaposition of the downthrown Tertiary volcanic rocks against the Mesozoic granodiorite and sediments.
Economic Geology

General Statement

Mining in the Ragged Top area has been limited to the exploitation of tungsten deposits. These deposits are of the "contact metamorphic" type and as such they are the result of metamorphic and metasomatic processes related to the intrusion of an igneous mass. This section of the paper discusses the type of alteration found in the "contact metamorphic" environment at Ragged Top and the nature, distribution, and extent of tungsten mineralization associated with that alteration.

Alteration

When an igneous mass intrudes a carbonate rock, temperatures, pressures, and fluids associated with that intrusion initiate a metamorphic process that culminates in the formation of characteristic mineral assemblages. These mineral assemblages, or "alteration zones", may be formed by the physical exchange of material between the intruding magma and the surrounding sediments or they may be formed by the simple recrystallization of the original material in the sediments without the addition or loss of any substances. This paper refers to these processes as additive or non-additive following the precedent set by Kerr (1946).

The assemblages resulting from the additive processes are referred to by the term "skarn". This word is an old Swedish mining term that originally referred to mineral assemblages commonly involved in the deposition of contact metamorphic magnetite deposits. The present usage of this term has developed from this original concept until it
includes almost all mineral assemblages formed by metasomatic processes active in contact metamorphism. "Tactite" is a term often erroneously used when referring to skarn assemblages. Tactite was first used by F. L. Hess (1919) to refer specifically to one type of skarn mineral assemblage and its use should be confined to only that particular assemblage.

**Marmorization**

Marmorization is the essentially non-additive process of recrystallizing limestone to marble. This is a well known phenomenon that frequently occurs when a carbonate rock is intruded by an igneous mass. Experimental evidence cited by Kerr (1946) shows the recrystallization of limestone to marble increases the permeability and porosity of the rock. Marmorization is the first alteration type to develop in the contact metamorphic environment so the resultant increase in permeability would play a significant role in ground preparation for the introduction of tungsten bearing solutions.

Marmorization is virtually pervasive in the carbonate rock of the Ragged Top area. The original limestone can only be examined in a few places where pods of light to medium gray limestone appear to have remained unaltered. Infrequent examples of this can be found northwest of 10,500 N, 10,500 E. By far the most common occurrence of the carbonate material is white, fine to coarse grained marble. Calcite crystals up to one centimeter long have been observed in this recrystallized rock. A typical example of marble from the Ragged Top area is illustrated by the white material in Figure 4.
Figure 4

Coarsely crystalline, massive marmorized limestone (white). Fine grained calc-silicates (brown). Located near 10,700 N, 10,300 E (Plate 1).
**Light Skarn Mineral Assemblage**

One or more alteration zones composed of light colored minerals are typically associated with the contact metamorphic environment in the western U.S. (Bateman, 1956, Collins, 1977, and Kerr, 1946). This stage of alteration is represented in the Ragged Top area by a mineral assemblage consisting of quartz, calcite, pale-colored garnet, epidote, wollastonite, tremolite, and occasionally scheelite. The alteration zone represented by these minerals displays several different configurations suggesting stratigraphic control in some cases and structural control in others.

Figure 5 illustrates stratigraphic control of this alteration zone. The picture is of the wall of a trench leading into the shaft at 10,850 N, 11,350 E (Plate 1). The areas labeled "Lsk" consist of fine grained epidote, calcite, and chalcedony. Remnant bedding from the original sediments remains visible and is almost vertical in the photograph. The mineral assemblage changes abruptly at a particular bed on the right side of the photograph indicating a distinct change in alteration type at a particular stratigraphic horizon.

Stratigraphic control of this alteration type is further indicated in the marmorized carbonate sequence near 12,500 N, 11,500 E (Plate 1). In this case, a partial development of the light colored skarn assemblage is indicated by the presence of light brown garnet and epidote crystals disseminated in a section of marble 15 centimeters thick. Marble on both sides of this section does not contain garnet or epidote. This is a clear example of stratigraphy controlling the development of the light skarn assemblage.
Figure 5

Photograph showing granodiorite, light and dark skarn mineral assemblages and the intrusive-sedimentary contact. Sedimentary bedding parallels contact. Located in trench at 10,850 N, 11,350 E (Plate 1).
Figure 6 illustrates an example of structure controlling the development of the light skarn assemblage. An open pit 20 meters by 40 meters at 12,420 N, 11,300 E (Plate 1) exposes the rocks seen in the photographs. The intrusive-sedimentary contact in Figure 6 dips approximately 70° to the north. The sediments in this area dip 18-23° to the northwest (not apparent in photograph). This situation causes sedimentary bedding and the intrusive contact to form a high angle, thus allowing a cross section of the sedimentary beds to come into physical contact with the intrusive rock. In this case, the light skarn assemblage has developed adjacent to the contact in a tabular shape that roughly parallels the attitude of the contact. The mineral composition of the alteration assemblage does not differ from one sedimentary bed to the next in this exposure.

**Dark Skarn Mineral Assemblage**

This alteration zone corresponds to the mineral assemblage referred to by Hess (1919) as "tactite". This assemblage in the Ragged Top area is essentially bi-mineralic. It consistently contains 60-80% zoned or massive dark brown garnet and 20-30% diopside. Accessory minerals are present in amounts up to 10% of the rock and include quartz, epidote, calcite, plagioclase, and scheelite. Occasionally pyrite, and rarely molybdenite, occur in amounts large enough to be seen by the unaided eye.

The configurations of the zones defined by this mineral assemblage are similar to those displayed by the light skarn assemblage. Both stratigraphic and structural features have influenced the formation of the dark mineral assemblage.
Figure 6

Photograph of granodiorite, light and dark skarn assemblages, and intrusive-sedimentary contact. Sedimentary bedding has a shallow dip not apparent in the photograph. Bedding does not parallel the contact. Located in pit at 12,420 N, 11,300 E (Plate 1).
Figure 6 also illustrates an example of structure controlling the development of the dark skarn assemblage. In this case, the light skarn assemblage occupies a position between the dark assemblage and the intrusive contact. The boundary between the dark assemblage and the light assemblage roughly parallels the intrusive contact while it is almost perpendicular to sedimentary bedding. This relationship is demonstrated in cross section E-E' on Plate 2. This configuration indicates the position and attitude of the dark mineral assemblage was determined by the attitude of the intrusive contact, not by the attitude of the original sedimentary bedding.

The shaft at 10,850 N, 11,350 E (Plate 1) exposes narrow zones of the dark skarn assemblage alternating with narrow zones of the light skarn assemblage. These zones correspond to the attitude of sedimentary bedding in the immediate area. In this case, lithologic or chemical differences in the stratigraphic column were important in determining the type as well as the configuration of the alteration assemblage.

The relationship between the attitude of the original sedimentary bedding and the attitude of the intrusive-sedimentary contact has been important in determining the size and shape of the alteration assemblage. Cross section A-A' illustrates two examples of the development of the dark skarn assemblage in the situation where the sedimentary bedding dips into the intrusive contact. These exposures crop out on the surface at 10,050 N, 9,950 E and 10,300 N, 9,850 E (Plate 1). It is important to note in these situations the high percentage of marble that has altered to skarn. This may be contrasted to the relatively low
volume of marble that has altered to skarn where sedimentary bedding parallels the intrusive contact. This is illustrated in the northern parts of cross sections B-B' and C-C' (Plate 2).

Newberry (1979) discusses the importance of structure in the formation of tungsten deposits. He states that one factor that aids in the development of economically recoverable deposits is the "deformation of the (sedimentary) sequence to direct metasomatic fluids away from the intrusive contact and trap them in the carbonate beds." It is apparent from the relatively large volumes of skarn in the Ragged Top area wherever carbonate sediments strike the intrusive contact at a high angle that this structural type aids in directing and trapping metasomatic fluids.

The development of minor folds in the carbonate rocks of the Ragged Top area has also served to direct and trap metasomatic fluids in the marble. Evidence for this can be seen at the intrusive-sedimentary contact near 10,600 N, 10,200 E (Plate 1). In this area, the dark skarn alteration assemblage is discontinuous along the intrusive contact. Minor folding caused bedding to strike the contact at a high angle in some places and to parallel the contact in others. Where bedding strikes the contact at an angle, metasomatic fluids were allowed to migrate along bedding planes and collect in "pockets" at the bend in the fold. Although skarn zones associated with these small folds rarely attain large volumes they do provide examples of geologic structure controlling the development of metasomatic alteration.

One common feature in the dark skarn assemblage of the Ragged Top area is the existence of quartz veins cross-cutting bedding. These
The Occurrence of Scheelite

Scheelite in the Light Skarn Assemblage

Scheelite in this alteration zone is rare in the Ragged Top area. There is a consistent association between scheelite and calcite wherever scheelite has been observed in this assemblage. Grains of scheelite are either surrounded by or adjacent to calcite. In at least one case scheelite was one of the earlier formed minerals of the light skarn mineral assemblage. Evidence for this is the existence of an intensely fractured scheelite grain with epidote, wollastonite, quartz, and calcite filling the fractures in the scheelite. These minerals could either be replacing scheelite or the scheelite grain must have been at least partially crystallized and fractured before the crystallization of the other minerals.

Although occasional exceptions have been described in the literature, typical light skarn mineral assemblages associated with contact metamorphic tungsten deposits in the western U. S. contain only small amounts of scheelite. Bateman (1956) and Collins (1977) state the lighter colored alteration assemblages formed from impure carbonate rocks. These impurities (aluminum and magnesium in Collins's example) interfered with the metasomatic processes that result in the crystalli-
Figure 7

Cross-cutting quartz veins in dark skarn assemblage. Located at 10,300 N, 9,075 E.
zation of scheelite in alteration assemblages formed from a pure carbonate. The Ragged Top area provides an example of scheelite occurrence that supports although does not prove the hypothesis of Bateman and Collins. The alternating light and dark skarn assemblages exposed in the trench and shaft at 10,800 N, 11,300 E (Plate 1) indicate that differences in the composition of the carbonate beds result in different types of alteration assemblages. The light skarn assemblages exposed here are barren of scheelite while the dark skarn assemblages usually contain easily visible amounts of scheelite. Although it cannot be definitely determined whether or not the carbonate beds that altered to the light colored assemblage contained impurities, it is obvious that compositional differences between bedding determined the presence or absence of scheelite.

Scheelite in the Dark Skarn Assemblage

Scheelite is disseminated through large volumes of the dark skarn assemblage. Most of the scheelite occurs as grains one millimeter to one centimeter in diameter although crystals up to several centimeters in diameter have been reported (Johnson, 1978).

Scheelite in the dark skarn assemblage has been observed at eleven separate localities in the project area. The locations of these areas are listed in Table 3.
Table 3

Location and occurrence of scheelite in dark skarn assemblage.

<table>
<thead>
<tr>
<th>Grid Coordinates (Plate 1) Northerly Easterly</th>
<th>Occurrence of Scheelite</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 10,050 9,950</td>
<td>Disseminated in elliptical area 50 meters in diameter.</td>
</tr>
<tr>
<td>2 9,950 10,000</td>
<td>Disseminated in 5 meter X 2 meter steeply dipping skarn.</td>
</tr>
<tr>
<td>3 10,025 10,150</td>
<td>Disseminated in walls of glory hole.</td>
</tr>
<tr>
<td>4 10,050 9,750</td>
<td>Scattered scheelite in sporadically developed skarn along 100 meter contact.</td>
</tr>
<tr>
<td>5 9,800 9,200</td>
<td>Scattered in &quot;pod&quot; of skarn 3 meters in diameter.</td>
</tr>
<tr>
<td>6 10,350 9,100</td>
<td>Scattered in steeply dipping skarn.</td>
</tr>
<tr>
<td>7 10,300 9,850</td>
<td>Disseminated in elliptical area 40 meters in diameter.</td>
</tr>
<tr>
<td>8 10,400 10,100</td>
<td>Scattered in sporadically developed skarn along 700 meters of intrusive contact.</td>
</tr>
<tr>
<td>9 10,850 11,350</td>
<td>Disseminated along narrow bedded zone of dark skarn.</td>
</tr>
<tr>
<td>10 12,450 11,300</td>
<td>Disseminated in &quot;pods&quot; in steeply dipping skarn zone exposed in pit.</td>
</tr>
<tr>
<td>11 12,350 11,475</td>
<td>Scattered in skarn exposed in prospect pit.</td>
</tr>
</tbody>
</table>

The most significant of the occurrences listed in Table 3 are those labeled 1 and 2. These occurrences represent the most likely place in the project area for the development of a large tonnage of dark skarn containing a consistent concentration of scheelite. The two areas are approximately 100 meters apart with the intervening area being obscured by excavation. The concentration of scheelite is consistent across the elliptical exposure and appears to be comparable to the scheelite concentration in occurrence number 2.

The other occurrences of scheelite in the area do not encourage the possibility of large tonnages of dark skarn or of reasonably high and
consistent concentrations of scheelite. The only possibility for a large tonnage of scheelite bearing skarn would be if the steeply dipping skarns retained or increased their thickness at depth. According to Kerr (1946, p. 192) attempts at mining in the Ragged Top area up to that time had revealed only shallow depths for the skarn. Mining since that time has been sporadic so it is doubtful any greater successes have been encountered.

Textural relationships observed in thin section reveal that scheelite was formed contemporaneously with most of the minerals in the dark skarn assemblage and continued to crystallize after the bulk of the skarn was formed. Contemporaneous formation is indicated by the relatively uniform grain size and the lack of cross-cutting relationships between scheelite and diopside, epidote, plagioclase, and most of the zoned garnet crystals. Rarely, the relationship illustrated in Figure 8 was observed. This relationship indicates replacement of garnet by scheelite. According to Bastin (1953, p. 37), replacement is demonstrated if one mineral transects features characteristic of another and if the transected feature (garnet zones in this case) is not warped around the transecting mineral (scheelite). If the garnet developed after the scheelite the zones would be deformed at the grain boundary.

The only minerals of the assemblage that can be shown to have formed after at least part of the scheelite are quartz and calcite. Both of these minerals fill fractures in scheelite grains and in one case a small veinlet with quartz and calcite completely divides a scheelite grain. This age relationship is consistent with contact metamorphic theory. The silica-rich solutions involved in the regressive
Figure 8

Schematic drawing of relationship between zoned garnet and scheelite grain, dark skarn assemblage.
stage of contact metamorphism are responsible for the deposition of the quartz. Although calcite is not usually considered a product of the regressive stage its presence can be explained. In this case, scheelite was crystallized as long as calcium and tungsten were available in the system. The supply of tungsten must have been exhausted before the supply of calcium so the leftover calcium crystallized in the form of calcite.

Scheelite, CaWO$_4$, forms a partial series with powellite, CaMoO$_4$. When irradiated with short-wave ultra violet radiation, scheelite and powellite can be easily distinguished from one another. Scheelite fluoresces bluish-white while powellite appears yellow. Tingley (1963) suggested that when scheelite and powellite are disseminated through the same rock in a contact metamorphic tungsten deposit, then more than one episode of mineralization is indicated. He further states that where there has been more than one episode of mineralization, the chance of an economic concentration of tungsten in that deposit is increased.

In the Ragged Top area, the only scheelite occurrences that are associated with powellite are occurrences 1, 2, and 3 (Table 3). This is one more feature of the scheelite occurrences in the immediate area of the old Ragged Top Mine that encourages the chance of an exploitable concentration of tungsten at this particular spot.

It should be mentioned that although molybdenum substitutes for tungsten to form powellite, it is very unusual to find more than a minor amount of molybdenum in the scheelite-powellite series (Mason and Berry, 1968). Further, it is impossible to distinguish powellite containing 5% molybdenum from powellite containing more than 5%
molybdenum by comparing the color of the mineral under ultra violet light. The color does not change with an increase in molybdenum after the 5% level is attained (Tingley, 1963). For these reasons, it can usually be assumed that the yellow-fluorescing powellite still contains a high percentage of tungsten. This means that the existence of powellite does not detract from the tungsten-producing potential of a deposit.
CONCLUSIONS AND RECOMMENDATIONS

Tungsten deposits in the Ragged Top area are of the contact metamorphic type and as such are related to the characteristic mineral assemblages that develop when carbonate rock is intruded by a magma that develops into a silica-rich igneous rock. The configurations and types of these mineral assemblages are dependent upon fluids issuing from or mobilized by the intruding magma, traveling along the intrusive-carbonate contact, and migrating into the intruded carbonate rock. The paths and extent of the migration of these fluids are controlled by various structural and stratigraphic features in the intruded sediments. The exchange of elements, including tungsten, between the fluids emanating from the magma and the carbonate rock is responsible for the formation of the mineral assemblages characteristic of this geologic environment.

Carbonate rocks in the Ragged Top area occur as pendants engulfed by a granodiorite pluton. Where sedimentary bedding parallels the intrusive-sedimentary contact only narrow zones of light or dark colored skarn develop. Where sedimentary bedding strikes the contact at a high angle, relatively large volumes of both types of skarn may develop, although in several cases in the Ragged Top area the light skarn assemblage is notably absent. This is particularly evident in the dark skarn exposure just west of the Ragged Top Mine and in the skarn exposure at 10,350 N, 9,100 E (Plate 1).

Although occasional scheelite occurrences have been observed in the light skarn assemblage, the bulk of the scheelite in the Ragged Top area is disseminated in the dark colored garnet-diopside skarn.
Scheelite crystallized contemporaneously with the minerals of this assemblage and continued to crystallize after the other minerals were formed. One clear example of scheelite replacing a zoned garnet crystal was observed. Quartz and calcite associated with the regressive stage of contact metamorphism crystallized later than at least a part of the scheelite. Molybdenum-bearing scheelite and pure scheelite occur in the dark skarn just to the west of the Ragged Top Mine. The co-mingling of these two types of scheelite in the same rock indicates a high probability that scheelite crystallized from more than one pulse of mineralizing fluid.

Based on the surface examination conducted for this investigation, the most likely place to find an exploitable concentration of tungsten is in the dark skarn 150 meters west of the western shaft at the Ragged Top Mine. The possibility of a large tonnage of dark colored skarn exists at this place and the concentration of scheelite appears consistent in the surface exposures in the immediate area. The indication of at least two pulses of mineralization is also a favorable feature of this area.

The next step in an evaluation of the ore potential of this area would have to be the procurement of subsurface information as well as quantitative data regarding tungsten concentrations. Trenching would be valuable in places where pediment veneer has covered possible intrusive-carbonate contacts. One likely place for this work would be between the Ragged Top Mine and the shaft 1.5 kilometers to the northeast. Drilling would obviously be needed to test the depth of the dark skarn and to determine the concentration of tungsten. This work
would be most valuable in the immediate area of the Ragged Top Mine. Possibilities exist for ore deposits at depth wherever the carbonate beds strike the intrusion at a high angle. All five cross sections on Plate 2 illustrate possible skarn configurations at depth.
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