1970

Geology of Redwood Valley California

Paul David Hecht

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GEOLOGY OF REDWOOD VALLEY, CALIFORNIA

By

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B.S., City College of New York, 1963

Presented in partial fulfillment of the requirements for the degree of

Master of Science

UNIVERSITY OF MONTANA

1970

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ACKNOWLEDGMENTS

The author expresses his gratitude and appreciation to:

The Corps of Engineers in general, and, specifically, to the South Pacific Division Laboratory for the use of its laboratory;

To Mr. George Graham, chief geologist of the Division Laboratory, for his many valuable suggestions and opinions, particularly on the petrography of the rocks;

To Mr. Raymond Newman for the photography;

To Mr. Ronald Gelnett, chief geologist of the San Francisco District, for his valuable suggestions;

To the University of Montana and Dr. Fred Honkala for their cooperation in setting up the program;

To Dr. Donald Hyndman, thesis advisor, for his many valuable ideas, suggestions, encouragement and guidance;

Finally, I express my deepest gratitude to my wife, Hellen, for her constant encouragement and assistance, and for typing the drafts and final copy of the thesis. This thesis is dedicated to her.
CHAPTER 1

INTRODUCTION

I. LOCATION

Redwood Valley is in the north-central section of the Coast Range of California. It is approximately 120 miles north of San Francisco and 12 miles north of Ukiah. The headwaters of the Russian River are 13 miles north of the valley. The Russian River flows through Redwood Valley and downstream becomes one of the principal rivers of the Northern Coast Range. Figure 1 shows the location of Redwood Valley and the Franciscan Formation.

II. ACCESS

The only major highway in the vicinity of the thesis area is U.S. Route 101. A paved secondary road runs north from Ukiah into Redwood Valley. There are numerous logging and ranch roads, but most of them are in poor condition.

III. PREVIOUS WORK

The earliest studies of the Franciscan began about 1850, and from that time to 1890 concentrated on the metamorphic and supposed metamorphic rocks of the Franciscan. Some early writers, Whitney (1865) and Becker (1885), believed most of the non-sedimentary rocks, including the
FIGURE 1. General geology of Northern Coast Ranges showing the location of Redwood Valley. Modified from Rice (1961).
volcanics and serpentine, were metamorphic in origin. The Franciscan was considered no older than early Cretaceous, and metamorphism occurred at the end of this stage. Andrew Lawson (1893) named the Franciscan Series rocks and published the San Francisco Folio (1914) containing the first detailed geologic maps of the Franciscan. His ideas included a definite sequence of five formations, shallow water deposition for most of the rocks and an unconformity with overlying Knoxville beds of Cretaceous age. Elmer Davis (1918) described the cherts and sandstones, concluding that the cherts were volcanic in origin and the sandstones non-marine fluvial in origin. Nicholas Taliferro (1943) suggested that the Franciscan was deposited after deformation of the Galice formation of Oregon and was pre-Knoxville. He divided the Franciscan into four stages of development: deposition of sandstone with little volcanism in stages 1 and 4, and increased volcanism in stages 2 and 3, with accompanying metamorphism.

Walter Irwin (1960), from 1953 to 1957, mapped an approximately 19,000 square-mile area of Northwestern California, including Redwood Valley. The reconnaissance mapping was done on 15-minute quadrangles and then compiled on a base map of one inch equals four miles. Approximately ten days were spent mapping each quadrangle.

The Franciscan rocks, theories on their origin, and their age relationships to bounding rocks and the general
structure of the Coast Range in which they are located have been summarized comprehensively by Bailey, Irwin and Jones (1964). Special emphasis was placed on new information gained by additional field checking, mapping and laboratory studies.

The only detailed mapping done near the thesis area was of four manganese mines which are located from three-fourths to one mile east of the area (Trask, 1952).

IV. PRESENT STUDY

The present study was done under a program set up by the Corps of Army Engineers to aid graduate students by giving them research projects of value to the Corps and acceptable as thesis projects to the student's graduate school.

Redwood Valley was chosen for the thesis because it was to be studied as a possible site for flood control and water storage dam and contained interesting rock types (glaucophane schist, for instance) and structure.

Field work began in June 1967 and consisted of approximately four months in the field, done in increments of one to two weeks and on weekends. Mapping was done on a Corps of Engineers map on the scale of one inch equals 1,000 feet. The area is bounded on the west by Highway 101 and covers about 20 square miles. An additional 10 square miles was mapped outside the thesis area to check continuity of rock
types and structure. The 7½-minute Redwood Valley Quadrangle and a blowup of areal photographs aided this mapping.

Most of the mapping was done on foot, but a four-wheel-drive vehicle was used during the later phase of the mapping. The numerous old logging roads and streams provided the best exposures of the rocks. Outcrops on the hillsides are few and generally widely spaced. A total of over 250 samples were taken from the field and studied in the laboratory. The laboratory work emphasized mineral identification, including detailed petrographic examination of thin sections of 35 specially chosen samples. All rocks were cut and studied by binocular microscope and by X-ray. When difficulty arose in mineral identification, rock samples were crushed and individual grains were studied in index oils. The universal stage and X-ray analysis of mineral separates were also used in cases of difficulty in identification. X-ray diffraction samples were prepared by taking a sample from the rock (or vein) under study and crushing and grinding it until the entire sample passed through a 325-mesh screen. The sample was then split and a portion packed into a sample holder. X-ray data was compared with ASTM cards for mineral identification.
CHAPTER 2

PHYSIOGRAPHY

The Northern Coast Ranges extend north from San Francisco to the Oregon border. They consist "dominantly of northwest-trending ridges that are approximately parallel to the structural and lithic grain of the area." (Irwin, 1960) Crest elevations vary from 2,000 to 6,000 feet, decreasing towards the coast.

"The drainage pattern is trellis, and although the major streams are chiefly parallel to the structural and lithic grain of the area, in some places they are markedly transverse. The principal rivers drain northwestward. An exception is the Russian River which flows southeastward toward San Francisco Bay for most of its length, but near Healdsburg it deviates sharply and flows southwestward, cutting across the grain of the Coast Ranges to discharge into the Pacific Ocean." (Irwin, 1960, p. 13)

The Ukiah Valley is one of the small intermountain valleys filled with large quantities of continental sediments of Quaternary age that are present in the central northern Coast Ranges. It starts at Redwood Valley, extends south for 17 miles, and is 4 miles wide. East of Calpella, erosion has exposed 400 feet of these Quaternary deposits.

Locally, numerous landslides are present. The largest one is just east of Highway 101 and extends over most of the western edge of the thesis area. This slide is thought
to be controlled by the large fault near the head of the slide. Highway 101 is continually being repaired because of movement of the slide. The other smaller slides in the area are shallow slumps resulting from the steepness of the slopes, the depth of weathering, and the heavy rainfall during the winter. Springs are plentiful and appear to be located along faults, fracture zones, or the glaucophane schist-sandstone contacts.
FIGURE 2. West slope of Laughlin Range. Notch is trace of major fault. Hummocky nature is indicative of the large landslide present. A large block of graywacke is exposed along the railroad tracks.

FIGURE 3. View south from Laughlin Range to Ukiah Valley. In background light area is Lake Mendocino. Trace of major fault is in the lower right corner.
CHAPTER 3

MINERAL DEPOSITS

One mile to the east of the thesis area and aligned almost parallel to it are the four separate mines described by Trask (1952). These mines produced 5,500 tons of manganese ore in the early 1900's, but have been dormant since 1920. The manganese deposits are typical of those found throughout the Coast Ranges in that the ore is in chert bodies in a metamorphosed Franciscan sequence of rocks. The ore bodies consisted of lense-shaped concentrations of rhodochrosite and hydrous manganese silicate (neotocite and bementite) in lense-shaped bodies of red chert. These chert bodies are generally bordered on the west by graywacke and on the east by altered basalt.
The rocks of the Northern Coast Ranges have been complexly folded and faulted. The interpretation of these complex structures is made extremely difficult by the homogeneous nature of the Franciscan rocks in which they occur. Only the larger structures, which include non-Franciscan rocks, have been mapped in any detail. The three major structures closest to the thesis area are the San Andreas Fault to the west, a possible en echelon extension of the Hayward Fault in the area, and the Diablo antiform of Bailey (1964, p. 150) to the east.

The general trend of faults and folds in the Northern Coast Ranges is to the northwest. The folds are broad, with some steep folds and local overturning. Ghent (1964) states there is strong indication of major overturning in his thesis area, which is in the north half of the Northern Coast Range. The Diablo antiform, as shown by Bailey, is a broadly folded arch of over 300 miles in length. The arch is cut by numerous broad en echelon folds which trend southeast and plunge gently to the east. One of these en echelon folds has been mapped in detail, 35 miles southeast of the thesis area (Bailey, 1964).
The San Andreas Fault is approximately 50 miles to the west of the thesis area. It is a right lateral strike slip fault with possible displacement along the fault of 350 miles or more (T. W. Dibblee, Jr., 1966). The Hayward Fault has also shown right lateral strike slip movement. It diverges eastward from the San Andreas Fault about 250 miles south of the thesis area and trends parallel to the San Andreas. Its known extent is to just north of Berkeley, California, "but it may continue as either a single fault or a series of en echelon faults." (Bailey, p. 154, op.cit.) The major fault in the western portion of the thesis area could be such an en echelon fault. The topographic expression of this fault can be traced for 40 miles, and it joins the fault north of Willits, shown on the Ukiah sheet of the Geologic Map of California.

The presence of major thrust and reverse faulting in the Franciscan is still in doubt. Papers by Romey (1962), Brown (1963), Irwin (1964), Holdaway (1963), and Davis, Holdaway, Lipman and Romey (1965) describe the pre-Franciscan thrust and reverse faulting present in the Klamath Mountains of California. McWitt (1961) has mapped small local post-Franciscan thrust faults. Ghent (1964) states the "inversion of the entire sequence by thrusting and/or recumbent folding is not without difficulties but this hypothesis best explains the observed relationships. . . . recumbent folding and thrusting are not strongly reflected in small scale structures."
The regional structural history is difficult to decipher because of the complexities discussed above, but a general sequence of events can be suggested as follows (Rice, 1961): The buried Franciscan rocks were uplifted during the late Cretaceous, with accompanying folding and faulting which created the northwest structural trend. The uplifted rocks were subjected to erosion until the late Miocene, at which time orogenic forces created the Coast Range parallel to the previously created trend. The last major tectonic event occurring in this region was the late Pliocene-Early Pleistocene warping and faulting. This tectonic activity created small basins such as the Ukiah Valley, Potter Valley and Round Valley. Since this time there has been variable amounts of uplift. Some terraces have been raised hundreds of feet, while others only tens of feet.

II. LOCAL

Folds

The strike and dip of the beds within the thesis area is fairly consistent and is generally N 10-30° W and 20-80° NE. Minor local variations are present and will be discussed in another section. The ridge which separates Redwood Valley from Potter Valley to the east, the lower western portion of which forms the eastern boundary of the thesis area, will be referred to in this report as Thomas Mountain (Figure 4). Figure 5 shows a cross-section perpendicular to the strike
of Thomas Mountain. The change of direction of dip from east to west would suggest either that this ridge is synclinal in structure or the two sides are separated by fault. The presence of the large volcanic body makes tracing of a change in dip direction impossible. If the structure is synclinal, the axis is somewhere along the eastern slope and probably trends and plunges to the northwest.

The only small scale folding observed in the thesis area is near the crest of Laughlin Range in Section 23. This folding occurs in a glaucophane-schist body and is shown in Figure 6. The structure appears to be a syncline which has been folded. The trend of the initial axis of the syncline was probably N 20° W. It was then refolded along an axis which probably trended N 40° E. A single outcrop of glaucophane schist which lies approximately 400 feet to the southwest of the main folded area shows a monoclinal fold (Figure 7). This fold has an axis that trends N 25° E, which suggests that it was formed during the second phase of folding.

A portion of Thomas Mountain extending south from the thesis area was mapped to trace the continuity of the structure. The area has extreme variation in strike and dip. The strike directions vary from N 50° W to N 85° E, and the dips from 10° to 80°. Three small anticlines were seen in outcrop and the strike of the axial planes varied from N 10° W to N 50° W. The above variations could possibly
FIGURE 4. West slope of Thomas Mountain, taken from Laughlin Range.
FIGURE 5. Geologic cross-section of Thomas Mountain. All rocks are part of the Franciscan Formation. No interpretation is given. Vertical exaggeration, 3X.
FIGURE 6. Map of strikes and dips of schist body on top of Laughlin Range.

FIGURE 7. Fold in glaucophane schist. Location plotted on Figure 6.
suggest superimposed fold sets. An alternative explanation is prelithification submarine slumping and sliding. This latter alternative is mentioned by numerous authors to explain the great variations in strike and dip found throughout the Franciscan terrains.

The possibility of isoclinal folding of the rocks present in the area is suggested by some schist which exhibits such folding microscopically and by reverse repetitions of distinctive sequence of units. However, there is no other field evidence of this type of folding, and the only suggestion that it has occurred is the possibility of recumbent folding noted by Ghent (1964).

**Faults**

The fault in the western portion of the thesis area trends N 45° W and extends over four and one-half miles of the area (Figure 1). It can be traced topographically for at least 40 miles and is represented in the thesis area by a shear zone which is about 1,000 feet wide (Figure 8). Present in the zone are highly sheared graywackes, basalts, schists, and one large block of serpentine. The serpentine has striations parallel to the trend of the fault. The sheared zone is extremely soft so that its trace is quite obvious from the topographic relief of the area. Large, active landslides lie just above and below the fault and many springs occur in the shear zone. The presence of the fault is also shown by the truncation of a large body of
FIGURE 8. South slope of Laughlin Range. Notch to left is trace of major fault. Notch to right is shear zone. Hummocky topography is large landslide.

FIGURE 9. Pillow basalt in abandoned quarry. Pillows are from 3 to 6 feet in diameter.
pillow basalts which lies just beyond the northwest corner of the thesis area (Figure 9).

The combination of the possible relationship of this fault with the Hayward Fault, the general nature of large faults in the region, and the orientation of the striations in the serpentine suggests a probable right lateral movement along the fault.

FIGURE 10. East slope of Laughlin Range from Redwood Valley. Notch at top is shear zone.

Present on the eastern slope of Laughlin Range (Figure 10) are two fracture zones that trend N 15° W. The upper zone is just below the crest of the ridge and is topographically visible to some extent. This zone can be traced for about four miles and contains numerous springs. The lower zone contains crushed sandstone and shale outcrops. This is
visible in Rock Creek, Mariposa Creek, and in the smaller stream beds between them, along a distance of one mile. The topographic expression of this zone extends one mile farther to the north and south, for a total extent of three miles. The orientation of these two zones is parallel to the general trend of fold axes in the Coast Ranges.

Three strike-slip cross-faults are present in the eastern portion of the thesis area. The northernmost fault strikes N 35° E and is apparently vertical. It can be traced across the entire thesis area and through two distinct saddles in Laughlin Range. This cross-fault truncates belts of chert and schist in the eastern portion of the area and two schist zones and a chert zone on the eastern slope of Laughlin Ridge. The movement of this northern fault cannot be deciphered from the surrounding geology. Its angle of intersection with the large western right lateral strike-slip fault is approximately 75°. A block of schist just north of this cross-fault is partially sheared and broken into randomly oriented blocks and fragments. This schist block was probably either pushed up from below or dragged along the fault to its present location.

The two cross-faults to the south strike N 45° E. The middle fault shows a right lateral displacement of the schist-sandstone chert sequence of approximately 1600 feet. The other shows a probable left lateral displacement of 3200 feet. The extension on the south fault truncates the two schist zones on the eastern slope of Laughlin Range.
The previously mentioned map of the Thomas Mine shows a vertical left lateral strike-slip fault striking N 75° E, with a displacement of approximately 300 feet.

**Age Relationships of Faults, Shear Zones and Folds**

The angular relationship between the western major right lateral strike-slip fault and the cross-faults and the left-hand character of the southern cross-fault (Figure 11) suggest that they were possibly formed by the north-south compressive force discussed by Billings (1954, pp. 221 and 222):

"Some geologists believe that the rifts of California are shear fractures formed by compressive forces acting in a north-south direction. Under such forces, if the easiest relief were east-west, two sets of vertical shear fractures would form, one set striking about N 30° E, the other about N 30° W. The former would be left-handed, the latter right-handed. . . . The folds, which trend northwest, imply compressive forces acting along northeast-southwest lines."

![Diagram](image)

**FIGURE 11.** General orientation and possible movements along the faults and shear zones.
The two major fracture zones on Laughlin Range appear, because of their orientation, to be related to the folding. The lower (eastern) one crosses the northern cross-fault with no displacement. This would seem to indicate that either the faulting preceded the folding or they were contemporaneous.
CHAPTER 5

PETROGRAPHY

The Franciscan Formation in general consists of a heterogenous assemblage of eugeosynclinal rocks. This assemblage has a known area of outcrop of 15,000 square miles, most of which is in the Coast Ranges. Its thickness is estimated, according to Bailey, to be greater than 50,000 feet. The major rock types are graywacke with shale, altered volcanic rock (greenstone), chert, minor limestone, and metamorphic rocks of the zeolite, glaucophane schist and eclogite facies. Younger ultramafic rocks, mainly serpentinites, have intruded much of the Franciscan, and therefore are not considered part of the formation. The description of the rocks studied in detail is in Table II of the Appendix.

I. GRAYWACKE, CONGLOMERATE AND SHALE

Graywacke

The term graywacke, for the purpose of this paper, is the equivalent of Gilbert's (Williams, Turner and Gilbert, 1959) wacke.

The graywackes generally contain angular to sub-angular grains of quartz and sodic-plagioclase with lithic fragments of greenstone, chert, shale or schist. Most have more than
ten percent matrix of chlorite and mica. Potassium feldspar is almost totally lacking. This fact is used to differentiate the Franciscan graywacke from that of the Coastal Belt to the west and Sacramento Valley sequence to the east. Bedding is quite irregular, and current features and graded bedding are rare. The unsorted nature of the graywacke and its lack of potassium feldspars indicate a rapid deposition from a terrain similar to the Franciscan. Such a source area could have been the older Paleozoic and Triassic rocks which are now present in Western Oregon. "The western Paleozoic and Triassic belt includes mildly metamorphosed shale, sandstones, cherts, greenstones and limestones." (Irwin, 1960)

Graywacke is the dominate rock type present in the thesis area. It outcrops along most of the creeks, streams, and along almost the entire length of the Russian River in the thesis area. One mile north of this area the river cuts through a narrow canyon composed entirely of graywacke.

The bedding in the graywacke is defined as the distance between interbeds or shale partings. It is quite irregular in the thesis area, and even in the same exposure. The beds range in thickness from one inch to 20 feet, but are most commonly about two feet. The shale interbeds range from thin partings to four feet in thickness.

The graywacke in the river and creek bottoms is generally fresh and light-to-medium gray in color, varying from tanish gray to light tan with the increase in weathering.
It is moderately to severely weathered on the upper half of Laughlin Range. (Figure 12)

![Figure 12. Graywacke outcrop near top of Laughlin Range: more massive in background, closely fractured in foreground. Dark bed is shaley graywacke.](image)

The graywacke is generally poorly sorted, with grains varying from pebble to silt size. Variation in grain size in a bed is generally 1/4 mm. to 2 mm. The individual grains are angular to sub-angular with some sub-rounded rock fragments.

Quartz grains comprise from 25 to 35 percent of the different graywacke outcrops, with an average of about 30 percent. These grains are clear and some contain minute bubbles. Many show undulose extinction and a few are composite grains.

Feldspar, considered only as mono-mineralic grains, makes up from 20 to 50 percent of the graywackes and averages
approximately 30 percent. K-feldspar was not found either microscopically or by staining (Bailey and Stevens, 1960). Albite is by far the most abundant feldspar, with some oligoclase. Albite or simple twinning is present in some grains. The grains vary from fresh to severely altered, the majority showing some incipient alteration, thereby hindering any attempt to get accurate An values.

Rock fragments constitute from 15 to 40 percent of the graywackes, with an average of 25 percent. The two most common clasts are altered, fine-grained, mafic volcanic rock and chert. The volcanic rocks are predominantly basalts with some glass. The chert is generally fine-grained quartz; a few grains show the radiating structure of chalcedony and a few others contain radiolaria. Metamorphic and sedimentary rock fragments are also present in all the samples studied microscopically. The metamorphic rocks are quartz-mica schist and the sedimentary rocks are shales.

The matrix of the graywacke makes up from 5 to 20 percent of the rock and averages 15 percent. The matrix in some samples fills the large interstices between grains, while in others it is just a thin film coating the grains. The matrix, which is generally also the cement, is very fine-grained and appears to be chloritic or sericitic.

Bailey, Irwin and Jones (1964) conducted a study to determine the reason for the great variation in specific gravity of Franciscan graywackes. "The results of this
work... indicate the conversion of albite to jadeite is the cause of the high specific gravity and that any Franciscan graywacke with a specific gravity of more than 2.71 probably is jadeitized." (Page 92) Specific gravity of graywackes in the thesis area varies from 2.72 to 2.74. This would, therefore, suggest they are jadeitized. The presence of veins containing aragonite in one graywacke outcrop also indicates some metamorphism of the graywacke.

**Conglomerate**

Only two outcrops of conglomerate have been found in the area. One has the same basic composition as the graywacke except the rock fragments are predominantly 3 mm. across. The other is a volcanic breccia composed almost entirely of 3 mm. angular volcanic rock particles with some chert and a minor percentage of quartz and feldspar grains. The mapped areal extent of these conglomerates is extremely small.

**Shale**

The shale and siltstone are seen in outcrop only as isolated thin beds in the graywacke or chert, but shale comprised over 100 feet of the 500 feet of rock cored along the axis of the proposed dam. The shales and siltstones interbedded with the graywacke have basically the same mineralogy and texture as the graywacke, but have smaller grains. They could be classified as micrograywacke. Those
interbedded with chert are red, contain more clay, and commonly are partially silicified.

II. CHERT

The chert present in the thesis area occurs in two distinct forms: ribbon chert interbedded with shale and massive chert. Both are varicolored, fine-grained and highly siliceous. The ribbon chert consists of one-inch to three-foot thick beds with very thin shale partings. These beds are lenticular and difficult to trace for any distance. They are composed of fine-grained quartz with some silicified radiolaria. The massive chert contains little or no radiolaria and no shale partings.

The large chert body in the Laughlin Range is massive, with beds up to 20 feet thick. This chert is brecciated with numerous veins of coarse-grained quartz filling the space between chert fragments. Some of this chert shows the radiating fan structure of chalcedony. The chert and the altered volcanic rocks appear to be spatially associated. This association could be a genetic one, with the chert lenses formed as gelatinous precipitates from silica-enriched water. At a temperature of 350° C. (the temperature at the contact of basaltic magma and deep sea water), and a depth of 13,000 feet below sea level, 1,000 ppm. of silica can be dissolved in the water. This silica would precipitate out upon cooling (Bailey, et al, 1964).
III. ALTERED VOLCANIC ROCKS (GREENSTONE)

The altered mafic volcanic rocks of the Franciscan consist primarily of pillow lavas, tuffs or breccias. The predominant minerals are plagioclase and augite. Volcanic deposits range in thickness from a few feet to over 7,000 feet and cover an area from a few hundred square feet to 20 square miles. These extensive meta-volcanics were probably submarine in origin. According to Bailey (1964), the average Franciscan magma is much like a normal tholeiitic magma but has a soda content intermediate between spilite and tholeiite. The cores of some pillows are rich enough in soda to be regarded as spilite under a chemical definition, but the rim and matrix are not.

The meta-volcanic rocks comprise about ten percent of the thesis area. They outcrop principally along a belt on the eastern slope of Laughlin Range. A very large block and numerous smaller boulders occur as tectonic fragments in the massive slide on the western slope of Laughlin Range. There is an excellent exposure of pillow structure in an abandoned quarry just west of the northwestern corner of the thesis area. This quarry can be seen from U.S. Highway 101 and contains well-developed pillows from three to six feet in diameter.

The outcrops of meta-volcanic rock within the thesis area show no pillow or flow structure. The rocks are generally massive and fine-grained, and usually green in
color. Their fine-grained texture makes a specific field identification almost impossible; therefore, the term greenstone has come into use for all fine-grained, greenish Franciscan rocks which appear to be volcanic in origin. The author believes that this use of the term creates confusion and makes some mapping erroneous. Some rocks have been classified greenstone, which, when later studied by the author in thin sections, proved to be members of the blueschist facies containing actinolite or some other green mineral.

The meta-volcanic rocks in the thesis area vary from diabases to basalts. They are generally aphanitic, but a few contain albite phenocrysts up to 3 mm. in size. They are all altered, so that none show both their original texture and composition. One outcrop does contain relict augite; another shows the original amygdaloidal texture and the rest of the rock was recrystallized to a mat of radiating albite crystals. The alteration could in general be classified as albitization, because almost all these rocks contain an abundance of secondary albite laths, ranging in size from very fine-grained to 3 mm. Rock from another outcrop does show some of the original diabasic texture, but the rock is now composed of large albite laths in a matrix of smaller albite laths and pumpellyite. Chlorite is commonly present in the altered volcanics.
IV. METAMORPHIC ROCKS

Metamorphic rocks constitute only a minor portion of the Franciscan. They can be divided into three facies: zeolite, blueschist (glaucophane) and eclogite. The zeolite facies is defined on the basis of zeolite minerals replacing, and filling fractures or vesicles in, the Franciscan rocks. The most common zeolite mineral found is laumontite. The blueschist facies includes (according to Bailey, 1964) vast areas of jadeitized metagraywacke and local areas of glaucophane-bearing rocks. The glaucophane rocks occur either as large areas of regionally metamorphosed rock, small areas with apparently gradational boundaries, or large, rounded tectonic blocks in unmetamorphosed rock or shear zones. The principal minerals are glaucophane and lawsonite.

The metamorphic rocks in the thesis area are easily weathered and form hummocky areas with the schist outcropping as blocks. The main outcrops are along lower western slopes of Thomas Mountain and the eastern slope and crest of the Laughlin Range. The schist in general exhibits schistosity in outcrop but some is quite massive. The almost continuous series of outcrops in the eastern portion of the map offered the best, in fact, the only opportunity for detailed study of the schist.

The mineral assemblages present contained many minerals unique to the blueschist facies. These minerals and the others present were studied in some detail, using microscopic
determination of their optical properties and X-ray analysis for comparison with the standard ASTM cards. The minerals studied are: actinolite, albite, chlorite, clinozoisite, glaucophane, jadeite, lawsonite, muscovite, pumpellyite, stilpnomelane, and zoisite. Their detailed description is in Table I in the appendix.

The determination of the mineral assemblages of the schists was generally done with the microscope; however, due to the large number of samples studied, some were determined solely on the basis of X-ray diffraction. The volcanic rocks described in the previous section were so classified because they contained some remnants of their character, but they are all metamorphosed to some extent. These rocks are therefore also considered among the metamorphic rock types. The quartz-bearing metamorphic assemblages present in the thesis area are (Figure 13):

- quartz, muscovite, albite
- quartz, chlorite, albite
- quartz, chlorite, albite, pumpellyite
- quartz, chlorite, albite, pumpellyite, glaucophane, actinolite
- quartz, chlorite, lawsonite
- quartz, chlorite, zoisite, actinolite
- quartz, stilpnomelane, glaucophane
The quartz-free metamorphic assemblages are (Figure 14):

- glaucophane, lawsonite, zoisite
- glaucophane, lawsonite, clinozoisite, chlorite
- glaucophane, albite, clinozoisite, chlorite, pumpellyite
- glaucophane, muscovite, zoisite, chlorite, pumpellyite
- glaucophane, muscovite, actinolite, chlorite
- chlorite, albite, lawsonite
- chlorite, albite, pumpellyite
- chlorite, lawsonite, muscovite, zoisite, pumpellyite
- chlorite, lawsonite, zoisite, actinolite
- chlorite, jadeite

The description of the thin sections containing these assemblages is in the appendix.

The occurrence of coarse-grained monomineralic veins in the metamorphic rocks is quite common. The usual minerals occurring individually in veins are quartz, calcite, glaucophane and albite. One vein consists of quartz, muscovite and glaucophane. The composition of the veins in the case of albite and glaucophane seem to be related to the composition of the rock, as these two minerals are present as veins only in rocks in which they are also present. One case was noted in which a glaucophane crystal from the rock cuts across a glaucophane vein.

The texture of the schists appears to be related to either grain size or the percentage of mica present. The coarser grained schists are generally schistose, while
ones with almost identical composition, but which are fine-grained, are massive. All the schists containing relatively large percentages of chlorite or muscovite are also schistose.
CHAPTER 6

PETROGENESIS

The origin of the schist bodies must account for two facts: The schist belt is linear in the eastern portion of the thesis area, and the sequence of this belt from west to east is: (1) graywacke rich in chlorite and possibly jadeitized; (2) schistose graywacke with pumpellyite; (3) quartz, chlorite, albite, pumpellyite, glaucophane, actinolite schist; (4) chlorite, lawsonite, zoisite, actinolite schist; (5) chlorite, lawsonite, muscovite, zoisite, pumpellyite schist; (6) glaucophane, chlorite, muscovite, zoisite, pumpellyite schist; (7) chloritic graywacke with aragonite; (8) glaucophane, chlorite, albite, clinozoisite, pumpellyite schist; (9) quartz, stilpnomelane, glaucophane schist; and (10) chlorite-rich graywacke. All the schists present are members of Turner's (1967) glaucophane-schist facies or Ernst's blueschist facies.

I. LINEARITY

There are three possible explanations for the linearity of schist belts. The first is the metamorphism of a normal bedded sequence, retaining the linearity of the beds. The second is increasing the grade of metamorphism along a parallel front. These two will be discussed later under the heading of SEQUENCE.
The third explanation is linearity due to stress.

Bailey (1964) states:

"The occurrence of glaucophane-bearing blue-schist in belts that parallel the prevalent direction of shearing suggest even a small increase in stress may have been operative in triggering the metamorphism of rocks already under high lithostatic pressure."

Coleman (1961) agrees that "in areas where rock strengths have sustained a lateral compression without failing by shear, high pressure-low temperature assemblages may have formed." Irwin and Coleman (1967) mapped a glaucophane schist body along the late Cretaceous thrust fault on the eastern edge of the Coast Range, and state:

"The blueschist probably formed in a zone of cataclasis and abnormally high water pressure under the thrust fault rather than in the generally postulated zone of extreme depth of burial."

Ernst (1961) also noted the possible importance of stress in decreasing the depth at which glaucophane schist will form. He states that the increased lithostatic stress caused by a large differential stress could mean a reduction to 20 km. in the depth of formation of high-pressure schist phases.

II. SEQUENCE

The origin of glaucophane-schist facies rocks has been a subject of controversy since 1878. The two major theories are (1) formation by chemical solutions from an intrusive ultramafic magma, and (2) formation during the early stages of orogeny in a geosyncline.
The formation of glaucophane schist by introduction of chemical solutions from an ultramafic magma is considered unreasonable for this area for two reasons: The first is the absence of an outcrop of the ultramafic source of the chemical solutions. The second is that according to data from Bailey, Irwin and Jones (1964), there is no need for the introduction of chemical solutions as the bulk chemistry of the schists is that of normal Franciscan rocks (Table 1). Turner (1967, page 294) states:

"There are large areas (many square kilometers) of jadeite metagraywackes, in some cases associated with coarsely crystalline glaucophane schists, that are virtually devoid of serpentinite. Here we see products of localized but still 'regional' metamorphism, unrelated to ultramafic intrusions."

There is general agreement that glaucophane schist will form in a high pressure-low temperature environment. A pressure temperature diagram by Bailey (1964) shows the relationship of pressure and temperature on minerals associated with the glaucophane facies (Figure 15).

Seki (1961) uses a P-T diagram to illustrate the regional metamorphic facies (see Figure 16). The sequence of rock types listed earlier can be explained by using this diagram. The parent rock could remain at the same elevated pressure and then increases and decreases in temperature would develop the rocks present in the sequence described above on page 25. An increase in temperatures to the east would develop (1) the chloritic rock present; then (2) the
FIGURE 15. Mineral transition of typical glaucophane-schist facies minerals, with relation to pressure and temperature. (Bailey, 1964, page 110.)
# TABLE 1

<table>
<thead>
<tr>
<th>Oxide</th>
<th>Average of 14 Gray-wackes</th>
<th>Average of 16 slightly altered Volcanics</th>
<th>Average of 3 Glaucophane Schists with quartz present</th>
<th>Average of 6 Glaucophane Schists with no Quartz present</th>
</tr>
</thead>
<tbody>
<tr>
<td>Si O₂</td>
<td>68.4</td>
<td>49.1</td>
<td>71.8</td>
<td>49.3</td>
</tr>
<tr>
<td>Ti O₂</td>
<td>.5</td>
<td>2.0</td>
<td>.4</td>
<td>1.9</td>
</tr>
<tr>
<td>Al₂ O₃</td>
<td>13.6</td>
<td>13.8</td>
<td>11.1</td>
<td>13.4</td>
</tr>
<tr>
<td>Fe₂ O₃</td>
<td>1.2</td>
<td>3.9</td>
<td>.8</td>
<td>2.0</td>
</tr>
<tr>
<td>Fe O</td>
<td>2.9</td>
<td>7.7</td>
<td>9.3</td>
<td>9.5</td>
</tr>
<tr>
<td>Mn O</td>
<td>.1</td>
<td>.2</td>
<td>--</td>
<td>.2</td>
</tr>
<tr>
<td>Mg O</td>
<td>2.2</td>
<td>6.1</td>
<td>2.9</td>
<td>7.1</td>
</tr>
<tr>
<td>Ca O</td>
<td>2.5</td>
<td>9.4</td>
<td>3.4</td>
<td>9.2</td>
</tr>
<tr>
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<td>3.9</td>
<td>3.0</td>
</tr>
<tr>
<td>K₂ O</td>
<td>1.6</td>
<td>.4</td>
<td>.5</td>
<td>.5</td>
</tr>
<tr>
<td>H₂ O</td>
<td>2.9</td>
<td>3.2</td>
<td>2.2</td>
<td>3.9</td>
</tr>
<tr>
<td>C O₂</td>
<td>.4</td>
<td>.8</td>
<td>.1</td>
<td>--</td>
</tr>
<tr>
<td>P₂ O₅</td>
<td>.1</td>
<td>.2</td>
<td>--</td>
<td>.2</td>
</tr>
<tr>
<td>TOTAL</td>
<td>100.1</td>
<td>99.7</td>
<td>100.8</td>
<td>100.2</td>
</tr>
</tbody>
</table>

chlorite-pumpellyite rock; and then (3) blueschist facies schist. The difficulty of this explanation is that the schist belts are quite narrow for the temperature increases needed and the source of this heat is not apparent. Also, the radical difference in total composition of the adjacent units would require a very large metasomatic introduction of several elements.

Turner (1960) derives the different schists of the glaucophane (blueschist) facies from rocks of different initial composition. His general breakdown is:

1. Quartz-Feldspathic (parent rock is graywacke)
   a. Quartz, muscovite, glaucophane schist
   b. Quartz, lawsonite, glaucophane schist

2. Basic (parent rock is basic volcanic)
   a. Lawsonite, glaucophane schist
   b. Albite, epidote, chlorite, glaucophane schist

FIGURE 16. Pumpellyite-Chlorite Facies
(Siki, 1961)
3. Chert (this is parent rock)
   a. Quartz, stilpnomelane, glaucophane

This appears to be in agreement with Table 1. The origin of the sequence can therefore be explained by the single grade metamorphism of an interbedded sequence of Franciscan rocks. The parent rocks from west to east would be graywacke (1) through (3); volcanic (4) through (6); graywacke (7); volcanic (8); and chert (9). (See page 36.)

Another reason this explanation is preferred is that the varied composition of the original rock types can be seen in some of the schists. The transition from chlorite graywacke to quartz-muscovite schist is fairly clear. The relic texture and grains of some schists, described on pages 30 and 31, indicate volcanic origin, and the glaucophane-stilpnomelane-quartz schist is clearly derived from a chert.

The presence of one schist containing glaucophane in the rock cutting across a secondary glaucophane vein and mineralic veins of glaucophane, albite and actinolite present throughout most of the schist areas does suggest a very mobile fluid phase. Turner (1960, page 544) states:

"Moreover rocks of this facies commonly show conspicuous effects of metamorphic differentiation, notably monomineralic segregation veins of such diverse phases as glaucophane, lawsonite, pumpellyite, jadeite, chlorite, actinolite, and so on. We conclude that the fluid phase is unusually mobile and active in glaucophane-schist metamorphism. In spite of this there are many rocks of this paragenesis whose compositions do not differ appreciably
from those of the parent basalts, cherts, and graywackes from which they were derived."

This explanation does raise one question: Why were some graywackes, volcanics and cherts metamorphosed to form glauophane-bearing schists and others not. The occurrence of a mildly metamorphosed graywacke containing aragonite suggests the possibility that some of the rocks could have been under high pressure-low temperature conditions and not have formed any of the diagnostic minerals. The reason for this most probably is variation in the initial composition of the rocks. This variability would be from bed to bed. (Table 2.)

The origin of the glauophane schist in the thesis area thus begins with the rapid deep burial of a sequence of graywacke, volcanics and chert of variable composition in an eugeosyncline. Rapid burial would permit a low thermal gradient so higher temperature facies do not form.
### TABLE 2

**VARIATIONS IN COMPOSITION OF FRANCISCAN GRAYWACKES AND VOLCANIC ROCKS**

<table>
<thead>
<tr>
<th>Oxide</th>
<th>Graywacke</th>
<th></th>
<th></th>
<th></th>
<th>Volcanic Rock</th>
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<tbody>
<tr>
<td></td>
<td>Minimum</td>
<td>Maximum</td>
<td>Minimum</td>
<td>Maximum</td>
<td></td>
<td>Minimum</td>
<td>Maximum</td>
<td></td>
</tr>
<tr>
<td>Si O₂</td>
<td>58.4</td>
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<td>43.8</td>
<td>52.9</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Ti O₂</td>
<td>.3</td>
<td>1.8</td>
<td>1.1</td>
<td>3.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Al₂ O₃</td>
<td>11.3</td>
<td>16.4</td>
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<tr>
<td>Fe₂ O₃</td>
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<td>2.7</td>
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<td></td>
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<tr>
<td>Mn 0</td>
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<td>--</td>
<td>.3</td>
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<td>Na₂ O</td>
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<tr>
<td>K₂ O</td>
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<tr>
<td>H₂ O</td>
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<td>2.3</td>
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<td></td>
<td></td>
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<tr>
<td>C O₂</td>
<td>--</td>
<td>4.8</td>
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<td>2.5</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P₂ O₃</td>
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<td>.4</td>
<td>.1</td>
<td>.4</td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

CHAPTER 7

SUMMARY

The geology of the Redwood Valley area is that of a complexly faulted typical Franciscan sequence of rocks. There is no strong evidence of large-scale folding, with only small minor folds evident. A major right lateral strike-slip fault is present in the western portion of the area. This northwest-trending fault appears to be part of the Hayward Fault system. The three northeast-trending cross-faults present are possibly related to this fault. They could all have formed during north-south compression. The principal rock types present are graywacke, chert, schist and altered volcanic. The schists are members of the glaucophane schist facies. The typical quartz-bearing assemblages are quartz, muscovite and/or chlorite, albite, lawsonite, zoisite, stilpnomelane, glaucophane and jadeite. The quartz-free assemblages are glaucophane, lawsonite and/or clinzoisite, zoisite, chlorite, muscovite, albite and actinolite. The apparent trend of the schists in the area and their sequence can best be explained by the metamorphism of interbedded graywackes, volcanics and cherts under high-pressure, low-temperature conditions. Their initial composition would vary greatly from bed to bed and among the same rock types. This would explain the areal
distribution and differences in mineralogy and degree of metamorphism of the rock types present.
TABLE I

DESCRIPTION OF MINERALS

**Actinolite**

(-) $2V = $ large, length slow, $\angle Z \leq C \approx 20^\circ$, cleavage $56^\circ$ and $124^\circ$, ASTM X-ray card No. 7-336. It occurs as medium to large individual crystals and small laths in the groundmass. One occurrence shows a gradation from actinolite to glaucophane.

**Albite**

(+ ) $2V \approx 70^\circ$, length slow, indices less than balsam, $An$ is generally 0. ASTM card No. 9-466. Albite occurs in veins, amygdules and as part of the rocks. It occurs as long, narrow radiating laths, short tabular crystals, and small to very small laths in the groundmass.

**Chlorite**

(+ ) $2V = 20^\circ$ to $40^\circ$, length fast, parallel extinction, weak green pleochroism, mostly magnesium variety. It occurs mostly in fine groundmass with some larger grains in veins.
**Clinohumite**

2 V ≈ 70°, length fast, r < v, occasional yellow-green interference color, parallel extinction. It occurs as part of some fine-grained groundmass areas and as individual elongated lathlike crystals.

**Glaucophane**

(-) 2 V = 0° to 50° (average about 45°), length slow, extinction maximum of 5°, cleavage 56° and 124°. X-ray indices vary greatly among different glaucophanes, pleochroism neutral to dark blue. It occurs in different forms: broad tabular, long, narrow laths; long needles; short needles; small laths; and very small laths in the groundmass. It also occurs as vein-filling material. The orientation of the optical axis in relationship to the elongation of the crystal indicates that the mineral is glaucophane and not crossite.

**Jadeite**

(+) 2 V ≈ 70°, length slow, extinction 30° to 35°, ASTM card No. 9-463. It occurs as a mat of anhedral crystals.

**Lawsonite**

(+) 2 V = large, length slow, parallel extinction, crystal minimum angle 68°. ASTM card No. 8-137. It occurs as euhedral, anhedral, and distorted pod-shaped crystals in the rocks and as tabular crystals in veins.
Muscovite

(-) $2V = 35^\circ$ to $40^\circ$, length slow, ASTM card No. 7-42.

It occurs mostly in veins, but occasionally as an isolated euhedral crystal in part of the groundmass.

Pumpellyite

(+) $2V = 40^\circ$, $r < v$, sometimes pleochroic neutral to apple green, ASTM card No. 10-447. It occurs mostly as fine crystals in the groundmass and occasionally as a large grain or in a vein.

Stilpnomelane

(-) $2V = 0^\circ$, pleochroic light to dark yellowish brown, ASTM card No. 2-0036. It occurs only as small, platy crystals in the altered chert.

Zoisite

(+) $2V = 35^\circ$ to $40^\circ$, length slow, some shows anomalous blue color, ASTM card No. 11-665. It occurs both as large tabular to lathlike crystal and as fine crystals in the groundmass. The smaller crystals exhibit the "anomalous" color.
TABLE II

DESCRIPTION OF THIN SECTIONS

<table>
<thead>
<tr>
<th>Specimen</th>
<th>RVT 13</th>
<th>Graywacke</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grains</td>
<td>Quartz</td>
<td>Feldspar</td>
</tr>
<tr>
<td>%</td>
<td>30</td>
<td>24</td>
</tr>
<tr>
<td>Chlorite</td>
<td>8</td>
<td>5</td>
</tr>
<tr>
<td>MRF</td>
<td>18</td>
<td>2</td>
</tr>
<tr>
<td>VRF</td>
<td>2</td>
<td>11</td>
</tr>
<tr>
<td>SRF</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Chert</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Magnetite</td>
<td>.5</td>
<td>.5</td>
</tr>
<tr>
<td>Serpentine</td>
<td></td>
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</tr>
<tr>
<td>Epidote</td>
<td></td>
<td></td>
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</tbody>
</table>

The rock is medium- to fine-grained and poorly sorted with the grains subangular to angular. The chloritic matrix comprises 20% of the specimen; the feldspar is fresh to slightly altered albite; metamorphic rock fragments (MRF) are predominantly quartz, chlorite schists; volcanic rock fragments (VRF) are basalts and diabases; and sedimentary rock fragments (SRF) are fine-grained graywackes and shales.

<table>
<thead>
<tr>
<th>Specimen</th>
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</thead>
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<td>Feldspar</td>
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<td>25</td>
</tr>
<tr>
<td>Chlorite</td>
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<td>MRF</td>
<td>14</td>
<td>13</td>
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<tr>
<td>VRF</td>
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<tr>
<td>Chert</td>
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<td></td>
</tr>
<tr>
<td>Magnetite</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The rock is a fine-grained RVT 13 with secondary veins of quartz and calcite.
Specimen RVT 148 Graywacke (Figure 17)

<table>
<thead>
<tr>
<th>Grains</th>
<th>Quartz</th>
<th>Feldspar</th>
<th>Chlorite</th>
<th>MRF</th>
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</thead>
<tbody>
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<td>29</td>
<td>49</td>
<td>2</td>
<td>3</td>
<td>12</td>
<td>1</td>
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The rock is medium grained, contains only 8% chloritic matrix, and the feldspar is almost entirely altered.

Specimen RV1 122 Altered Graywacke
This rock has the typical graywacke composition except there has been alteration of some of the minerals present. It contains sericite and numerous calcite and quartz veins. There is a small amount of pumpellyite present.

Specimen RV1 124 Schist
The minerals present are chlorite, clinozoisite, albite, pumpellyite and glaucophane. The rock contains medium-grained crystals of albite with some glaucophane in a fine-grained matrix of chlorite, clinozoisite and pumpellyite. The albite generally shows some alteration to sericite and the clear crystals contain a few glaucophane rods.

Specimen RV1 125 Schist
The minerals present are chlorite, glaucophane, zoisite, pumpellyite and muscovite. Medium-size prismatic crystals of glaucophane, zoisite and muscovite are in a very fine-grained matrix of chlorite, glaucophane, zoisite and pumpellyite. The rock contains numerous veins of glaucophane, muscovite and chlorite. Figure 18 shows large acicular glaucophane crystal cutting across a glaucophane vein and into fine-grained rock.
FIGURE 18. RVT 125 with a large glaucophane crystal cutting across a vein of glaucophane and into the fine-grained glaucophane-chlorite zoisite rock.

FIGURE 19. RVT 126 containing pod-shaped crystals of lawsonite in a chlorite matrix with some secondary quartz.
**Specimen RVT 126 Schist**

The minerals present are chlorite, lawsonite, zoisite, pumpellyite and muscovite. The rock is schistose with streaks of chlorite wrapped around pods of lawsonite (Figure 19). Crystals of zoisite and muscovite are present to a minor extent in a groundmass of quartz and chlorite. Secondary quartz is present as veins parallel to the schistosity.

**Specimen RVT 127 Schist**

Principal minerals are glaucophane, zoisite and lawsonite. The zoisite, lawsonite and minor glaucophane occur as large crystals in a matrix of fine glaucophane laths (Figure 20).

**Specimen RVT 132 Altered Graywacke**

The principal minerals are the same as the other graywackes. In addition there is pumpellyite. The rock is a graywacke in which the grains have been distorted and schistosity has developed. Secondary quartz and pumpellyite has been introduced.

**Specimen RVT 133 Schist**

Minerals present are actinolite, zoisite, lawsonite and chlorite. The zoisite and lawsonite occur as large crystals in a matrix of low-iron actinolite laths and magnesium-rich chlorite (Figure 21).
FIGURE 20. RVT 127 with large lawsonite (L) and zoisite (Z) crystals in a matrix of glaucophane laths.

FIGURE 21. RVT 133 with large zoisite (Z) and lawsonite (L) crystals in a matrix of actinolite laths and chlorite.
Specimen RVT 134  Schist
Minerals present are chlorite, albite, actinolite, glaucophane, pumpellyite, quartz and calcite. The rock contains small laths of albite and medium crystals of actinolite and minor pumpellyite in a fine-grained chlorite, albite, glaucophane groundmass. A large vein of albite is present with inclusions of very fine needles of glaucophane (Figure 22). Secondary quartz and calcite are present.

Specimens RVT 135, 142 and 143  Radiolarian Chert
The radiolarian cherts have circular radiolaria in a very fine-grained matrix of quartz, chlorite and goethite. The radiolaria have been replaced by either coarser grained quartz or chalcedony.

Specimen RVT 136  Schist
The major component is glaucophane with minor lawsonite, clinozoisite and chlorite. The large tabular glaucophane crystals occur with some clinozoisite and lawsonite in a fine-grained glaucophane-chlorite matrix. Some of the glaucophane shows a schistosity (Figure 23).
FIGURE 22. RVT 134 showing albite vein containing glaucophane needles, in a chlorite-albite groundmass.

FIGURE 23. RVT 136 showing schistose glaucophane (G) crystal with clinozoisite crystal in a glaucophane-chlorite matrix.
Specimen RVT 137 Metachert
The rock contains laths of glaucohpane and small flakes of stilpnomelane in a granoblastic mass of quartz (Figure 24).

Specimen RVT 154 Chert
The chert is very fine grained and contains numerous veins of coarse-grained quartz and chalcedony.

Specimen RVT 174 Schist
The thin section is almost entirely long laths of glauco- phane with minor chlorite. The hand specimen contains some actinolite blades and veins of muscovite. One actino- lite blade appears to grade into glaucohpane.

Specimen RVT 175 Schist
The rock is composed of albite, chlorite, quartz and pumpellyite. Medium to large crystals of albite with numerous small laths and pumpellyite are in a groundmass of fine-grained secondary quartz and chlorite. Some of the large albites appear corroded, and some of the small laths show flow (Figure 26).

Specimen RVT 173 Schist
The rock contains a mosaic growth of jadeite in a ground- mass of chlorite (Figure 25).
FIGURE 24. RVT 137 containing glaucophane laths and small stilpnomelane flakes in granoblastic quartz (plane light).

FIGURE 25. RVT 173. Mozaic intergrowth of jadeite with some chlorite (plane light).
**Specimen RVT 189 Schist**
The rock contains numerous long, narrow, semi-radiating albite laths and a few large lawsonite crystals in a very fine chlorite groundmass. It has numerous veins of albite with some calcite (Figure 27).

**Specimen RVT 194 Altered Volcanic (Schist)**
The rock is variable in texture. One portion is diabasic with numerous albite laths, and the other is more random with tabular albite crystals, some pumpellyite and ilmenite outlining skeletal crystals of possible augite. The groundmass throughout is chloritic.

**Specimen RVT 224 Graywacke**
The rock is a lithic graywacke with over 50% rock fragments of chert, metamorphic and volcanic rocks. Secondary chert is present in a vein and also engulfing some of the grains.

**Specimen RVT 250 (K) Volcanic Breccia**
The rock is a coarse-grained volcanic breccia containing over 80% angular volcanic fragments with some chert and graywacke particles in a chloritic groundmass. The individual volcanic fragments vary greatly in composition (Figure 28).
FIGURE 26. RVT 175 containing partially corroded large albite crystals with smaller albite laths showing distortion of the foliation around it, all in a chlorite matrix.

FIGURE 27. RVT 189 with radiating long albite laths in a chlorite groundmass cut by an albite (A), calcite (C) vein.
Specimen RVT 251  Schist
The schist is very fine-grained and composed of actinolite, quartz, zoisite and chlorite. The rock has tight folds in it (Figure 29).

Specimen RVT 252  Altered Volcanic
The rock has a diabasic texture with numerous amygdules. The principal minerals are long, narrow albite laths with minor pumpellyite in a chloritic groundmass (Figure 30).

FIGURE 28. RVT 250 (E) is a volcanic breccia with large grains of different volcanic rock (V) and some chert (C) and graywacke (G) grains in a chlorite matrix.
FIGURE 29. RVT 251 is a fine-grained schist with tight folds.

FIGURE 30. RVT 252 is an altered amygdaloidal volcanic rock with albite laths in a chloritic groundmass. Albite fills the amygdules in the Figure.
BIBLIOGRAPHY


The map illustrates various geological features and formations, including:

- **Alluvium**
- **Terrace**
- **Landslide**
- **Graywacke**
- **Altered Volcanics**
- **Chert**
- **Schist**

Additionally, the map highlights:

- **Fault**
- **Shear Zone**

The locations are marked with specific geographic names such as Ridge, Creek, and a general index for the Russian River Redwood Valley.

The map is a detailed representation of the area's geological and topographical characteristics, useful for understanding the local geology and potential landslide-prone areas.