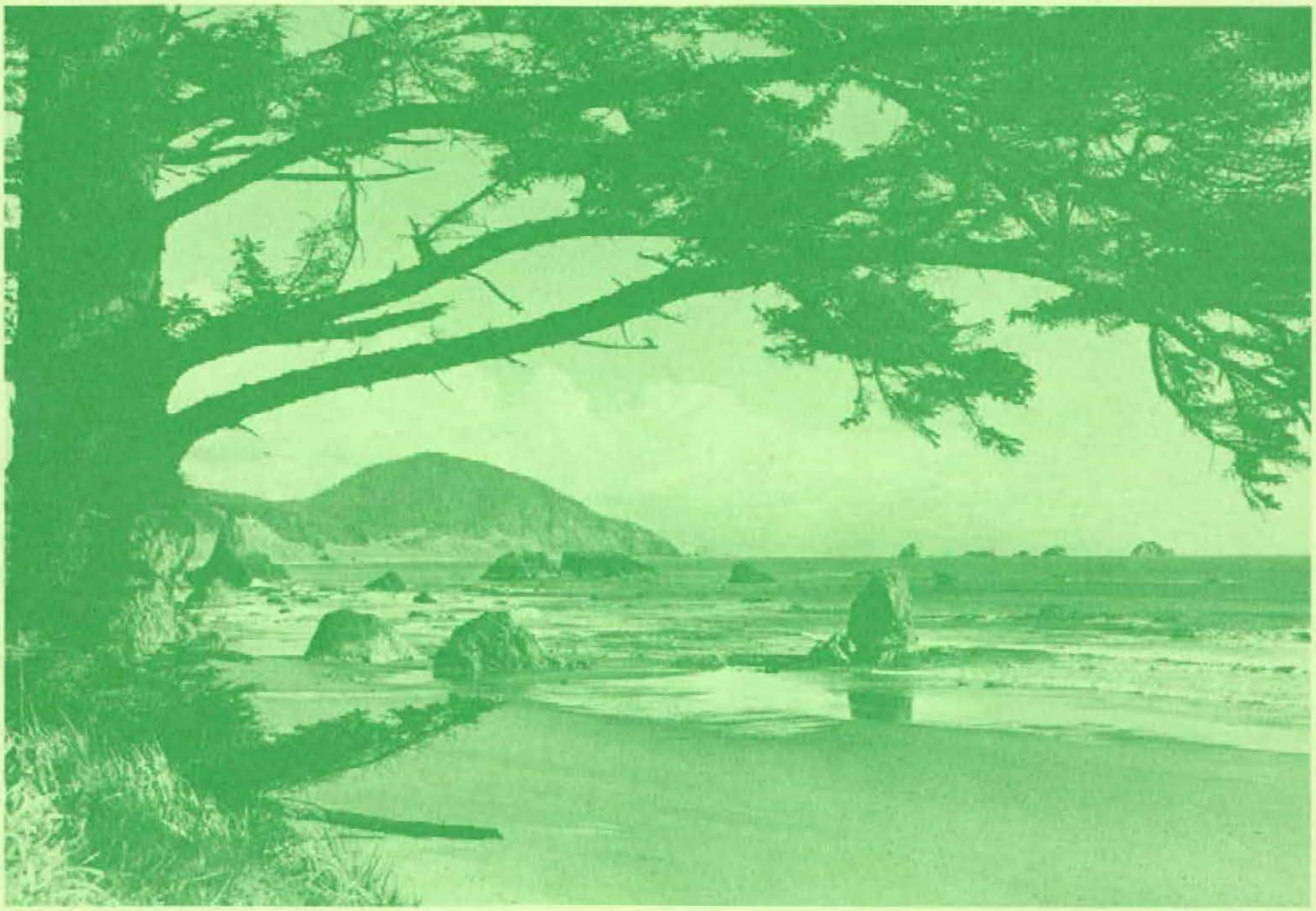
Geology of the Southwestern Oregon Coast West of the 124th Meridian



STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES

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GEOLOGY OF THE SOUTHWESTERN OREGON COAST WEST OF THE 124th MERIDIAN

By

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1971

FOREWORD

The Klamath Mountains Province of southwestern Oregon is probably one of the more geologically interesting regions in the state. Historically, it was in this part of Oregon, near the present town of Jacksonville, that gold was discovered in 1850. Since that time, several million dollars in precious metals, copper, mercury, chromium, and nickel have been mined from this highly mineralized region. Mineral exploration is still being carried on in the Klamath Mountains by private companies in the hope of finding new deposits.

One of the primary functions of the State of Oregon Department of Geology and Mineral Industries is to encourage development of our mineral resources in order to enhance the economy of the state and to provide the raw materials required by our technological society. At the present time, yearly per-capita demand for minerals is about $150. The U.S. Bureau of Mines believes that by the year 2000 our requirement will be approximately $420.

In order to carry out a mining-exploration program in the most efficient manner, it is necessary to utilize all available geologic mapping. For the past several years, Dr. R. H. Dott and his graduate students from the University of Wisconsin have been investigating the extremely complex geology that underlies the Klamath Mountains Province, and their preliminary reports have been very useful to economic geologists in outlining the most favorable areas for mineral exploration. This bulletin summarizes the field studies carried out by the University of Wisconsin personnel in southwest Oregon, supplemented by all available published and some unpublished mapping. The information presented in this report will provide much new geologic data for the use of exploration companies. If the mining industry is to meet the future demands for mineral products, it will need to make use of all of the most recent geologic mapping in those mineralized regions showing the greatest promise. Southwestern Oregon is an area that warrants further investigation.

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Oregon State Geologist

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Abstract

Until 1969, the southwestern coast of Oregon had not been studied in detail since the pioneer mapping of J. S. Diller at the turn of the century. From 1959 through 1970, University of Wisconsin geologists conducted a variety of studies, but with emphasis upon sedimentology and its relation to tectonic history. Beginning about 1965, U.S. Geological Survey and University of Oregon geologists also began working in the area. In the late 1960's, great advances in the understanding of offshore geology and of the enigmatic Franciscan complex of northern California as well as the formulation of the theory of plate tectonics all provided important insights for the understanding of the Oregon coast.

The Mesozoic rocks of the region comprise four tectono-stratigraphic subprovinces that can be compared approximately with better understood counterparts in northern California. First is a north-central area (probably a large klippe) with a Klamath and Sierra type basement of greenschist metasediments and metavolcanics (Galice Formation) intruded by diorite plutons and all unconformably overlain by a thick Lower Cretaceous conglomerate and graywacke sequence (Humbug Mountain and Rocky Point Formations), which is similar to the Cretaceous sequence of California's Sacramento Valley. Second is a central mixed blueschist and greenschist terrane (Colebrooke) with associated large ultramafic masses, some of whose mineralogic characteristics and isotopic dates suggest origin somewhere in the upper mantle during late Paleozoic time. Both rocks now appear to comprise large thrust sheets emplaced during medial Cretaceous time; they are somewhat like blueschists and serpentinites along the eastern side of the northern California Coast Ranges. A portion of the Galice Formation is the most probable precursor of the Colebrooke Schist. A third subprovince along the coast and on the north edge of the map area is underlain by the latest Jurassic (Tithonian) Otter Point Formation, which consists of intensely sheared broken formations of mudstone, graywacke, conglomerate, chert, and volcanic rocks, and mélanges that, in addition, include serpentinite pods and small dioritic masses. A fourth major division is underlain by the Dothan Formation, which has long been a subject of stratigraphic controversy. It now appears that the Dothan is coextensive with, and partly equivalent in age to, the Franciscan of California as has long been suggested by California geologists. The Otter Point Formation certainly is equivalent in age to the Jurassic portion of the Franciscan, but its relation to the Dothan is not clear. The Otter Point is much more sheared than the Dothan, contains more conglomerate, slightly more mafic volcanic rocks, and has oppositely directed paleocurrent features. The Franciscan is a larger entity that probably is equivalent to both Oregon units.

Apparently underthrusting or subduction of an oceanic lithosphere plate beneath the edge of the continental plate occurred episodically during late Mesozoic time. Rocks of the Klamath basement (Galice) and also the Colebrooke terrane, whose original location is unknown, were metamorphosed and intruded by diorites during Late Jurassic (Nevadan) orogenesis. This classic tectonic event along the Pacific coast seems to reflect a culmination of sea-floor spreading between 125 and 150 million years ago. A latest Jurassic (Tithonian) volcanic arc-trench system immediately developed near the present coast, and within it the Otter Point-Dothan-Franciscan complexes were formed. In Early Cretaceous time, the Klamath Province farther east was partly overlapped by marine strata. Then a second culmination of late Mesozoic sea-floor spreading in medial Cretaceous time (about 100 million years ago) is thought to have caused large-scale westward dislocation of some Klamath rocks into the coastal area, and also the overthrusting of the Colebrooke Schist and ultramafic sheets over both the Klamath outlier and the Otter Point-Dothan complexes. Although the older rocks were considerably deformed at that time, they were not metamorphosed. It may be that these most distinctive thrust sheets merely represent the last of a long, more or less continuous phase of sea-floor spreading and plate subduction rather than a discrete, short-duration thrusting event.

Tectonic quiescence occurred during latest Cretaceous and early Cenozoic times when marine sedimentation (Cape Sebastian, Hunter's Cove, and several Paleocene to Eocene formations) occurred on the west and north margins of the coastal region as well as on the eastern margin of the Klamath province. Finally, in late Cenozoic time (roughly the last 30 million years) a totally different tectonic style

was superimposed, which is characterized by vertical San Andreas-like fault zones trending north-northwest. Whereas evidence suggests continuing (or resumption of) sea-floor spreading from the modern Gorda submarine ridge, the late Cenozoic structures along the coast are closely akin to those of the central and southern California Coast Ranges where no ocean-plate underthrusting or subduction is currently occurring. Thus southwestern Oregon, northwestern California, and the adjacent oceanic region together constitute an exceptionally complex region with structural characteristics both of spreading and nonspreading lithosphere plates. The strain suffered by "nonspreading" western California has been propagated at least 200 miles northward from the Mendocino oceanic transform fracture zone along the margin of the continental lithosphere plate, but the continental Americas plate must be decoupled from the spreading Gorda oceanic plate, which appears to be underthrusting the continent at the present time.

GEOLOGY OF THE SOUTHWESTERN OREGON COAST WEST OF THE 124th MERIDIAN

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Introduction

Purpose

The accompanying regional map (Plate I) is a progress report. It presents a compilation of both detailed and reconnaissance geologic mapping accomplished by myself and former students in the coastal mountains of southwestern Oregon between 1958 and 1968, supplemented by all available published and some unpublished mapping (see index map, page 5). As the text was being written in 1969, after completion of the map, a significantly different structural interpretation involving more thrust faulting than is shown here was proposed (Coleman, 1969), and Upper Jurassic fossils were found by Ramp in float in the southeastern corner of the map area within the Dothan Formation outcrop area (Ramp, 1969). Two alternate structural interpretations for the central part of the map are portrayed in cross sections C-C', and several alternate interpretations of other problematic structural and stratigraphic relationships are discussed herein with their apparent advantages and shortcomings noted. The chief purpose of the map is to show the distribution of contrasting rock units, critical stratigraphic relationships, and major rock boundaries. Subsequently derived field and laboratory data may alter the structural interpretations.

The coastal region of southwestern Oregon consists of heavily vegetated mountainous terrain with nearly 4,000 feet of maximum relief (Figure 1). Rainfall approaching 100 inches per year has produced deep weathering, as well as dense vegetation that results in poor rock exposures, except along rivers, sea cliffs and new roads. The distribution of exposures for selected areas can be found in various theses completed at the University of Wisconsin, which are cited in the bibliography. Copies of all such theses are on file with the State of Oregon Department of Geology and Mineral Industries in Portland.

Mapping was done on topographic maps with a scale of 1:62,500 enlarged to 3 inches per mile for use in the field. The complex structure, monotonous lithologies, paucity of fossils, and poor outcrops of the mapped area impaired field work. New logging roads and the relocation of the Coast Highway (U.S. 101) minimized the additional handicaps imposed by the impenetrable brush.

Geologic work began in the coastal region at the turn of the century, and it may well be another half century before a full understanding of southwestern Oregon geology is realized. If this map hastens the process, it will have served its intent.

Previous mapping along the coast

J. S. Diller, giant among early Pacific Coast geologists, was the first man to map in southwestern Oregon. After preparing the Roseburg Folio (1898), he moved to the Coos Bay district, which had become the major source area of coal for coastal cities such as San Francisco, and did the Coos Bay Folio

(1901). Following this project, Diller extended his work southward into the northern part of the area of the present map. Some coal existed here, too, but placer and lode gold deposits among the Sixes River and Johnson Creek drainages (northern part of Plate I area) doubtless provided the greater incentive for the project. The resulting Port Orford Folio, published in 1903a, included the northern one-third of the present map -- that is, from its northern border south to latitude 42°30'.

One must marvel at the accomplishments of Diller and his assistants in such a formidable task as they undertook in mapping approximately one thousand square miles in three field seasons. Their accomplishment is partly explained by the fact that many inland areas actually were more accessible then than today because of active mining and homesteading. Diller's field notebooks, copies of which were obtained through the courtesy of the U.S. Geological Survey Library in Denver, reveal a great deal more structural data and considerable insight into Diller's ideas and debates about critical field relationships than appear in the terse folio. Some of these insights are referred to subsequently. It is noteworthy, also, that his field notes reveal that Diller actually had covered a much larger region in reconnaissance fashion than his publications alone indicate.

In 1902 Diller published a paper in which he emphasized the importance of an inferred Miocene peneplanation of the Klamath Mountains. Although his arguments for a widespread peneplane are not compelling today, the article does represent an early recognition of an important mid-Cenozoic change in tectonic behavior of the region. In 1903-b and again in 1907, Diller synthesized his concepts of Mesozoic stratigraphy in southwestern Oregon. The second of his stratigraphic papers apparently was stimulated in large part by an attach by Louderback (1905) on the relationships and ages of certain of Diller's stratigraphic units. It appears in retrospect that both were partly right and partly wrong.

In 1916, Butler and Mitchell completed a report on the mineral resources of Curry County. While this report included a virtually unknown large area south of the Port Orford map, it was of such a reconnaissance nature that it added relatively little new insight. In 1943, a reconnaissance map was prepared by Treasher of the coastal margin from Gold Beach to the California border, but it was not generally available and added little. Meanwhile, Maxson (1933) had published a general map that included Del Norte County, California.

Beginning in 1949, the first of a new phase of reports by U.S. Geological Survey geologists under the leadership of Francis G. Wells appeared. Three reports and maps of areas to the east of the present map that are of special importance include an extensive report on the Kerby quadrangle (Wells, Hotz, and Cater, 1949), a geologic quadrangle map of the Galice quadrangle (Wells and Walker, 1953), and a bulletin on the Gasquet quadrangle in northwestern California (Cater and Wells, 1954). In 1955, Wells produced an uncolored preliminary map of southwestern Oregon (scale 1 inch per 4 miles), and in 1961 he culminated his work in the region by coauthoring with Peck a colored geologic map of western Oregon (scale: 1:500,000). Also in 1961, Ramp published a comprehensive summary report of the chromite deposits in southwestern Oregon, which included descriptions of some of the areas near the eastern border of the present map area. In 1968, Baldwin published a reconnaissance map of an area south of Agness. In 1969, Lent completed mapping of the southern half of the Langlois quadrangle, which overlaps most of the eight townships on the north-central edge of the map. Also in 1969, Coleman of the U. S. Geological Survey completed an investigation of several ultramafic masses in the central and eastern parts of the area of Plate I, as well as petrologic studies of the Colebrooke Schist. His work has led to an important reinterpretation of regional structural relationships.

Previous stratigraphic studies

Many reports bearing on regional stratigraphic and paleontologic problems that relate to the coastal region have appeared in the past decade. In 1959, Imlay and others published an important stratigraphic synthesis of latest Jurassic and earliest Cretaceous strata (the Myrtle Group) in southwestern Oregon.

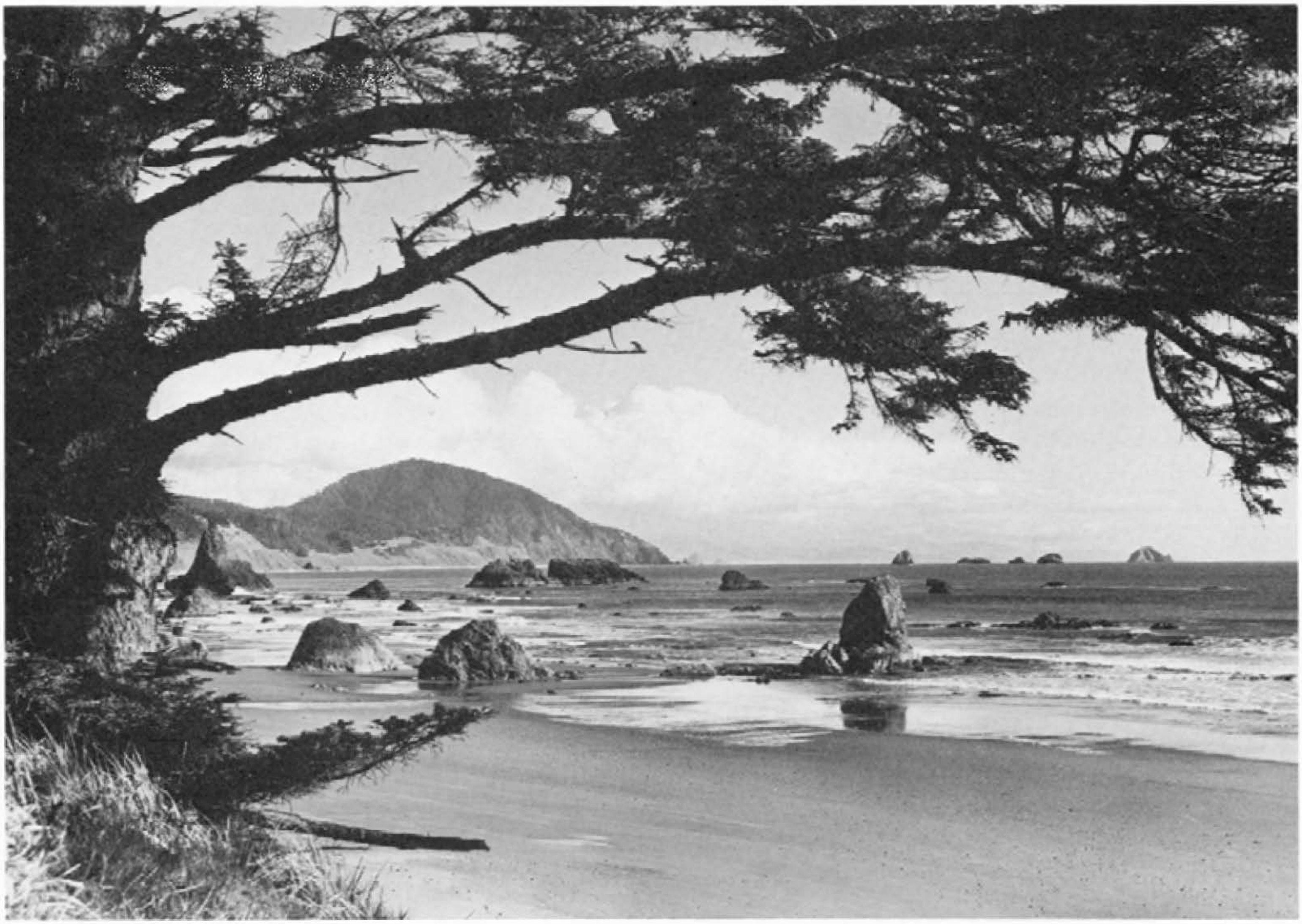


Figure 1. Humbug Mountain, the highest prominence on the southwestern Oregon coast, as seen looking southeast from near Port Orford. The mountain is composed of massive Lower Cretaceous conglomerate. Sea stacks in the foreground are the Otter Point Formation, which is in fault contact with Lower Cretaceous strata (Rocky Point Formation) in the left distance. Pliocene sands and gravels occur in cliffs behind the camera. (Photograph by Henry Lowry, Eugene, Oregon.)

Subsequently both Imlay and Jones contributed extensively to an understanding of the biostratigraphy of Mesozoic rocks both in Oregon and northern California (Imlay, 1959, 1960, 1961; Jones, 1960, 1969; and Bailey and others, 1964). A Cretaceous correlation chart for the Pacific Coast prepared by Popenoe and others (1960) relates rocks on the Oregon coast to those of surrounding regions. Camp and Koch (1966) described a Jurassic Ichthyosaur rostrum from the present map area. Meanwhile, Cenozoic deposits and fossils along the coast have received the attention of Bandy (1944; 1950), Baldwin (1945; 1965), Durham (1953), Addicott (1964), and Janda (1969).

Investigations in northern California

Several studies in northern California have a direct bearing upon Oregon coastal geology. Taliaferro (1942), Wells and others (1946), and Rice (1953) referred to the "Franciscan" all strata south of the border that are mapped here as "Dothan." Subsequently, practically all California geologists have considered the Dothan to be coextensive with the Franciscan assemblage. Although this treatment has been questioned in the past (Dott, 1965) owing to the paucity of detailed mapping and obvious structural complexity in northwesternmost California, it now appears that the Dothan and the Franciscan are, at least in part, contemporaneous.

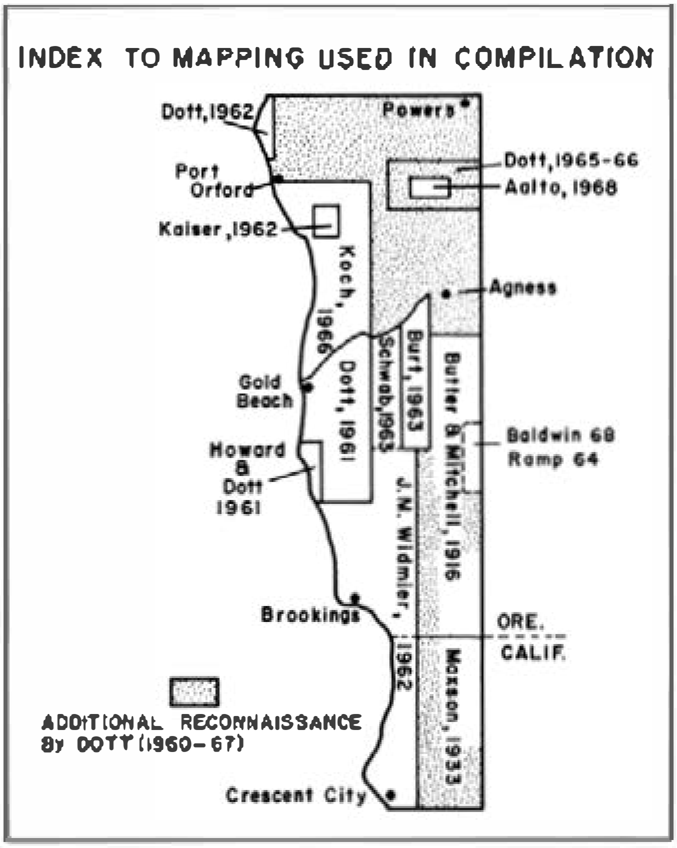
Noteworthy in the recent explosion of Franciscan literature are reports describing lithology, fossils, structure and metamorphism by Irwin (1957, 1960, 1964), Bailey and Irwin (1959), Bailey, Irwin and Jones (1964), Bailey and others (1966), and Blake, Irwin and Coleman (1967). Of particular interest is the recognition of the important role of major thrust faulting within and at the western margin of the Klamath Province (Irwin, 1960, 1964; Davis and Lipman, 1962). Closely related thereto has been the study of widespread blueschist metamorphism within Franciscan rocks of northern California (Blake and Ghent, 1965; Blake and others, 1967). Gluskoter (1964) demonstrated that some stratigraphic order existed in the Franciscan, at least locally, but he, as well as Hsu and Ohrbom (1969), also showed that K-feldspar distribution must be interpreted with caution in Franciscan rocks. Isotopic dating of northern California rocks (Lanphere and others, 1968; Suppe, 1969) also has considerable bearing upon an understanding of adjacent Oregon geology.

Offshore geologic and geophysical studies

Recent marine investigations have shed considerable light upon the relationships of onshore and continental-shelf geology to that of the Pacific crust. In this regard, the concept of plate tectonics, which was first proposed as the present map was being drafted, seems to offer an appealing explanation of the gross structural features of the coastal region. The first relevant marine work was the magnetic survey by Raff and Mason (1961), which was impossible to relate to onshore geology without the "New Tectonics." A bathymetric study by Byrne (1962) was followed by another farther south by McManus (1965), in which the major Blanco fracture zone was recognized. Morgan (1968) discussed possible movements of hypothetical lithosphere plates for the Pacific Northwest, and Tobin and Sykes (1968) and McEvilly (1968) documented recent seismicity in the offshore region. Most recently, Silver (1969a, 1969b) has traced onshore structures across the shelf in northern California, and also has discovered deformation in Cenozoic continental slope deposits apparently related to thrusting of a decoupled oceanic lithosphere plate beneath the continent. Silver has thus shown why ocean-crust structures, such as the Blanco fracture zone, are not directly relatable to onshore features. Clifton and others of the U.S. Geological Survey are currently studying nearshore marine sedimentation.

University of Wisconsin studies

In 1959 I chose the southwestern coast of Oregon as a laboratory for investigating relations between tectonism and sedimentation in an orogenic belt. My introduction to the region came in 1955 while I was working for Humble Oil & Refining Co. Excellent sea-cliff and river exposures of Mesozoic strata contained interesting sedimentary structures, and the presence of diorite-bearing late Mesozoic



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conglomerates around Port Orford offered the prospect of dating conclusively a major orogenic and plutonic event. Great labor was required to establish the basic relationships essential to any detailed sedimentological studies, however, owing to structural complexities. J.G. Koch (1960) mapped the Humbug Mountain area for a master's thesis and expanded that work into a doctoral project, much of which was published in 1966. An important unconformity between Cretaceous and older metamorphic and igneous rocks was documented along Elk River. W. R. Kaiser (1962) completed a study of the petrology of the Pearse Peak Diorite and associated metasedimentary rocks underlying the Cretaceous (summarized by Koch and others, 1961). Meanwhile, J.K. Howard mapped the Cape Sebastian area farther south, where fossiliferous Upper Cretaceous strata occur (Howard and Dott, 1961), and J. M. Widmier undertook a doctoral project extending from Howard's area to Crescent City, California (Widmier, 1962). Including my investigation of the Cape Blanco-Blacklock Point area (Dott, 1962) in the northwest corner of the map area, these studies cover all of the coastline.

Poor exposures and relative inaccessibility discouraged mapping inland, but two projects (Burt, 1963; Schwab, 1963) were undertaken in the Collier Butte quadrangle east of Gold Beach where fossiliferous strata were known. Because hoped-for critical unconformable relations were not found there, clues were sought next in Diller's field notes for other favorable inland areas, especially where the "Nevadan unconformity" might be found. In 1965, the search bore fruit on the east slope of Barklow Mountain (Dott, 1966a), and then Aalto remapped the critical area surrounding that locality (Aalto, 1968).

In 1965 a brief preliminary summary of the apparent stratigraphic and structural relationships arising from the Wisconsin work up to that time was presented (Dott, 1965). A more detailed account has awaited publication of the present map and text in which a number of revisions are incorporated. All stratigraphic names proposed herein and elsewhere by me and by former Wisconsin students were cleared with the United States Geological Survey's Committee on Stratigraphic Names.

Of a more topical nature, Dott and Howard (1962) described some sedimentary structures in the Upper Cretaceous sediments near Cape Sebastian, and Dott (1963) illustrated features from Jurassic and Lower Cretaceous strata of the region. Aalto and Dott (1970) discussed the sedimentology of deep-water conglomerates in the Jurassic and Lower Cretaceous rocks. A discussion of Upper Cretaceous sedimentology is in preparation. Dott (1966b) published a sedimentological and paleogeographic study of the Upper Eocene deposits of the Coos Bay region farther north in which a generalized pre-Eocene paleogeologic map of all of southwestern Oregon was included. Mesozoic rocks of the present map area also were discussed in terms of provenance for the Eocene sediments. Kevin Scott also briefly studied Eocene strata that rest unconformably upon Mesozoic rocks in the northern part of the map area (Scott and Dott, 1963). In 1967, Laidon completed a petrologic study of modern beach sands within the map area. In 1970 Medaris and Dott published data suggesting a mantle origin for some of the ultramafic rocks and related them to a sea-floor spreading hypothesis.

Acknowledgments

Work leading to this report was financed largely by grants from the Wisconsin Alumni Research Foundation to the Graduate School of the University of Wisconsin, and by more limited funds from the State of Oregon Department of Geology and Mineral Industries. The Department has always been most encouraging in every possible way. The Oregon Highway Department was helpful in granting permission for us to camp for extended periods at Humbug Mountain and Harris Beach State Parks. Many local citizens were most hospitable, but especially the Benjamin Gardner and Harvey Crook families of Pistol River. I am very grateful for all of the courtesies extended by these and other local citizens.

Stimulating consultations over several years with Robert Coleman, David Jones, Porter Irwin, Warren Addicott, Ralph Imlay, and Robert Brown of the U.S. Geological Survey, and LenRamp, R. E. Corcoran, and Hollis M. Dole of the Oregon Department of Geology and Mineral Industries have been most helpful.

Jones and Imlay kindly verified many of our fossil identifications. Discussions with Salem Rice of the California Division of Mines, E. M. Baldwin of the University of Oregon, and L. G. Medaris of the University of Wisconsin have been invaluable in the completion of the work. Even more important were the labor and stimulus of the many students whom I directed in Oregon. J. B. Hayes, now of Marathon Research Corp., Littleton, Colorado, kindly provided data from X-ray studies of clay minerals. Isotopic dates were provided without charge through the courtesy of H. Baadsgaard of the University of Alberta, Marvin Lanphere of the U.S. Geological Survey, and under a Student Project Grant to J. G. Koch by Geochron Laboratories. Commercial dates also were performed by Geochron and by Isotopes, Inc.

This report was first written in the fall of 1969 while I was a Visiting Professor at the University of California at Berkeley. It is a pleasure to acknowledge not only the timeliness of that visit, but more especially the important insights into Franciscan geology gained through discussions with C. M. Gilbert, M. N. Christenson, and Michael Perkins, and from field trips during the visit. Discussions of the Franciscan with W. R. Dickinson, B. M. Page, and E. I. Rich of Stanford University and J. K. Hsu of the University of Zurich also were very valuable. Eli Silver, then at Scripps Institution of Oceanography and now with the U.S. Geological Survey, greatly clarified my knowledge of the offshore. Special thanks are due Robert Coleman for criticizing the manuscript carefully, and also for his friendly and unselfish sharing of ideas and wise counsel on the perplexities of the ultramafic rocks and blueschist metamorphism. His sharing of a wide experience with these and with Coast Range structures in California were of great importance in completing the manuscript.

Tectonic Setting

The Klamath geologic province lies at the continental margin on the western edge of the Cordilleran mobile belt and straddles the California-Oregon border. Klamath rocks comprise a large, westwardly convex arcuate pattern named the Mendocino orocline by Carey (1958). Diller (1903b), Taliaferro (1942), Irwin (1960; 1964) and others have stressed the fact that Klamath rocks generally lie in younger-westward bands; these are closely comparable to bands in the Sierra Nevada (Davis, 1969). Carey (1958), Wise (1963), and Hamilton and Myers (1966) speculated that the Klamath bands originally were straighter and had been bent into their present arcuate (orocline) pattern by northward movement of western California relative to the interior of the continent. Davis (1969), however, suggests that westward thrusting of the Klamath at a lower angle than the Sierra rocks accounts for the present arcuate pattern.

Diller regarded all of the coastal Mesozoic rocks as part of the Klamath Province -- a view accepted by the writer until recently. Irwin (1964) argued that a more fundamental structural boundary is the thrust-fault zone bounding Franciscan rocks on the east; he assumed that it extended into Oregon along the east margin of the Dothan Formation, a view which now seems verified (Hotz, 1969). According to this interpretation, however, the outlying Galice Formation, intruded by diorite in the north part of the present map area, is anomalous, for such rocks typify the interior Klamath Province farther east. Irwin speculated that the latter had been thrust relatively westward across the Dothan rocks. Because of the now overwhelming evidence that rocks formed in different tectonic environments have been jumbled together structurally, the subsequent discussion of rock units is organized by distinct subprovinces. Although the map explanation (Plate I) is not so divided, the subprovinces are clear from the areal distribution of major map units.

Several zones of heterogeneous mixtures of intensely sheared rocks are readily apparent. Some such zones vary from a quarter to half a mile wide, trend north-northwest, are rather straight, and contain many vertical shear surfaces within them. The clearest example is the Pistol River shear zone, extending southeast from Cape Sebastian to Carpenterville (Plate II). Several linear arrangements of sea stacks (for example, Mack Reef south of Crook Point, T. 38-39 S., R. 15 W., see Figure 35) represent resistant tectonic blocks within such zones. In addition, Otter Point rocks, which are most intimately associated with shear zones, strike dominantly north-northwest. All of the above led to the conclusion that a complex of major vertical fault zones similar to the San Andreas fault extends 100 miles north from the California border along the Oregon coast (Dott, 1965) (Figure 2). Koch (1966) measured many subhorizontal slickensides on steeply dipping surfaces, which also suggested strike-slip movement. We did not exclude thrust faulting from consideration -- indeed, we found evidence of thrusting at several localities (for example, south of Pistol River, southeast of Humbug Mountain, and at Wedderburn) -- but we regarded it as subordinate to, and a local manifestation of, the vertical faults. Now it is clear that the two types of faulting formed at different times; they reflect very different stress regimes, but their effects are superimposed in a most confusing manner.

Inland a few miles the structural style appeared to reflect the Klamath arcuate pattern, although a few large, vertical faults also occur there. A long-standing generalization among southwestern Oregon workers that serpentinite masses occur along faults seemed confirmed by our own observations. Moreover, Kays and Bruemmer (1964) deduced from gravity data that serpentinite masses 25 miles east of the present map area probably are steeply dipping. Indeed, sheared vertical serpentinite pods do occur within steep fault zones along the coast (Blacklock Point, Myers Creek, Carpenterville, and along the Coquille River fault north of Agness in the northeast part of the map area), but in retrospect the structural model of high-angle faults dominated our thinking too much. Lent (1969), for example, found it impossible to establish any prevalent trend to sheared zones within the Otter Point Formation along the north edge of the present map area.

In 1965, following exceptionally heavy winter rains and floods, an exposure was discovered on the Rogue River 10 miles above Gold Beach by Bailey and Jones (1965) that revealed Colebrooke Schist and small pods of serpentinite thrust over the Otter Point Formation. It was apparent that the entire western margin of the Colebrooke is a thrust contact. Subsequently, Coleman (1969) recognized the probability of much larger allocthonous bodies of both schist and serpentinite in the central part of the map area, and Lent (1969) simultaneously recognized the overthrust relation of schists at the north edge of the area. All of this supported Irwin's earlier (1964) thrusting speculation. Although vertical fault zones, as portrayed in Plate I, become a kind of ruling hypothesis in our work, it is now clear that, whereas some of the "shear zones" certainly are steep and straight in trend, others represent zones of relatively low-angle displacement that have been modified by subsequent deformation and extensive landsliding. Medaris and Dott (1970) presented a map that displays in simplified form Coleman's concept of a large allochthon cut by several Cenozoic faults (reproduced in figure 36).

The concept of mélanges was introduced to the Pacific Coast by Hsu (1968) and in the same year the "new global tectonics" offered a plausible mechanism of underthrusting of oceanic crust to explain the vast sheared and chaotic Franciscan and Otter Point terranes (see Hamilton, 1969). It now appears that pervasive mélange structures were formed in southwestern Oregon (Figure 3) and northern California during Jurassic and Early Cretaceous times and were culminated by the emplacement of large, discrete thrust sheets in mid-Cretaceous and possibly in early Cenozoic times. Northwest-trending vertical faults presumably related to the San Andreas system then were superimposed on all older structures in late Cenozoic time (Dott, 1965; 1969) to produce the present complex structures.

The continental shelf is very narrow off southwestern Oregon, and submarine seismic activity offshore is considerable (Figure 2). The seismicity, together with Pleistocene terraces elevated hundreds of feet above sea level, attests to continuing mobility of the region. Silver (1969a; 1969b) cites evidence that oceanic underthrusting due to sea-floor spreading from the Gorda rise 100 miles west of the coast is continuing today, although the continental plate margins show a pattern of strain more akin to that of the California Coast Ranges to the south than to that of the nearby spreading ocean floor. Apparently the continental and oceanic plates are decoupled here (see Medaris and Dott, 1970).

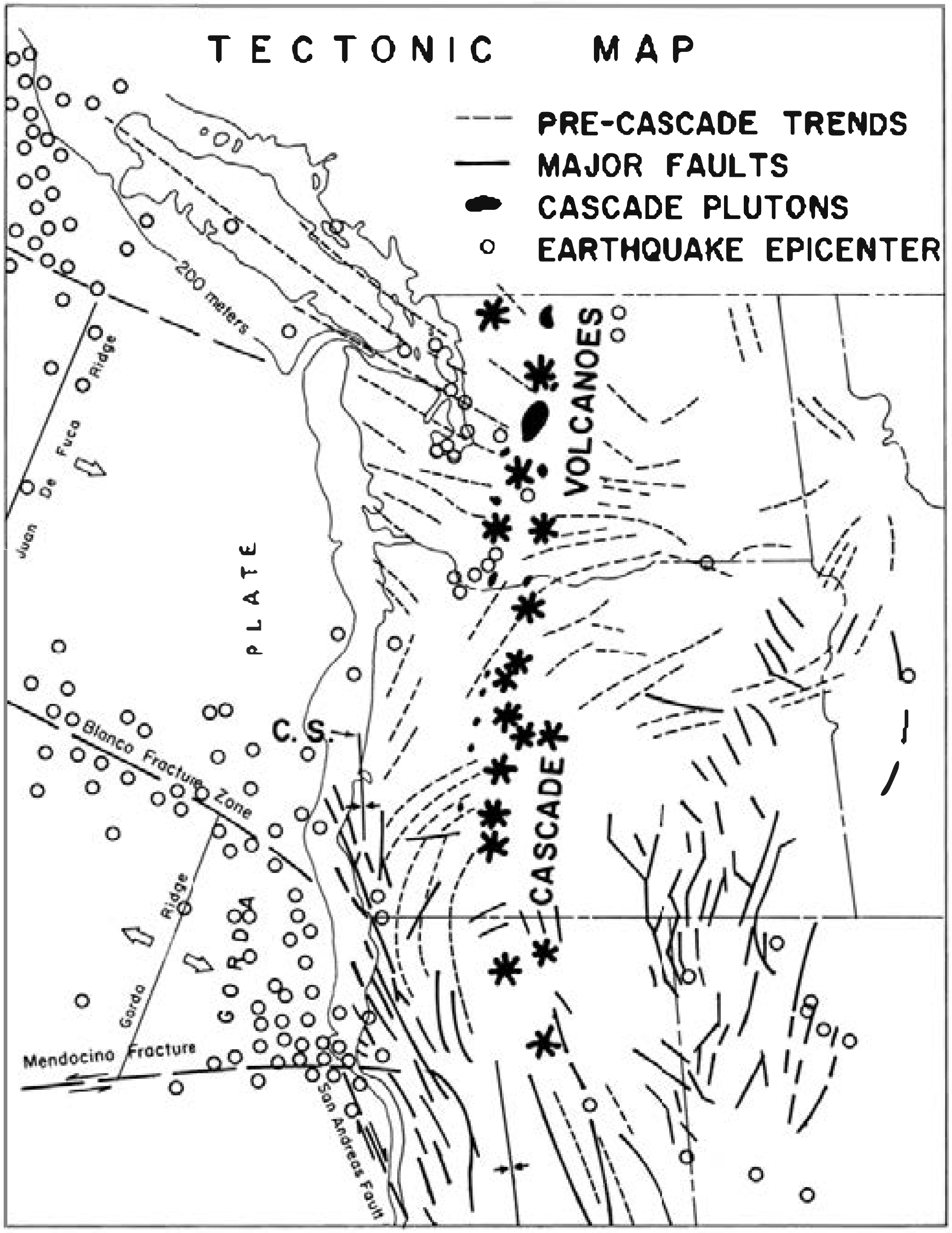


Figure 2. Tectonic setting of the Pacific Northwest and adjacent oceanic crust. Note the discordance between the Mesozoic to early Cenozoic arcuate structural pattern (dashed lines) and the superimposed late Cenozoic Cascade volcanic arc and faulting (heavy lines). Lateral and block faulting are confined to the western edge of the American lithosphere plate, and do not extend to the Gorda oceanic plate, which appears to be continuing to spread from the Gorda-San Juan de Fuca ridge system and to be thrust beneath the continent. C.S. is the Coos Bay synclinorium. (Onshore: after Dott, 1965; offshore: after McManus, 1965; Morgan, 1968; Tobin and Sykes, 1968).

Figure 3. Intensely sheared mudstone and sandstone typical of the Otter Point Formation in which boudinage effects have almost obliterated the bedding (note the small fold faintly defined by relict bedding at right). Such characteristics typify mélanges and broken formations (see Hsu, 1968). Most shear surfaces here are steep and trend roughly north-south. (Exposed in sea cliff just north of Sisters Rock, SW¼ T. 34 S., R. 14 W.)

Tectonic Subprovinces of the Map Area

For discussion of Mesozoic stratigraphic units, the map area has been divided into several distinct subprovinces, the rocks of which probably were deposited in separate areas and later were structurally telescoped together.

The central region includes two distinct portions, a northern part with Klamath-type rocks (Galice, diorite plutons, Humbug Mountain, and Rocky Point units) and a southern part with the Colebrooke Schist and closely associated ultramafic, glaucophane, and amphibolite rocks. The central region extends roughly from Sixes River south to the middle of the map area at approximately the latitude of Collier Butte (T. 37 S., R. 12 W.).

The coastal region includes the late Mesozoic Otter Point, Cape Sebastian, and Hunters Cove Formations from Whalehead (T. 39 S., R. 14 W.) north to Sisters Rock (T. 34 S., R. 14 W.), and also from Port Orford to the north edge of the map. Otter Point rocks predominate across the north edge of the map as well.

The southern region includes all of the Dothan Formation outcrop area -- essentially from Collier Butte to the south edge of the map in California, where it includes rocks mapped as Franciscan. Cenozoic rocks are treated in one section for the entire area. Inferred correlations of strata among the three subprovinces are shown in the accompanying chart (Table 1).

Mesozoic Rocks of the Central Region of the Map Area

Galice Formation (Late Jurassic)

Definition: The Galice Formation was named by Diller (1907) for exposures on Galice Creek

Table 1. Inferred correlations of strata among the map subprovinces.

MAP SUB-PROVINCES →				COASTAL	CENTRAL		SOUTHERN	
CENOZOIC	QUATERNARY			Elevated marine terraces			Elevated marine terraces	0 – 5 m.y.
	TERTIARY		Pliocene	"Empire", St. George and Wymer Fms.				
			Miocene					25 m.y.
			Oligocene				Mt. Emily intrusives	
			Eocene	Undifferentiated Eocene	Un iffer ntiated Eocene			
			Paleocene					65 m.y.
CRETACEOUS		UPPER	Maestrichtian	Hunters Cove Fm.	Klamath Terrane	Colebrooke Terrane (thrust over Klamath and Coastal terranes)		
			Companion	Cape Sebastian Ss.				
			Santonian					
			Coniacian					
			Turonian					
			Cenomanian					
		LOWER	Albian					100 m.y.
			Aptian					
			Barremian (Neocomian)		Rocky Pt. Fm.	JK undiffer-entiated		
			Hauterivian (Neocomian)					
			Valanginian (Neocomian)		Humbug Mt. Cong.			
			Berriasian (Neocomian)					130–135 m.y.
JURASSIC		UPPER	Portlandian or Tithonian	Otter Point Fm.		?	?	
			Kimmeridgian		Pearse Peak Diorite	Colebrooke Schist	Dothan Fm. (= Franciscan?)	
			Oxfordian	?	Galice Fm.	ultramafic complex (possibly Paleozoic)		
			Callovian		?		?	150–160 m.y.

(25 miles east of the map area) where there is a thick succession of black slates, less common thin sandstones, and locally abundant volcanic rocks. Subsequently the formation was described extensively by Wells and others (1949) and Wells and Walker (1953). In the Port Orford Folio, Diller (1903a, p. 1, 2) noted the presence in the Johnson Creek drainage (T. 32 S., R. 12 W.; see Figure 4) of "Jurassic slates" with fossils like those of the Mariposa Slate of the Sierra Nevada with which the Galice is correlative. But Diller judged the slates to cover only a small area, so he mapped them within the "Myrtle Formation," which led to gross errors in relative age assignment for several rock units. Wells (1955) and Wells and Peck (1961) later differentiated these slates as the Galice Formation. We have recognized similar strata in the Johnson Creek area, where we, too, found fossils like those of the type Galice (Dott, 1966a). They also occur to the southwest and west, as was suggested by Diller's field notes. Kaiser (1962) and Koch (1966) described metasediments and metavolcanics assigned to the Galice along the Elk River east of Humbug Mountain; no fossils other than undiagnostic foraminifers were found there, but lithology and stratigraphic relationships leave no doubt of their identity.

Lithology: The Galice rocks are dominantly black carbonaceous argillite and slaty or phyllitic mudstones interstratified with firmly indurated gray sandstone beds, which commonly show incipient cleavage (Kaiser, 1962; Koch, 1966). Minor fine, rounded conglomerate and very rare bedded chert also are present. A distinctive banded lithology consists of alternating mudstone and cross-laminated fine sandstone layers generally between one-half and one inch thick. Coarser sandstones average about 3 to 5 inches but range up to several feet in thickness; they commonly are graded and contain dark mudstone pebbles. Petrographically the sandstones are lithic-feldspathic wackes. Plagioclase, quartz, chert, and black mudstone chips dominate within a sericitic matrix; no K feldspar was detected and volcanic detritus is rare. Albite and oligoclase, carbonate, chlorite, epidote, and zircon are present. The Galice strata represent zeolite and lower greenschist metamorphic grades. Hornfels is characteristic adjacent to diorite plutons, but contact metamorphism was in general very mild. Powdery white veinlets adjacent to diorite contacts, especially where sheared, contain the zeolites laumontite and leonhardite (Kaiser, 1962). The density of six sandstones ranges from 2.54 to 2.71 (average 2.61).

Volcanic rocks of the type area include andesitic to rhyolitic flows, breccias, and tuffs (Wells and others, 1949). Near the coast volcanic rocks are less conspicuous and have received only cursory study. Kaiser (1962) mapped considerable "greenstone" which may be Galice on the west side of the Pearse Peak Diorite just east of Humbug Mountain. The greenstone represents cataclasised mafic igneous rock showing chlorite, epidote, and hornblende. Nearby, just above Bald Mountain Creek bridge (NW. corner sec. 20, T. 33 S., R. 14 W.), volcanic breccia is exposed. Scattered greenstones with ellipsoidal or pillow structure and minor associated bedded chert occur in areas mapped as Galice in the northeastern corner of the map area along Johnson Creek (Figure 4).

Age and stratigraphic relationships: The Galice Formation is the oldest satisfactorily dated rock in the entire coastal region. Buchia concentrica collected from slates at a locality on Sucker Creek (NE¼NE¼ sec. 33, T. 32 S., R. 12 W.) dates the rocks as late Oxfordian to early Kimmeridgian (Dott, 1966a). This age conforms with the long-standing lithic correlation with the type Galice Formation. No base has been recognized for the Galice strata in the coastal region, and the entirely volcanic Rogue Formation, which is adjacent to the Galice in the type area (Wells and Walker, 1953), was not recognized. Possible relationships to the Colebrooke and Dothan Formations are discussed in later sections.

The Galice was coeval with the lithologically very similar Mariposa Slate of the western Sierra Nevada in California. Both were metamorphosed, deformed, and intruded by diorite. In the coastal Oregon region, the Galice is overlain unconformably by unmetamorphosed Early Cretaceous (Valanginian) conglomerate, thus closely dating the effects of the classic Nevadan orogeny (Dott, 1965; 1966a). Late Jurassic or Tithonian fossils originally reported from the conglomerate were misidentified, according to Imlay and Jones (written communication, 1970).

Colebrooke Schist (Jurassic)

Definition: Diller (1903a) coined the name Colebrooke Schist, which was modified by Kaiser (1962) and Koch (1966) to Colebrooke Formation because of a great diversity of lithologies. Diller's

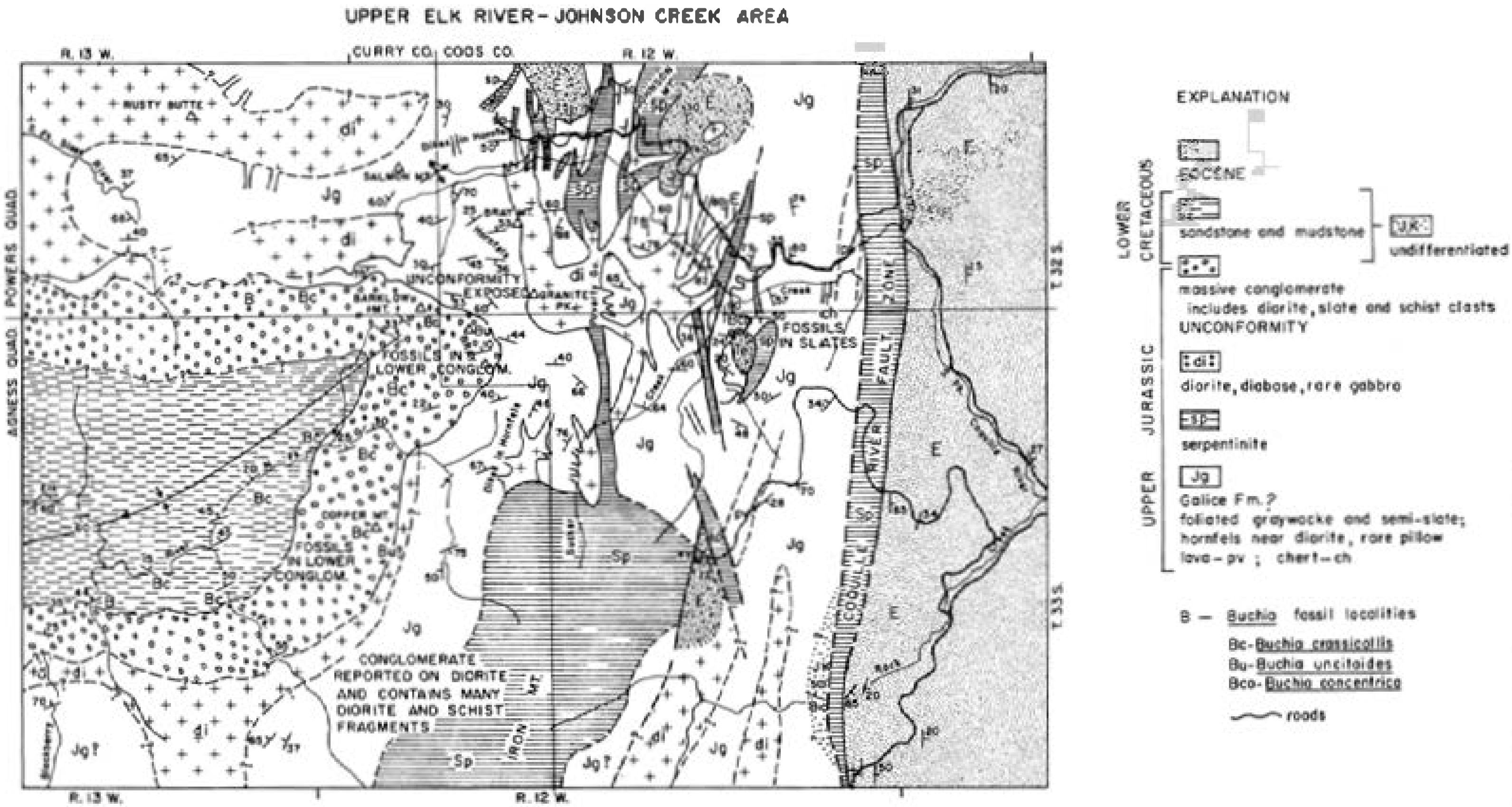


Figure 4. Geologic map of the Barklow Mountain–Johnson Creek–upper Elk River area showing the "Nevadan" unconformity at the base of the Humbug Mountain Conglomerate. Note the relation to the Galice Formation, Bray Mountain Diorite (which has been dated isotopically; see Table 3), serpentinites, and Eocene strata. (Northwest and southeast corners after Diller, 1903a; remainder after Dott, 1966a, and Aalto, 1968)

designation is used in this report. The unit was named for Colebrooke Butte in T. 34 S., R. 14 W. (misspelled "Colebrook" on the 1954 topographic quadrangle map). The Colebrooke lies in the central and northern part of the region, and is largely, if not entirely, allochthonous upon essentially unmetamorphosed Upper Jurassic and Lower Cretaceous rocks (see cross section B-B'). Coleman (1969; also oral communication, 1969) believes that it is an immense allochthonous nappe, and was metamorphosed elsewhere before being overthrust to its present positions. Some small areas of schist (notably at the extreme northwest corner T. 33 S., R. 14 W.), however, cannot be explained simply as remnants of a single huge, post-Early Cretaceous klippe because they lie in deep valleys surrounded by Cretaceous conglomerate that contains schist detritus and vein quartz pebbles with carbonaceous inclusions (Koch, 1966; Lent, 1969), and they are overlain unconformably by that conglomerate. Diller (1903a) considered the Colebrooke as possibly of pre-Devonian age, but it now seems clear that it was derived from Jurassic (chiefly Galice) rocks, which were metamorphosed near the Jurassic-Cretaceous Period boundary.

Lithology: The Colebrooke Schist consists chiefly of gray-to-black, thinly stratified, fine-grained sediments metamorphosed to carbonaceous quartz-mica phyllite and schist. Mudstone and fine sandstone were the dominant original lithologies, but considerable sandstone and fine conglomerate also were present, especially in T. 35 S., R. 13 W. Large, lustrous mica patches in the conglomerates represent recrystallized mudstone chips. Principal minerals include quartz, chlorite, white mica, albite, and carbonaceous material thought to be in part graphite. Less common are epidote, calcite, clinozoisite?, stilpnomelane, amphibole, sphene, and the blueschist mineral lawsonite (Kaiser, 1962; Koch, 1966; Lent, 1969; Coleman, 1969). White quartz veins with minute carbonaceous seams are ubiquitous. The bulk specific gravity of 28 samples of metasandstones averages 2.72 ($\pm$ 0.125 standard deviation) with a range of 2.54 - 3.18.

Metavolcanic rocks and associated chert comprise 5 - 10 percent of the formation. Some basaltic flows still show ellipsoidal structures, and are not foliated. Being resistant, they tend to be more laterally traceable than any other lithology (see Figure 5). Prominent examples referred, at least tentatively, to the Colebrooke occur along the Rogue River north of Skookumhouse Butte, in Copper Canyon 2 miles west of Agness, and south of Foster Creek (T. 34 S., R. 12 E.). Foliated pyroclastic rocks also are present. The metavolcanic rocks contain chlorite, actinolite, albite, epidote, stilpnomelane, and pumpellyite, but no lawsonite (Coleman, unpublished manuscript). According to Coleman, bulk chemical compositions are like that of oceanic basalts and of basalts in the Franciscan complex, but at least a few are more silicic (see Table 2).

Metamorphic grade: The Colebrooke metasedimentary mineral assemblage indicates a metamorphic grade transitional between greenschist and blueschist facies, but metabasalts show only greenschist minerals (Coleman, 1969). Coleman found lawsonite in 15 percent of 130 metasediment specimens studied by him (unpublished manuscript). No metamorphic zonation like that seen in similar northern California schist terranes was found. Coleman believes that Colebrooke metamorphism occurred at about 200 - 250°C. and 5 - 6 kilobars pressure.

Structure: The Colebrooke has suffered at least two distinct penetrative deformations. The main foliation, which is related to metamorphic recrystallization, parallels original stratification (S_1), and dips at low angles. Overprinted upon S_1 foliation and early folds is a pronounced strain-slip cleavage (S_1) parallel to a second phase of folding with north-south axes according to Coleman (1969). Coleman also reports a statistical eastward vergence of recumbent fold axial planes, which he believes is most consistent with an interpretation of eastward overthrusting. Westward thrusting, however, is suggested by the easterly dip of the exposed thrust zone on Rogue River and by the overturning of Lower Cretaceous strata below the thrust north of Colebrooke Butte (T. 34 S., R. 14 W.)

Age of metamorphism: Whole-rock K-Ar dating (Dott, 1965) of Colebrooke Schist specimens of 125 $\pm$ 6 m.y. and 138 $\pm$ 10 m.y. and a Rb-Sr isochron date of approximately 130 m.y. (Coleman, unpublished manuscript) all point to metamorphism -- or, better, final cooling -- of the Colebrooke around 130-135 m.y. ago, or very near the Jurassic-Cretaceous boundary, the exact age of which is still somewhat uncertain.

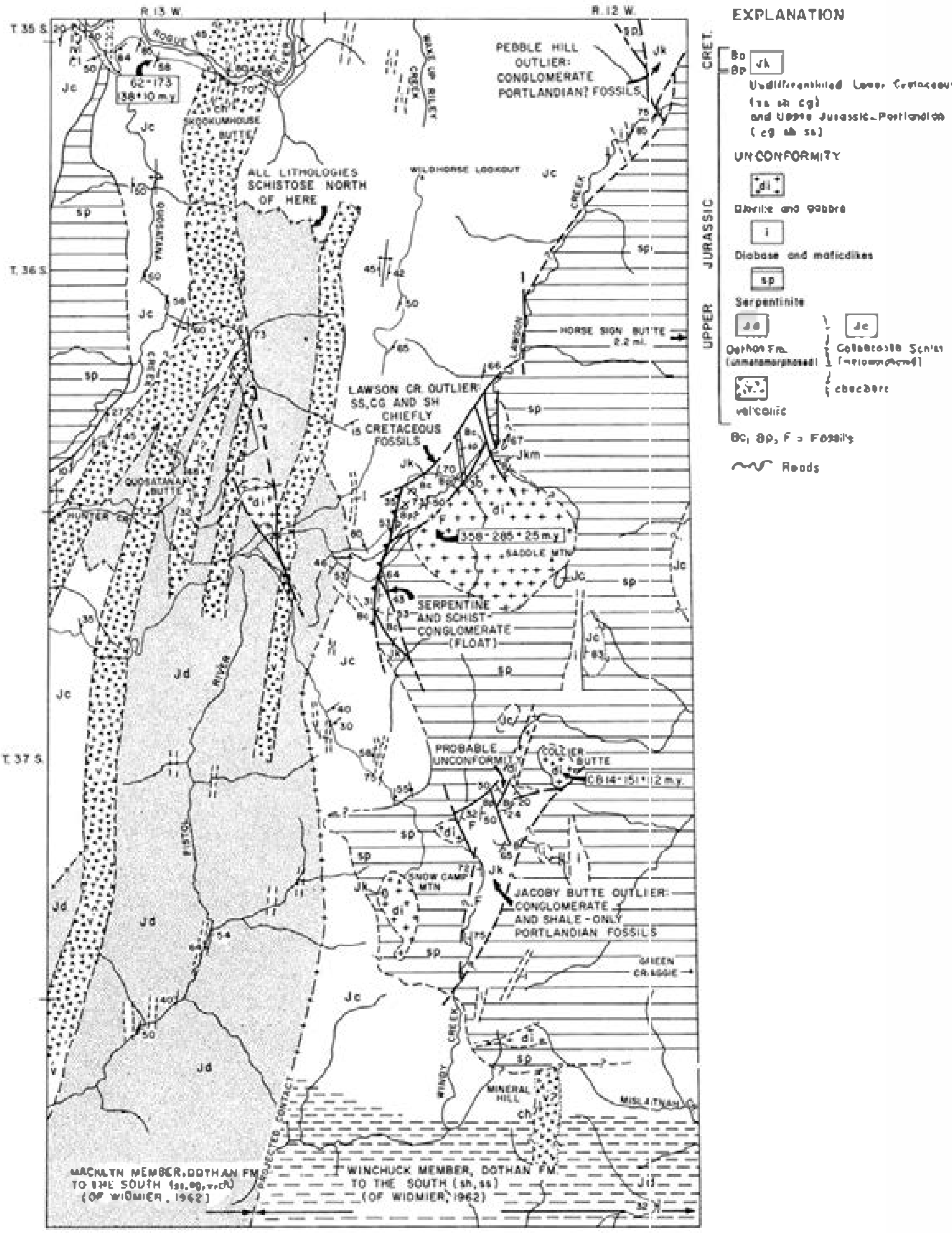


Figure 5. Geologic map of the Collier Butte-Quosatana Butte region showing the distribution of the Colebrooke Schist and Dothan Formation as well as two large ultramafic masses and outliers of Upper Jurassic and Lower Cretaceous strata (JK.). (West half after Schwab, 1963; east half after Burt, 1963.)

Table 2. Selected chemical analyses of igneous rocks.

	Diorites				Otter Point				Dothan	Colebrooke
	Pearse Peak*			Collier Butte	Pillow Lava	Diabase Dike	Pillow Lava	Diabase Dike	Pillow Lava	Pillow Lava
	5268	5262	5140	CB-14	61-70	61-70A	62-123A	62-123	S-61	62-154B
SiO_2	50.14	60.88	54.48	64.19	49.27	48.20	40.83	53.14	61.80	52.04
TiO_2	1.42	0.41	0.31	0.52	1.19	2.27	1.20	1.43	1.43	1.16
Al_2O_3	15.26	17.71	13.81	16.43	19.62	16.72	16.11	11.52	16.59	18.32
Fe_2O_3	1.19	2.92	1.73	2.37	2.41	2.82	3.08	7.80	6.31	2.35
FeO	8.75	2.17	3.9	1.95	4.10	5.09	4.03	3.60	0.59	4.69
MnO	tr.	tr.	tr.	0.20	0.21	0.41	0.22	0.43	0.06	0.19
MgO	7.21	2.21	8.67	1.54	5.22	6.60	5.06	7.50	0.50	4.04
CaO	9.34	4.32	6.69	3.89	8.08	8.74	14.40 †	6.73	1.55	5.60
Na_2O	2.76	4.17	5.03	4.18	4.67	4.22	4.11	4.80	9.50	6.42
K_2O	0.95	2.68	0.46	1.86	0.62	1.04	0.02	0.28	0.20	0.21
P_2O_5	0.24	0.16	0.02	0.13	0.10	0.44	0.09	0.10	0.30	0.10
H_2O+	2.22	1.47	2.02	1.93	4.05	2.92	5.08	2.02	0.75	4.04
H_2O-	0.23	0.54	0.67	0.04	0.00	0.00	0.00	0.00	0.00	0.00
CO_2	0.00	0.00	0.00	0.00	0.00	0.00	5.28 †	0.00	0.00	0.00
Total	99.71	99.64	99.84	99.23	99.54	99.47	99.51	99.3	99.58	99.16
$\frac{K_2O}{Na_2O}$	0.344	0.642	0.091	0.444	0.132	0.246	0.004	0.058	0.002	0.032

* From Diller (1903a); all other analyses by H. N. Wiik, Helsingfors, Finland. The two dikes intrude the pillow lavas with corresponding sample numbers. † Contains calcitic amygdules.

Locations:

5268 Summit of Bald Mountain, SE¼ sec. 33, T. 33 S., R. 14 W.
5262 Brush reek, SE¼ sec. 5(?), T. 34 S., R. 14 W.
5140 Coast road, SE¼ sec. 7, T. 34 S., R. 14 W.
CB-14 Summit Collier Butte, sec. 21(?), T. 37 S., R. 12 W.
61-70 and 61-70 - Pistol River, NE¼ sec. 22, T. 38 S., R. 14 W.
62-123 and 62-123 - M In Fork Hunter reek, NW¼ sec. 13, T. 37 S., R. 14 W.
S-61 North of Brownie's Bluff, SE¼ sec. 35(?), T. 37 S., R. 13 W.
62-1548 - North Fork Pistol River, NW¼ sec. 5, T. 38 S., R. 13 W.

Similar schists in northwestern California: Schists similar to the Colebrooke bound the Dothan (or Franciscan?) rocks east of Crescent City and for many miles southward along their east side in California, as was noted by Diller (1903b) and other early workers. Two klippe of carbonaceous schist occur near Orick, California (see Weed Sheet of the Geologic Map of California) 40 miles south of Crescent City. They rest upon Franciscan rocks much as the Colebrooke rests upon Otter Point rocks in Oregon. Diller and other early workers considered the California schists to belong to the Klamath terrane, specifically to be metamorphosed Galice sediments with a major fault separating them from the Franciscan assemblage. There has been general agreement that such a relation does exist, but the exact position of the Klamath boundary thrust fault relative to -- and its effects upon -- the Franciscan were less clear. Diller noted that schists on the top of South Fork Mountain (100 miles southeast of the present map area) were different from those lower on the west side of the mountain, and recently it has been shown that Franciscan rocks have been metamorphosed to blueschist with the grade of metamorphism increasing uphill toward the typical South Fork Mountain schist (Kilmer, 1962; Blake and Ghent, 1965). This upside-down metamorphism has been interpreted as indicating that at least some of the schist in South Fork Mountain is metamorphosed Franciscan rather than meta-Galice, and that the major Klamath boundary thrust lies above rather than below the blueschists. Rb-Sr dating of the topographically low Franciscan metasediments, which contain Early Cretaceous Buchia species, indicates metamorphism very soon after sedimentation at 105 ± 16 m.y. ago. Because the blueschist metamorphism of Franciscan rocks seems to have been closely related to the Klamath boundary fault, thrusting there is inferred also to have occurred in medial Cretaceous time. On the other hand, Blake and others (1967) acknowledge a difficulty in many cases in distinguishing the South Fork Mountain schist from Galice metasediments directly to the east, and Suppe (1969) reports a K-Ar date of 136 m.y. from Picket Peak "near the type locality," which is very similar to dates obtained from the Colebrooke. These discrepancies may reflect more than one protolith for the South Fork Mountain schist.

Both field evidence and isotopic dating indicate that metamorphism of Mesozoic rocks in the western Klamath and Coast Range Provinces was complex. At least three more or less distinct periods of blueschist metamorphism are now recognized in California (circa 150 m.y., 125 m.y., and 105 m.y.; Suppe, 1969). A clear understanding of the metamorphic rocks is crucial to ultimate interpretation of structural details in the region, but as is shown more fully below, the correct age and structural relationships of the Dothan Formation in Oregon are intimately involved in understanding the metamorphism. The Colebrooke-type schists east of Crescent City, which have never been studied as much as the South Fork Mountain or Colebrooke Schists, may either be Dothan (Franciscan?) sediments metamorphosed next to the Klamath boundary fault or they may represent metamorphosed Klamath basement (Galice?) thrust over the Dothan.

Probable precursors and structural relationships of the Colebrooke

Most recent workers agree that the Colebrooke closely resembles the Galice Formation (Kaiser, 1962; Dott, 1966a; Coleman, 1969; Lent, 1969). Coleman cites chemical data that also suggest to him a close similarity between Colebrooke and Galice rocks. They are said to be slightly higher in silica, and lower in lime, strontium, uranium, and thorium than the other Mesozoic formations, but the differences are statistically very small. Local patches lithologically identical with the Colebrooke occur within areas of the Galice and along the Brushy Mountain-Iron Mountain fire road (T. 34 S., R. 12 W.). An apparent metamorphic gradation from typical Colebrooke schists with foliation in all lithologies northward to Galice slates and only faintly foliated sandstones was reported (Dott, 1966a). Coleman (unpublished manuscript) believes, however, that a thrust fault separates the two units near Iron Mountain. Therefore, an important issue is whether or not all of the large area of Colebrooke is allochthonous. Coleman finds blueschist and greenschist minerals in the Colebrooke, but only greenschist minerals to the north in Galice rocks. He also finds that the Colebrooke in this region shows two distinct deformations, whereas nearby Galice rocks show but one. A final contrast noted here and elsewhere by Coleman is that the Galice terranes include far more dioritic intrusions than occur in areas of the Colebrooke. Subsequent studies in the region should include extensive detailed structural analysis of all metamorphic rocks in order to test fully the Colebrooke-Galice relationship.

The apparent field relations in the central part of the mapped area led to the postulate that Dothan rocks also may have been metamorphosed to form some of the Colebrooke Schist (Schwab, 1963; Dott, 1965). This suggestion was based first upon the apparent increase of metamorphic grade northward between the Chetco and Rogue Rivers (Plate I; Figure 5). Local incipient cleavage characterizes the mudstones near Brookings (Widmier, 1962), and some phyllite is present locally in the mudstone south of the Chetco River on Long Ridge (T. 38 S., R. 12 W.).

Farther north near Snow Camp Mountain and Quosatana Butte, extensive zones of phyllite and schist are interbedded with nonfoliated sandstones and conglomerates. Still farther north at Rogue River all rock types are foliated. The apparent continuity of metavolcanic zones from unmetamorphosed Dothan terrane (Widmier, 1962) northward into Colebrooke terrane (Schwab, 1963; Burt, 1963) lends support to this interpretation. Moreover, the Dothan-Colebrooke contact at Snow Camp Mountain (which Coleman has reinterpreted as a thrust) aligns with the projected boundary between the sandy Mecklyn member and the mudstone-rich Winchuck member of the Dothan mapped by Widmier (1962) farther south.

A preliminary petrographic comparison of Dothan sandstones with metasandstones of the Colebrooke (Schwab, 1963) suggested that the two were similar in major components. All of these observations, together with the relatively high specific gravity of Dothan sandstones (2.67 ± 0.034 standard deviation of 31 samples), tended to support our hypothesis that the Dothan is pre-Nevadan and could have served as a protolith of the Colebrooke Schist (see upper cross section C-C'). However, more extensive structural and metamorphic data gathered by Coleman from both Dothan and Colebrooke rocks, together with possible Late Jurassic (post-Nevadan) fossils found by Ramp (1969) in apparent Dothan strata, now all but rule out the Dothan as a second protolith for the Colebrooke.

Glaucophane schists and amphibolites

Glaucophane-bearing blueschists were mapped in the north part of the area by Diller as "amphibole schists," and were interpreted as contact metamorphic rocks (Diller, 1903a, p. 3). Although Coleman found fine lawsonite widely distributed in the Colebrooke Schist, the high-grade glaucophane rocks and amphibolites appear to be more or less isolated tectonic blocks associated with major fault zones (Koch, 1966; Coleman, unpublished manuscript), thus they are discussed separately here although they are generally too small to show on the map.

In addition to examples mapped by Diller, by Lent (1969), and by Coleman (1969), examples occur near a major fault half a mile southeast of Blacklock Point (SE¼ sec. 24, T. 31 S., R. 16 W.; Bott, 1962), at several localities within one mile southeast of Sisters Rock (SE¼ sec. 6, T. 35 S., R. 13 W.; Koch, 1966), and above Pistol River in sec. 24, T. 38 S., R. 14 W. (Widmier, 1962). Finally, wave-washed boulders of blueschist occur on the northeast side of Cape Blanco. Blueschists studied by Koch (1966) and Lent (1969) contain glaucophane, chlorite, epidote, crossite, actinolite, zoisite, clinozoisite, quartz, albite, muscovite, garnet, magnetite, and hematite; jadeite has been reported only in the far north (Lent, 1969). Most examples are strongly foliated and, in some, green bands alternate with blue. While much of the glaucophane rock appears closely related to the Colebrooke Schist, in northern California similar tectonic blocks of relatively high-grade gneissic glaucophane-epidote-garnet rocks yield isotopic dates of about 150 m.y. (Lee and others, 1964; Suppe, 1969), which are older than dated for other blueschists. Common proximity of such rocks to the western thrust boundary of the Colebrooke suggests tectonic emplacement of the blocks from some deep zone. North of the Sixes River, the glaucophane rocks are randomly scattered (Diller, 1903a; Lent, 1969) and probably represent remnants of an eroded thrust sole.

Amphibolites: Koch (1966) noted the presence of local amphibolites too limited in extent to show on Plate I, which he believed had developed from diorite or gabbro. They are composed of green hornblende, chlorite, andesine, oligoclase, sphene, zircon, pyrite, hematite, magnetite, and carbonate. Glaucophane and almandine garnet are sparingly present. Coleman (unpublished manuscript) has studied amphibolites at other localities, especially those associated with the large ultramafic mass in the east-central part of the map area ("gneissic rocks" of Plate I). Gneissic hornblende diorite, amphibole gneiss, and amphibole pegmatites are more extensive still farther east (Well and others, 1949; Wells and Walker, 1953). The summit of Big Craggies (T. 37 S., R. 12 W.) consists of coarse amphibole pegmatite and amphibolite. Coleman interprets it as part of a klippe of amphibolite and peridotite. Preliminary K-Ar data for a single amphibole from the Big Craggies amphibolite suggest that metamorphism of these high-grade

Table 3. Isotopic age data.

Values reported are averages of at least two replicate analyses (± factor represents total analytical error). Procedures used for K and Ar analyses by isotope dilution at Isotopes, Inc., as well as Ar and K analyses at Geochron are flame photometry. See text for further discussion of field relations and interpretations of results. (Largely after Dott, 1965)

Sample No.	Locality	Rock type	Mineral	Laboratory†	Average Ar^{40*}, ppm	$Ar^{40*}/Ar^{40}tot$	Average %K	Apparent Isotopic Age, m.y.
Rhg	SE¼NW¼ sec. 36, T. 40S., R. 14W.	Rhyodacite sill intruding Dothan Formation	Whole rock	I	0.00652	0.35	3.23	30 ± 1
RD62-62	NW¼NE¼ sec. 5, T. 39S., R. 14W.	Mafic dike in Late Cretaceous Hunters Cove Formation	Whole rock	I	0.00200	0.25	0.93	28 ± 1
RD62-190	NE¼SE¼ sec. 14, T. 16N., R. 2W.	Granite boulders in Dothan Formation conglomerate	Biotite (chloritized)	G	0.0150	0.13	2.01	103 ± 10
				G	0.0103	0.27	1.265	110 ± 25
CS-1+	NW¼NW¼ sec. 20, T. 33S., R.14W.	Colebrooke Formation quartz-mica schist	Whole rock	G	0.0170	0.44	1.84	125 ± 6
62-173+	NE¼NE¼ sec. 3, T. 36S., R. 13W.		Whole rock	G	0.0163	0.46	1.595	138 ± 10
62-82+	SW¼SE¼ sec. 34, T. 36S., R. 14W.	Mafic dike in peridotite (probably in a klippe)	Amphibole	G	0.00078	0.29	0.0808	130 ± 15
65-60	NE¼SW¼ sec. 29, T. 32S., R. 12W.	Bray Mt. Diorite intruding Galice Formation	Hornblende	U	0.00267	0.64	0.322	135 ± 4
ERR-1	NW¼SW¼ sec. 15, T. 33S., R. 14W.	Pearse Peak Diorite intruding Galice Formation	Biotite	G	0.0298	0.46	2.85	141 ± 7
				A	0.03268	0.89	3.64	145 ± 4
Q-11+	NE¼NE¼ sec. 27, T. 33S., R. 14W.		Hornblende	G	0.0192	0.24	0.91	275 ± 20§
18-25-7	SE¼SW¼ sec. 20, T. 39S., R. 13W.	Vitric andesite or dacite (probably tectonic blocks within Dothan Formation)	Whole rock	I	0.00198	0.40	0.18	149 ± 4
CB-14+	Top Collier Butte (T. 37S., R. 12W. unsurveyed)	Collier Butte Diorite	Hornblende	G	0.0103	0.665	0.915	151 ± 12
35-8+	1.5 mi. WNW of Saddle Mt. (T. 37S., R. 12W., unsurveyed)	Saddle Mt. Diorite	Hornblende	G	0.00405	0.06	0.185	285 ± 25
16-28-5	SE¼NW¼ sec. 3, T. 39S., R. 14W.	Mafic dike in shear zone	Whole rock	I	0.00577	0.32	0.36	215 ± 5

* Radiogenic Ar^{40}. † I, Isotopes, Inc.; G, Geochron Laboratories; A, University of Alberta; U, U.S. Geological Survey (Menlo Park)
\+ Dated under Student Project Award by Geochron Laboratories. § Anomalously high; see text.
Constants: $\lambda\beta = 4.72 \times 10^{-10} yr^{-1}$; $\lambda\epsilon = 0.585 \times 10^{-10} yr^{-1}$; $K^{40}/K = 1.22 \times 10^{-4}$ g/g (at lab U atomic abundance of $K^{40} = 1.19 \times 10^{-4}$)

rocks may have been contemporaneous with metamorphism of the high-grade blueschist tectonic blocks in California (circa 150 m.y.; Coleman, personal communication, 1970).

Ultramafic rocks associated with the Colebrooke Schist

The large masses of serpentinite and peridotite bordering small dioritic and gabbroic masses all occur within or adjacent to the Colebrooke Schist (Plate I, Figure 5). They are chiefly harzburgite with minor dunite and pyroxenite. All are extensively serpentinized to lizardite and clinochrysolite and minor associated brucite. The Signal Buttes and Snow Camp masses, as well as the possibly related Vondergreen Hill (sec. 32, T. 35S., R. 14W.) andCorpenterville (sec. 3, T. 39S., R. 14W.) bodies, contain enstatite, diopside, forsterite, and spinel (Medaris and Dott, 1970). A high aluminum content of the pyroxenes and spinels, together with apparent Paleozoic K-Ar dates (Table 3) from two dioritic bodies within the ultramafic masses (Dott, 1965), suggests original crystallization in the mantle more than 200 million years ago, and subsequent structural transport -- possibly by sea-floor spreading -- to their present sites. Calcium-silicate metasomatic border haloes in practically all adjacent rocks (Coleman, 1967) and universally sheared contacts also point to tectonic emplacement. Coleman believes that the large ultramafic masses are sheets emplaced by overthrusting, but not necessarily everywhere the same thrusting as that which affected the Colebrooke; emplacement of some of the serpentinite may have preceded that of the Colebrooke. According to the concept of sea-floor spreading, the underthrusting of an oceanic crust beneath a continental plate should have been more or less continuous t rough Mesozoic time.

Around Signal Buttes and from there northwestward to Rogue River, intimate jumbling of large masses of schist and serpentinite tend to support the interpretation that the Colebrooke moved upon a "tectonic carpet" of serpentinite (Coleman, 1969), although some of the mixing could reflect landsliding. The serpentinites at and north of the mouth of Rogue River also are interpreted by Coleman to be eroded outliers of a thrust sheet, which interpretation seems supported by a prevalence of nearly flat shear surfaces in Otter Point sediments in road cuts west of Wedderburn (Figure 6). Koch (1966) interpreted this area to be a shear zone dominated by vertical faults with subordinate small thrusts. It may be that here, as at Sisters Rock, Port Orford, and elsewhere, vertical Cenozoic faults have been superimposed upon older flat thrust sheets.

Dioritic and gabbroic intrusive rocks

Distribution: Dioritic stocks collectively referred to as "gabbro" by Diller (1903a) and dikes of diorite and dacite are common in the northern half of the map area, where most intrude t e Galice Formation. Several stocks and dikes of diorite and some gabbro (for example, Snow Camp Mountain, Collier Butte, and Saddle Mountain; Figure 5) and at least one granite (south end of Iron Mountain, NW¼ T. 34 S., T. 12W.) occur within large ultramafic masses. In the Kerby quadrangle a few miles east of the present map area, dioritic masses of batholithic areal proportions and granodiorite stocks occur (Wells and others, 1949); similar ones also occur in northernmost California (Lanphere and others, 1968). All appear to be petrologically related (see Lund and Baldwin, 1969), and they yield similar isotopic dates. Coleman (unpublished manuscript) has made the important observation that diorite intrusives are almost completely lacking in the Colebrooke Schist. This, he feels, is further evidence that the Colebrooke was not formed where it now lies.

Pearse Peak Diorite: The most completely studied intrusive in the area is the Pearse Peak pluton (T. 33S., R. 14W.) (Kaiser, 1962; Koch, 1966). It consists of hornblende diorite at its margins and hornblende-biotite quartz diorite in the center. Hornblende, which varies considerably in abundance, and plagioclase are dominant constituents. The plagioclase is strongly zoned, ranging from An_{30} to An_{46} (Kaiser, 1962). Quartz comprises 5 to 10 percent, while biotite, untwinned intermediate microcline, sphene and magnetite are accessorites (Figure 7). The northwest margin of the stock contains some pyroxene. Representative chemical analyses of this and other diorites appear in Table 2, and they are notable for rather low K_2O/Na_2O ratios. Most of the minerals, but especially the plagioclase and biotite, show alteration. The southwestern border has suffered extreme cataclasis along what Koch (1966) named the Brush Creek shear zone. There the rock shows extreme alteration with development of laumontite,

Figure 6. Intensely sheared sandstone and mudstone of the Otter Point complex along U.S. Highway 101 just west of Wedderburn at the mouth of the Rogue River. As in Figure 3, boudinage effects in the mudstone are conspicuous, and brittle fracture characterizes the more massive sandstones. The shear surfaces, however, are nearly flat here. Koch (1966) assumed local thrusting related to strike-slip faulting. Coleman and Blake (personal communications, 1969) regard this as a result of large-scale, low-angle thrusting assumed to have emplaced nearby ultramafic masses and the Colebrooke Schist. Their interpretation, which has much to recommend it when considered in the regional context of thrusting, would alter the map interpretation of Plate I in this area (W½ T. 36 S., R. 14 W.).

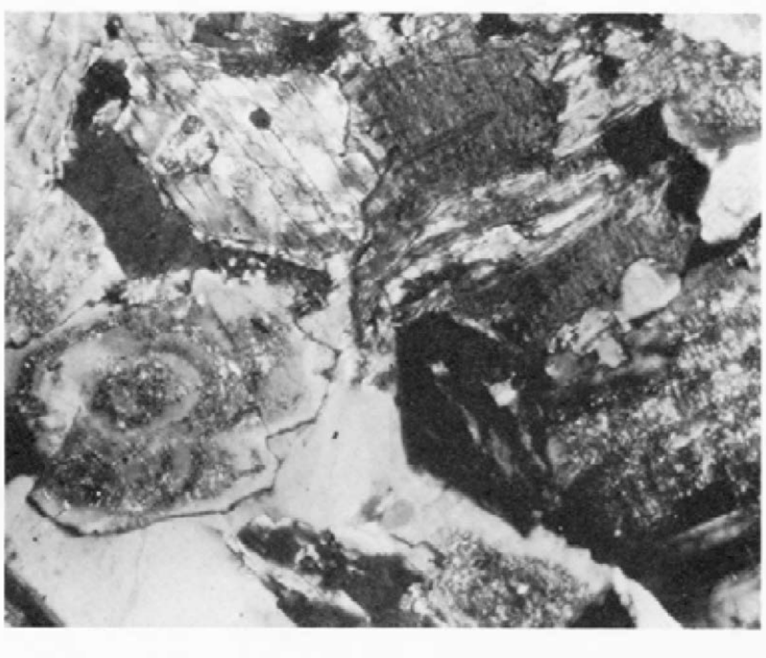


Figure 7. Photomicrograph of the typical Pearse Peak quartz diorite phase, showing characteristic subhedral, zoned and selectively altered plagioclase (left center) with hornblende above and to right, and quartz below. Upper right corner has biotite with prehnite interleaved. (After Kaiser, 1962) (X 45)

leonhardite and prehnite (Kaiser, 1962). A narrow hornfels zone is present at contacts with Galice metasediments.

<u>Other diorite masses:</u> The Collier Butte and Snow Camp diorite bodies, which are surrounded by serpentinite, also have been studied petrographically. The Collier Butte body is more silicic, but otherwise is similar to the Pearse Peak, being composed of zoned and altered plagioclase (An_{37-45}), quartz, and hornblende with 1 percent K feldspar, and minor biotite, chlorite, sphene, clinozoisite, magnetite, and pyroxene (Burt, 1963). The rock is faintly porphyritic. It appears to be intrusive into the surrounding ultramafic complex, for it has sharp contacts and contains serpentinite inclusions. The nearby Snow Camp Mountain diorite contains considerably more clinopyroxene and no quartz. The Saddle Mountain Diorite, which apparently is much older than the others, is composed of twinned and zoned plagioclase (An_{31-43}), clinopyroxene, minor amphibole, magnetite and epidote; K feldspar and quartz are insignificant. Its contacts with the ultramafic rocks are sheared and altered, and it clearly is faulted against Lower Cretaceous strata along Lawson Creek (see Figure 5).

The remaining stocks and dikes in the map area vary somewhat in composition and texture. Dacitic dikes are very poor in mafic minerals, while some dark gabbroic dikes are rich in mafics. Distinctive porphyritic dikes with large zoned plagioclase phenocrysts are especially common in the northeastern part of the map area.

<u>Ages:</u> The fossiliferous Humbug Mountain Conglomerate of Early Cretaceous age unconformably overlies the Galice Formation and contains abundant fragments of Pearse Peak-type diorite as well as Galice material. Thus the Pearse Peak and related diorites in the map area are pre-Early Cretaceous, although Diller considered them post-Early Cretaceous and pre-Eocene. He noted many "gabbro" and dacite clasts in the Cretaceous conglomerates, but apparently he was more impressed by dacitic dikes cutting serpentinite, the latter of which he was convinced must be post-Cretaceous. That he was aware of the conflicting evidence is clear from his field notes (see Dott, 1966a for more details), but there is no hint of this in the published folio. It was common practice at the turn of the century to interpret most contacts between ultramafic and Cretaceous rocks as intrusive, whereas today there is adequate evidence of structural dislocation in practically all cases (Coleman, 1967).

K-Ar dating of biotite from the Pearse Peak body yielded results of 141 ± 7 and 145 ± 4 m.y. as reported earlier (Dott, 1965). One date of 275 ± 20 m.y. from hornblende is regarded as spurious (see Table 3). Recently Marvin Lanphere of the U.S. Geological Survey obtained a K-Ar date of 1 5 ± 4 m.y. on hornblende from my sample of the Bray Mountain diorite mass (SW cor. T. 32 S., R. 12 W.). A gabbroic dike cutting peridotite (SE¼ sec. 34, T. 36 S., R. 14 W.) earlier gave a K-Ar date from hornblende of 130 ± 15 m.y. (This was from a small, rather isolated exposure that now appears to be a klippe, thus is of limited value for interpretation.) The Collier Butte Diorite yielded a hornblende K-Ar date of 151 ± 12 m.y. (Dott, 1965). Recent K-Ar dating by the U.S. Geological Survey on hornblendes and micas from the Pearse Peak, Iron Mountain (T. 33 S., R. 12 W.), and Game Lake (T. 36 S., R. 12 W.) diorite bodies confirm the range 135 to 145 m.y. for final cooling of most dioritic plutons in the region (Coleman, personal communication, 1970).

It appears that the formation of diorites of similar composition occurred widely in the Klamath region during Late Jurassic time (Oxfordian to Tithonian). Those in Oregon correspond closely to the "northern group" of plutons (145 to 155 m.y.) in northern California (Lanphere and others, 1968), although the Pearse Peak and Bray Mountain bodies may be slightly younger. Collectively these plutons reflect a major episode of well-dated, classical Nevadan plutonism. The isotopic dates suggest a gap of perhaps as much as 10 or 15 million years between plutonism and Colebrooke metamorphism. Alternatively, it is possible that plutonism and metamorphism were contemporaneous, if the schists remained above the argon-fixing temperature (150° to 200° C.) longer than did the diorites. Because of subsequent large-scale structural dislocations; however, the plutonism and the metamorphism of the Colebrooke may not have been as closely related either in time or space as had been assumed.

At least two dioritic to gabbroic bodies within serpentinite masses appear to be much older than the others. The Saddle Mountain pluton, which is only 2 miles northwest of the Jurassic Collier Butte Diorite, yielded a K-Ar hornblende date of 285 m.y., and a small gabbroic body within the intensely sheared Carpenterville serpentinite mass yielded a whole-rock K-Ar date of 215 m.y. (see Table 3).

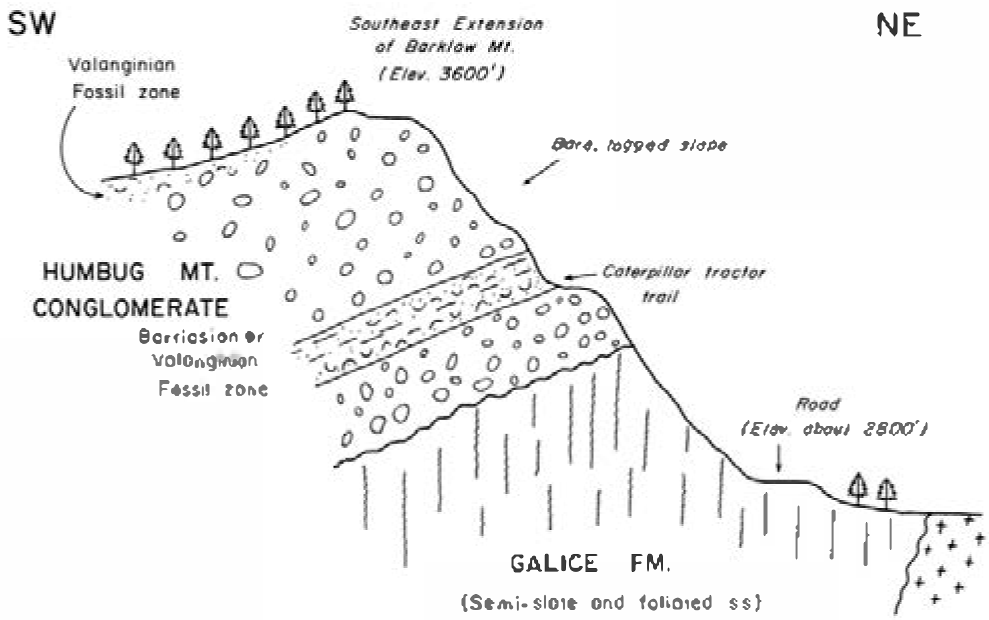


Figure 8. Cross section through the southeast end of Barklow Mountain showing the angular unconformity at the base of the Humbug Mountain Conglomerate and relative positions of fossil zones. The isotopically dated Bray Mountain Diorite stock, with many dike apophyses, cuts the Galice Formation just to the right of the diagram area; hornfels is common adjacent thereto.

Such old dates suggest an entirely different (probably sub-crustal) origin for these rocks than for the other diorites (Medaris and Dott, 1970).

Humbug Mountain Conglomerate (Early Cretaceous)

Definition: Widespread coarse, massive conglomerate was discussed by Diller (1903a), who noted that it was concentrated in the lower part of the "Myrtle Formation," which he had named (1898) in the Roseburg quadrangle 50 miles inland. Later the Myrtle was elevated to group rank (Imlay and others, 1959). Diller found it very difficult both to map the conglomerate and to discern structures within the "Myrtle" rocks, partially due to his failure to recognize the great unconformity between it and the dioritic and metasedimentary Galice complex (figure 8). This error resulted partly from his belief that only a small area of "Jurassic slates" existed in the Johnson Creek drainage, where one of his assistants had found fossils (see discussion of Galice Formation). In retrospect it is difficult to understand how Diller so underestimated the contrasts between the unmetamorphosed Cretaceous strata and the slightly metamorphosed and intruded Galice. Recognition and tracing of the major unconformity between them was a major key to interpreting the northern part of the map area. One result was the realization that the actual area of "Jurassic slates" (Galice Formation) is about five times as great as Diller supposed.

The term "Myrtle," although perhaps useful as a loose time-stratigraphic designation for Early Cretaceous strata on the coast, has been abandoned as a formal rock unit name here because the coastal strata are lithologically distinct from the type Myrtle Group, and physical continuity between the two areas is interrupted by a wide zone of Eocene rocks. Koch (1966) named and defined the Humbug Mountain Conglomerate for outcrops on Humbug Mountain, a bold promontory on the coast in sec. 35, T. 33 S., R. 15 W. (Figure 1). The formation is at least 2,500 feet thick, and appears to range up to 5,000 or 6,000 feet both there and along the Elk River, 4 miles to the northeast. Near the north edge of the map area, it is at least 1,000 feet thick at Mount Avery (Lent, 1969), and from 2,000 to 3,000 feet thick at its eastern limit in Copper and Barklow Mountains (Figure 4).

Basal (Nevadan) unconformity: In 1959 an exposure of the unconformity at the base of the Humbug Mountain Conglomerate was discovered on Elk River (SW¼SW¼ sec. 8, T. 33 S., R. 14 W.), but it was 6 years before another locality was found. On the east side of Copper Mountain Diller recorded in succession slate, diorite, conglomerate with "*Aucella piochii*," and on the west side of the mountain he recorded "*Aucella crassicollis*." *Aucella* was subsequently referred to the genus *Buchia*. Three miles to the north on the southeast side of Barklow Mountain he reported a similar sequence from slates up to conglomerate. Using Diller's field notes as a guide, I was fortunate, in 1965, to find the contact exposed on the east face of Barklow Mountain along a fresh logging trail (Dott, 1966a). Fossil control in older and younger rocks brackets the age of the unconformity as early Early Cretaceous. (Imlay and Jones [written communication, 1970] have re-evaluated the collections reported in 1966 as "Upper Jurassic -- Portlandian"; these are now regarded as Berriasian or Valanginian.)

Lithology: Along Elk River, at least the lower 1,500 feet of the formation is so massive that attitudes can rarely be determined. The unit is very coarse there, containing boulders 2 feet in diameter, but averaging between 2 and 4 inches (Figure 9). Similar coarse conglomerate also occurs above the unconformity on Barklow Mountain. Partial columnar sections of the formation were published by Koch, but they represent higher parts of the formation in which more sandstone and mudstone occurs interstratified with characteristic heterogeneous conglomerate. Graded bedding characterizes many of the higher beds; graded conglomerate units average about 2 to 3 feet, but range up to 10 feet thick (Figure 10). They are best exposed on the southwest and northwest sides of Humbug Mountain, and on the headland just north of Myrtle Creek (sec. 19, T. 34 S., R. 14 W.). Alternating mudstone and sandstone units average a few inches in thickness, but some sandstones range up to 4 or 5 feet in thickness. The coarse, massive lower conglomerates apparently represent deposition adjacent to a rugged shoreline, probably along active fault escarpments, whereas the upper, partly graded sequence represents unusually coarse turbidity current deposits and grain flows (Koch, 1966; Aalto and Dott, 1970). The shallow-water fossils, which occur in conglomerate and sandstone, are displaced elements (see Imlay, 1959).

Conglomerate clasts, most of which are moderately well rounded, include a variety of igneous and metamorphic types clearly derived from the underlying basement, as well as some clasts derived by scour of contemporaneous sediments. Koch (1966) found that various igneous rocks comprised about 60 percent, metamorphics 30 percent, and sedimentary only 10 percent of the clasts. Petrographic analysis revealed diorite, amphibolite, andesite, keratophyre, propylite, dacite, rhyolite, lapilli tuffs, chert, schist, phyllite, slate, vein quartz, and unmetamorphosed sandstones (Koch, 1966). In the Barklow Mountain area, proportions are similar, with more metamorphic clasts near the base; igneous types are about equally divided between porphyritic volcanic and dioritic varieties. A few percent of white, milky quartz pebbles also are present (Dott, 1966a). Farther north, Lent (1969) reported chert 30 percent, schist and phyllite 20 percent, diorite 15 percent, volcanics 20 percent, sandstone 10 percent, and quartz 50 percent. Fabric is not conspicuous in the conglomerates, but a slight preferred orientation of elongate clasts may be seen in some units.

The sandy matrix of the conglomerates, as well as interstratified sandstones, is angular, poorly sorted, and heterogeneous in composition (Figure 11). In general, the sandstones are feldspathic-lithic (chert) wackes with 10 to 15 percent total feldspar (0 to 5 percent K feldspar), up to 25 percent quartz, 5 to 10 percent volcanic clasts, and 60 to 80 percent sedimentary fragments (Koch, 1966). Of the last, Koch considered 20 to 25 percent to be chert; however, it is probable that some of this is devitrified volcanic glass that is very difficult to distinguish from true sedimentary chert; pebbles of similar material with white feldspar phenocrysts occur in most of the Mesozoic conglomerates of the region. Variable but important amounts of phyllite fragments and serpentinite also are present, and Lent (1969) reports lawsonite, prehnite, clinopyroxene, and garnet locally in sandstones. The abundant matrix in the sandstones is dark, and is composed of chlorite, illite, vermiculite, and interstratified chlorite-montmorillonite (in order of decreasing abundance as determined by J. B. Hayes). Mudstones of similar composition interstratified in the upper Humbug Mountain Conglomerate are dark gray to black, and have scattered calcareous lenses. Macerated plant debris and rare pelecypods are concentrated in siltstone laminae.

Age and correlation: The Humbug Mountain Conglomerate contains mollusks at its base on Barklow Mountain that have been dated as Early Cretaceous (Berriasian or Valanginian) (Imlay and Jones,

Figure 9. Coarse Humbug Mountain Conglomerate along Elk River a few hundred feet above the basal unconformity (SW¼ sec. 8, T. 33 S., R. 15 W.). Note the well-rounded shapes of most boulders, poor sorting, and lack of perceptible stratification. Light-colored clasts are Pearse Peak Diorite and darker ones (especially angular one at left) are Galice metasediments and metavolcanics.

Figure 10. Graded conglomerate units typical of the upper Humbug Mountain Conglomerate exposed in first headland just north of Myrtle Creek, sec. 19, T. 34 S., R. 14 W. The conglomerate here contains many black, faintly slaty pebbles derived from the Galice Formation. Diller (1903a) reported them to be schist, implying derivation from the Colebrooke Schist exposed only half a mile to the south. His lithologic terminology was somewhat misleading, however; more definite Colebrooke-like pebbles are present on the lower Elk River (see text).

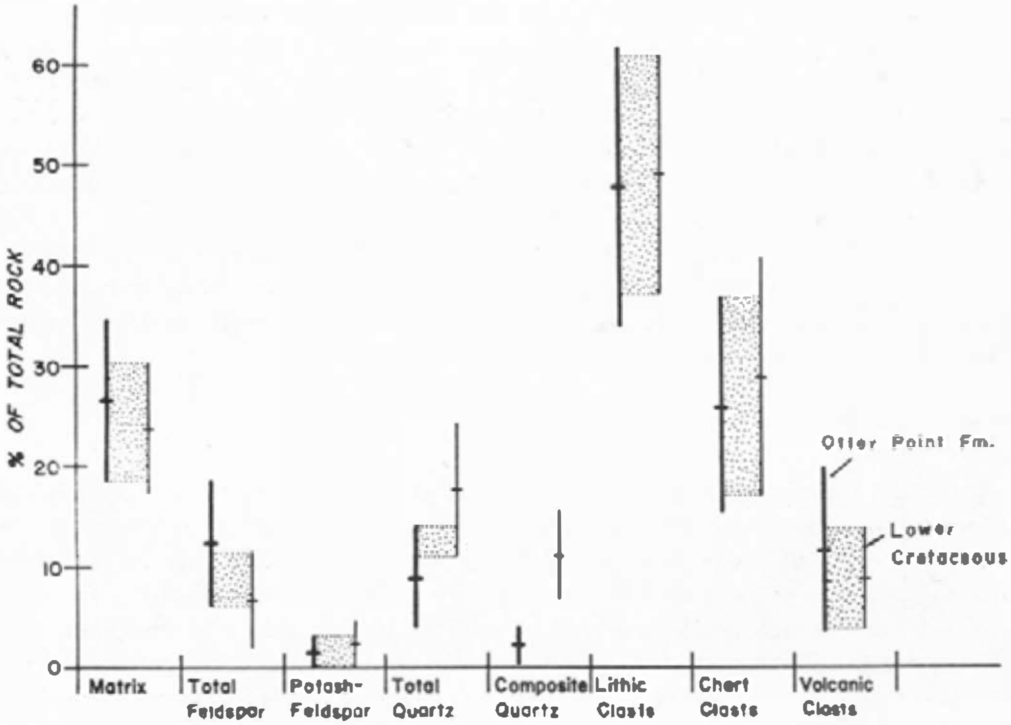


Figure 11. Comparison of sandstone compositions for the Otter Point and Lower Cretaceous (Humbug Mountain and Rocky Point) formations. Vertical bar represents ±1 standard deviation, and cross bar is the mean value. Note the general overlap of values (stippled) except for composite (polycrystalline) quartz. (After Koch, 1966; Koch's doctoral thesis [1963] contains much additional statistical treatment of the compositional data.)

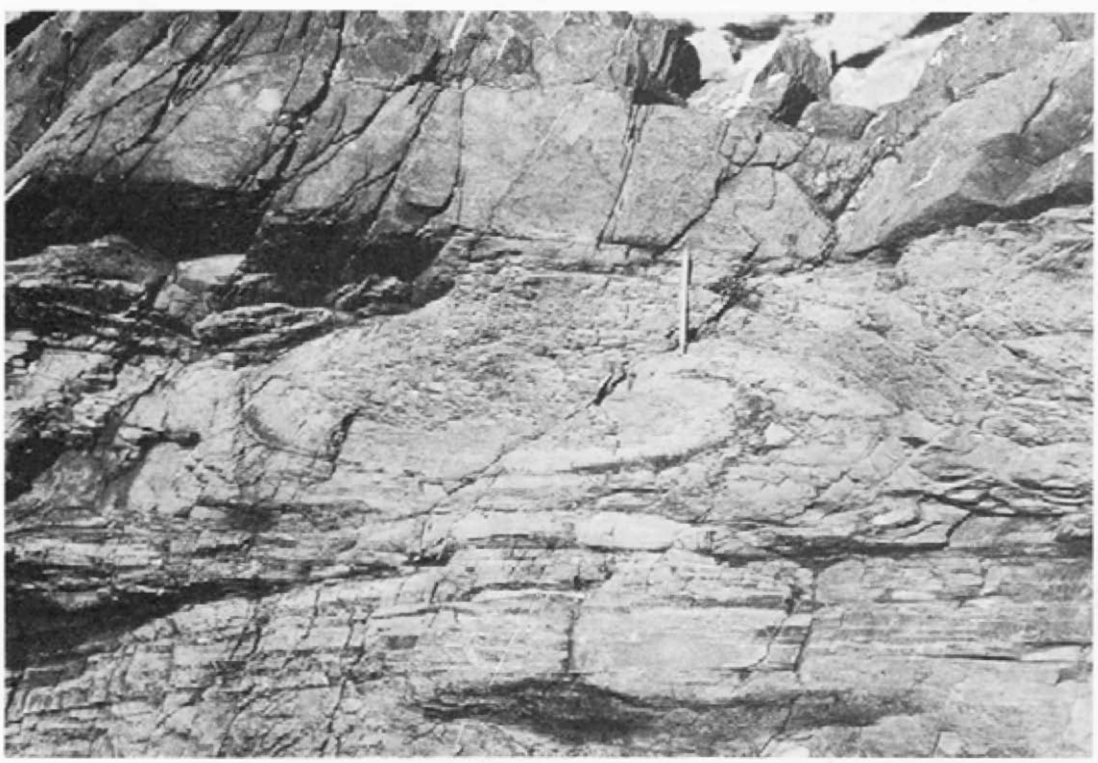


Figure 12. Contorted zone within alternating graded sandstone and mudstone units typical of the Rocky Point Formation; pencil provides scale. (Sea cliff near Rocky Point about 1.5 miles north of Humbug Mountain.)

written communication, 1970). No fossils are known from the massive lower half of the formation near the coast, but the pelecypod Buchia crassicollis occurs in the upper half throughout the region. Associated with Buchia on the coast are the ammonoids Hannaites, Eodesmoceras?, Sarasinella hyatti, and Phylloceras?, and the belemnoid Aulacoteuthis. This latter assemblage indicates an Early Cretaceous (Valanginian) age for at least the upper half of the formation (Koch, 1966). Possibly the largely barren lower portion is somewhat variable in age due to unconformable onlap, but restudy of Buchia zones in the area by Jones (1969) suggests that none of the formation is of Late Jurassic age.

The Humbug Mountain Conglomerate apparently is correlative with parts of the Riddle and Days Creek Formations of the formally defined Myrtle Group near Roseburg (Imlay and others, 1959). Similar faunas occur on the west side of the Sacramento Valley, and at scattered localities in the Franciscan assemblage of northern California (Bailey and others, 1964).

Rocky Point Formation (Early Cretaceous)

Definition and lithology: Koch (1966) applied the term Rocky Point Formation to a sequence about 6,000 feet thick of alternating sandstones and mudstones, which crop out continuously in sea cliffs north of Humbug Mountain at Rocky Point in the NW¼ sec. 15, T. 33 S., R. 15 W. The unit also occurs both south and north of Pearse Peak and in the upper Elk River syncline (Plate I, Figure 4). Lent (1969) believes that the formation may be in excess of 8,000 feet in thickness near the Sixes River.

The Rocky Point Formation differs from the underlying Humbug Mountain Conglomerate in containing much less (and finer) conglomerate. It is characterized by graded sandstones averaging from 2 to 5 feet thick that alternate with beds of dark gray mudstone, which average from 3 to 5 inches in thickness (Figure 12). Granule and fine-pebble conglomerate is almost entirely confined to the bases of the graded sandstones. The pebbles are composed of chert, igneous, and some metamorphic r cks. The sandstones are compositionally and texturally identical with those in the upper Humbug Mo ntain Conglomerate (Koch, 1966). Average density of 26 sandstones from both formations is 2.54 (range = 2.41-2.78). The two fo mations have a gradational contact, their distinction being arbitrarily determined by the highest significant cobble or boulder conglomerate.

Besides graded bedding, the Rocky Point Formation contains some sole marks (both flutes and grooves), fine cross lamination, convolute laminae, and a few zones of contorted strata (Figure 12; see also illustrations in Dott, 1963 and Koch, 1966). Koch determined that paleocurrents flowed toward the we t. The Rocky Point sediments probably were deposited largely by turbidity currents. The coarseness (excess of 6:1 ratio of conglomerate-plus-sandstone to mudstone) qualifies the sequence as so-called proximal turbidites (Aalto and Dott, 1970).

Age and correlation: The Rocky Point Formation contains Buchia crassicollis, Sarasinella cf. S. angulata, S. cf. densicostata, Kilianella, Neocraspedites?, and Olcostephanus cf. O. quadriradiatus of Early Cretaceous (Valanginian) age (see Koch, 1966). The Buchia commonly are concentrated in coa se sediments, as at Rocky Point; concentrations of large plant debris also are common. The formation is correlative with part of the Days Creek Formation near Roseburg (Imlay and others, 1959), part of the Lower Cretaceous sequence of the Sacramento Valley, and some of the Franciscan assemblage (Bailey and others, 1964).

Undifferentiated Late Jurassic and Early Cretaceous strata (Myrtle Group) of the east-central region

On the east-central edge of the map area from Snow Camp Mountain to Agness, undifferentiated uppermost Jurassic and Lower Cretaceous strata ("JK") are present. The rocks were referred to the Myrtle Group by Imlay and others (1959). Burt (1963) and I have mapped them on Jacoby Butte (near Collier Butte) and along Lawson Creek to the northeast (Figure 5), and Baldwin (1968) has studie them at and south of Agness. Coleman (unpublished manuscript) postulates that most of these areas are allochthonous upon ultramafic and Colebrooke rocks. To date no basal contact has been seen, although Tithonian mudstone and conglomerate are present at Jacoby Butte and Sevenmile Peak. Most of the undifferentiated strata are Cretaceous as indicated by Buchia species and ammonoids (Figure 5). No volcanic rocks are associated, and the beds consist of well-stratified dark mudstone and sandstone with prominent zones of very well-rounded pebble and cobble ("ball bearing") conglomerate. Most of the conglomerates are well sorted and closely packed. The lack of associated volcanic rocks, greater abundance of fossils, and less prominence of graded bedding together suggest that these strata were deposited in more stable shelf or slope environments than those inferred for the Tithonian-aged Otter Point rocks farther west (Aalto and Dott, 1970).

Undifferentiated strata ("JK") north of the Sixes River apparently all belong to the Otter Point complex (Lent, 1969), so are discussed below.

Mesozoic Rocks along the Coast

Otter Point Formation or complex (Latest Jurassic)

Definition: A complex flysch-like assemblage of steeply dipping and sheared latest Jurassic black mudstone, sandstone, conglomerate and volcanic rocks cropping out along most of the coastline from Cape Blacklock south to Whalehead was named the Otter Point Formation by Koch (1966) in reference to a headland located 3 miles north of the mouth of Rogue River. The Otter Point lies north, west and south of the Klamath-type rocks previously described for the north part of the map area and adjacent to the Colebrooke Schist farther south. The formation is bounded almost everywhere by faults. Although its original thickness is unknown, it is assumed to have been thousands of feet. There is little stratigraphic continuity within the Otter Point rocks, for they have been intensely sheared in many areas (Figures 3 and 6). Sheared serpentinite pods and a few small masses of diorite are associated. Because of the pervasive shearing, lack of preserved stratigraphic order, and the presence of exotic rock masses, the Otter Point as a whole should be considered a tectono-stratigraphic complex or mélange, rather than a true rock-stratigraphic unit (Hsu, 1968). Exotic rocks, such as serpentinite, are not everywhere present, so that many individual outcrops qualify as Hsu's broken formation; accessible examples occur at the Heads in Port Orford, and in the headlands and U.S. Highway 101 road cuts in T. 39 S., R. 14 W. No formal attempt has been made to differentiate separate mélange units within it. In spite of the rather chaotic over-all character of the Otter Point, some lateral continuity of lithic units, such as conglomeratic and volcanic zones, certainly does exist as is shown on the map.

The Otter Point complex, besides being structurally complicated, is also the most lithologically varied unit in the region. Therefore, no single locality or stratigraphic section can adequately characterize it. For this reason, Koch designated and illustrated several reference columnar sections. Of the entire Otter Point, black mudstone and thin, fine sandstones comprise roughly 30 to 40 percent, whereas coarse sandstones and conglomerates comprise from 20 to 30 percent each; volcanic rocks make up the remainder. The type section is dominantly vertical, thinly bedded black mudstone and fine sandstone (Figure 13), with a thin volcanic breccia at the top and pebbly mudstone at the base. Either faint graded bedding or fine cross laminae occur in many of the sandstones, and light gray calcareous nodules are common in the mudstones. Mollusks and plant debris occur sparingly throughout (Koch, 1966). Elsewhere, portions of the unit are dominated by thick and coarse graded sandstone with only thin mudstone intercalations, such as Koch's reference section near Miller Creek in Squaw Valley (6 miles northeast of Otter Point) and in Belemnite Cove 20 miles south (NW$\frac{1}{4}$ sec. 16, T. 39 S., R. 14 W.), which area has been referred to the Otter Point since Widmier (1962) first studied it (Figure 14). A third distinctive lithologic type is dominated by thick pebble-to-boulder conglomerate, both graded and nongraded, as in Koch's reference section at Nesika Beach, 2 miles north of Otter Point. Zones of ellipsoidal lavas and volcanic breccias are distributed throughout the outcrop area. They, together with massive conglomerates, being relatively resistant to erosion, tend to be the most easily mapped lithologies.

North of Sixes River, Lent (1969) has recognized Otter Point sediments and volcanic rocks in most of the area shown as "JK" along the north margin of the present map. He characterizes it there as so sheared and discontinuous that no consistent trends could be discerned. He also found serpentinite more or less randomly distributed within areas of the Otter Point rocks. Diller collected Buchia piochii at several localities north of Sixes River (Imlay, written communication, dated 1953).

Figure 13. Otter Point, 3 miles north of the mouth of Rogue River. Vertical black mudstone and thin sandstones of the type section of the Otter Point Formation are overlain at the right by light-colored Pleistocene shallow-marine sands exposed on an elevated marine terrace.

Figure 14. Flysch-like sequence of thick, graded sandstone units alternating with mudstone in the Otter Point at "Belemnite Cove" (NW¼ sec. 16, T. 39 S., R. 14 W.). Graded bedding and sole marks show that the sequence is overturned. It was deposited by turbidity currents that flowed from south-southwest to north-northeast. This sequence represents a large block of well-stratified strata surrounded by intensely sheared Otter Point conglomerate and graywacke; thus it is a block within a broken formation terrane (see Hsu, 1968).

Conglomerate: The conglomerates are as variable as they are conspicuous. Prominent conglomerate sequences, some with boulder-size material, occur from Houstenaden Creek (sec. 9, T. 39 S., R. 14 W.) to Whalehead Creek (sec. 3, T. 40 S., R. 14 W.) (Widmier, 1962; Aalto, 1968), on the north bank of Rogue River from Squaw Valley road in sec. 9 eastward into sec. 11, T. 36 S., R. 14 W., and in the lower Pistol River area. Most common are massive, ungraded conglomerates composed of well-rounded and well-sorted chert pebbles with high sphericity. Next in abundance are less sorted pebble conglomerates with considerable sandy matrix; many, though not all of this type, show graded bedding as in Koch's Nesika Beach section. Penecontemporaneous mudstone clasts tend to be abundant in these.

Coarse, massive, but poorly sorted conglomerates with many rounded boulders and cobbles, while less abundant over-all, are conspicuous because they are as much as 100 feet thick and are well exposed. Notable examples occur at Indian Sands headland near Whalehead (sec. 33, T. 39 S., R. 14 W.), where boulders as much as 1.5 feet occur, and intermittently in headlands from Miller Creek (sec. 16, T. 39 S., R. 14 W.) south to Thomas Creek. They are interstratified in a sequence of finer massive conglomerates, graded sandstones, and thin mudstones (Figure 14), all of which have been intensely fractured and sheared (Widmier, 1962; Aalto, 1968). One of the most beautifully rugged portions of the entire Oregon coast was carved from these resistant rocks in the 6-mile stretch from Houstenaden Creek south to Whalehead (Plate I; see Figure 35). Sugarloaf Mountain (sec. 34, T. 31 S., R. 13 W.) contains coarse conglomerate tentatively referred by Lent (1969) to the Otter Point, but blueschist clasts reported to be present suggest that this example actually may represent a younger formation.

Smaller conglomerate pebbles are composed chiefly of black, gray, green and red chert. Less abundant in various sizes are andesite, keratophyre, porphyritic greenstone, dacite, white vein quartz, phyllite, and, in the coarsest clasts, dioritic, granodioritic, and gabbroic varieties (Koch, 1966; Aalto, 1968). Penecontemporaneous mudstone and sandstone clasts as well as rare mollusks, belemnoids, and plant debris also occur sporadically. Presence of many coarse plutonic clasts near Whalehead suggests proximity of that area to a rugged tectonic island during latest Jurassic time.

Rare but distinctive unsorted pebbly mudstones occur near Otter Point, in the southwest face of Cape Blanco (Figure 15), at the Sisters Rock road junction with U.S. Highway 101 (sec. 31, T. 34 S., R. 14 W.), on the north side of "Belemnite Cove," and at Indian Sands headland near Whalehead. By far the most spectacular example is at Cape Blanco, illustrated by Dott (1962; 1963) and by Aalto and Dott (1970) (see Figure 34). A lenticular mass 60 feet thick and half a mile long of unstratified and completely mixed sediment slabs as much as 20 feet long, rounded pebbles and boulders as large as 3 feet in diameter, large chunks of trees and belemnoids are all set in a muddy and sandy matrix that comprises about half of the rock. The mass is overturned, and occurs interstratified with thick, graded sandstone units as much as 7 feet thick, which display sole marks formed by currents that moved in an east-west sense.

Sandstone: Thin, fine sandstone occurs throughout the Otter Point, although thicker and coarser sandstone is prominent locally (Koch's reference section near Miller Creek in Squaw Valley, at "Belemnite Cove," and at Cape Blanco). Most of the latter show graded bedding, but sole marks are rarely seen. Mudstone clasts, plant debris, and rare mollusk shells are also present.

Petrographically most of the sandstones are feldspathic and lithic (chert-volcanic) wackes. They contain less than 5 percent K feldspar, less than 6 percent polycrystalline quartz in contrast to Lower Cretaceous sandstones (Figure 11). In volcanic zones, volcanic detritus is predominant (Koch, 1966; Aalto, 1968). Lent (1969) distinguished two sandstone types north of the Sixes River -- a massive feldspar-rich variety with 2 to 3 percent K feldspar, and a darker, lithic variety with relatively less quartz and feldspar; white veins of laumontite also are present. The typical dark color of Otter Point sandstone results from a predominantly chloritic matrix (X-rayed by J. B. Hayes, written communication, 1964) as well as an abundance of dark chert, mudstone and other rock fragments. The average density of 60 sandstone samples is 2.61 (range = 2.26 - 2.85).

Volcanic rocks and bedded chert: The volcanic rocks are predominantly keratophyre, basalt (and spilite), pyroxene andesite, and propylite (Koch, 1966). Some chemical analyses are presented in Table 2. Aphanitic textures are most common, but a distinctive type of porphyritic pillowed basalt with white plagioclase phenocrysts as much as half an inch long is widespread (Figure 16). Examples are exposed at the mouth of the Sixes River and on Blacklock Point, along Rogue River (sec. 2, T. 36 S.,

Figure 15. Spectacular unstratified pebbly mudstone mass in Otter Point rocks on the west face of Cape Blanco. Normal, stratified graded graywackes at bottom of view show overturning, thus were deposited upon a submarine mudflow that produced a lens half a mile wide and 60 feet thick (maximum). The deposit contains chaotic sediments with large chunks of wood, belemnoids, and all sizes of clastic sediments. Note slabs of thinly bedded Otter Point sediments within the mass. (See also Dott, 1962 and 1963).

Figure 16. Otter Point pillow basalt with conspicuous coarse feldspar phenocrysts exposed on Pistol River (NE¼ sec. 22, T. 38 S., R. 14 W.). Such porphyritic pillow lava seems to be characteristic of the Otter Point.

R. 14 W., south of Rogue River (in SW¼ sec. 28, T. 36 S., R. 14 W.), on Hunter Creek (secs. 20 to 21, T. 37 S., R. 14 W.), on the north side of Sundown Mountain (SW¼ sec. 3, T. 38 S., R. 14 W.), on Pistol River (NE¼ sec. 22, T. 38 S., R. 14 W.), and at Crook Point (see Plate II). Besides pillow structures, flow rocks locally show vesicles and amygdules. Minor tuffaceous rocks also are associated locally. Lent (1969) found zeolitic metamorphism (laumontite-prehnite-quartz) to be prominent in Otter Point volcanic rocks near a thrust contact with Colebrooke schists at the north edge of the map area.

Volcanic breccias of dioritic and gabbroic composition -- some with diabasic texture -- are widespread and have been a source of confusion. They are best seen in well-washed outcrops in streams or sea cliffs. The fragments typically are 1 to 2 inches across, but may be slightly coarser. Two varieties of breccia can be distinguished. One has speckled, angular fragments all of identical texture and composition, whereas the second has typical diabasic clasts mixed with darker and finer grained fragments as well as a few coarser dioritic ones (Figure 17); sedimentary rock fragments are almost entirely absent. What little matrix is present appears to be chloritized, fine-grained igneous material. Characteristic association of the breccias with pillowed volcanics of similar composition suggests that they are explosion breccias or agglomerates erupted from the same submarine vents as the lavas. Their angular, unsorted texture and absence of in-mixed sedimentary debris suggest that the breccias formed in moderately deep water below the deepest wave agitation. The breccias are present in most of the thicker volcanic sequences, but are most accessible in Hunter Rock next to U.S. Highway 101 (center sec. 12, T. 37 S., R. 15 W.), just south of Crook Point, on the summit of Sundown Mountain, in a single thin zone at Otter Point, on the beach at Sisters Rock, and within volcanic zones on Hunter Creek and Pistol River. A few dioritic and gabbroic dikes with textures and compositions much like that of the breccia fragments occur within the Otter Point Formation. Because of their similarity and common proximity to volcanic zones containing breccias, it is assumed that these, too, were emplaced during volcanic episodes (see Table I). Dikes and breccias isolated from obvious pillowed rocks, however, are more problematical. Identical breccias and pillow lavas occur in the Franciscan of California.

Bedded chert occurs in small, lenticular masses within several volcanic-rock zones, most notably on the south side of Blacklock Point, around Sisters Rock, just east of Gold Beach (SW¼ sec. 5, T. 37 S., R. 14 W.), and along lower Hunter Creek. Color varies among white, gray, black or brown, red, and green. Both Koch (1966) and Lent (1969) identified radiolarian tests in several samples, but most of the chert has been recrystallized.

Age and correlation: Besides plant debris and Radiolaria, fossils include *Buchia piochii*, belemnoids, ammonoids (*Phylloceras*? and *Protocanthodiscus crossi*) (Koch, 1966), and an ichthyosaur rostrum (Camp and Koch, 1966). Though fossils are not common in the Otter Point, *Buchia piochii* of latest Jurassic (Tithonian) age occurs widely. Hsu (1968) notes that mélange sequences are difficult to date in the conventional sense, because tectonic processes may have brought together blocks of diverse ages. The very wide distribution of *Buchia piochii* and the complete absence of fossils of any other age, however, suggest that the Otter Point contains only Tithonian strata.

The Otter Point rocks have been correlated with the Riddle Formation near Roseburg (Imlay and others, 1959), the Knoxville Formation of the northwest Sacramento Valley, and part of the Franciscan assemblage (Bailey and others, 1964). Of those units, the Otter Point most closely resembles the Franciscan both lithologically and structurally. Further discussion of possible relationships with the Franciscan and the enigmatic Dothan Formation appears below.

Cape Sebastian Sandstone (new name) (Late Cretaceous)

Occurrences of Upper Cretaceous strata: In two restricted areas, Upper Cretaceous (Campanian-Maestrichtian) strata occur on the coast, and they contrast markedly with all older units. The larger area encompasses about 30 square miles at and south of Cape Sebastian (west-central part of map area; see Figure 18 and Plate II), a smaller one covers only a few square miles north of Blacklock Point (northwest corner of map area). A third area of possibly equivalent-age rocks has been mapped by Lent (1969) north of the Sixes River (not shown here). Although locally the Upper Cretaceous rocks have been folded, faulted and intensely fractured, over-all they are distinctly less indurated and deformed than most of the older rocks. Moreover, they lack associated volcanic rocks, are petrographically distinct, and contains

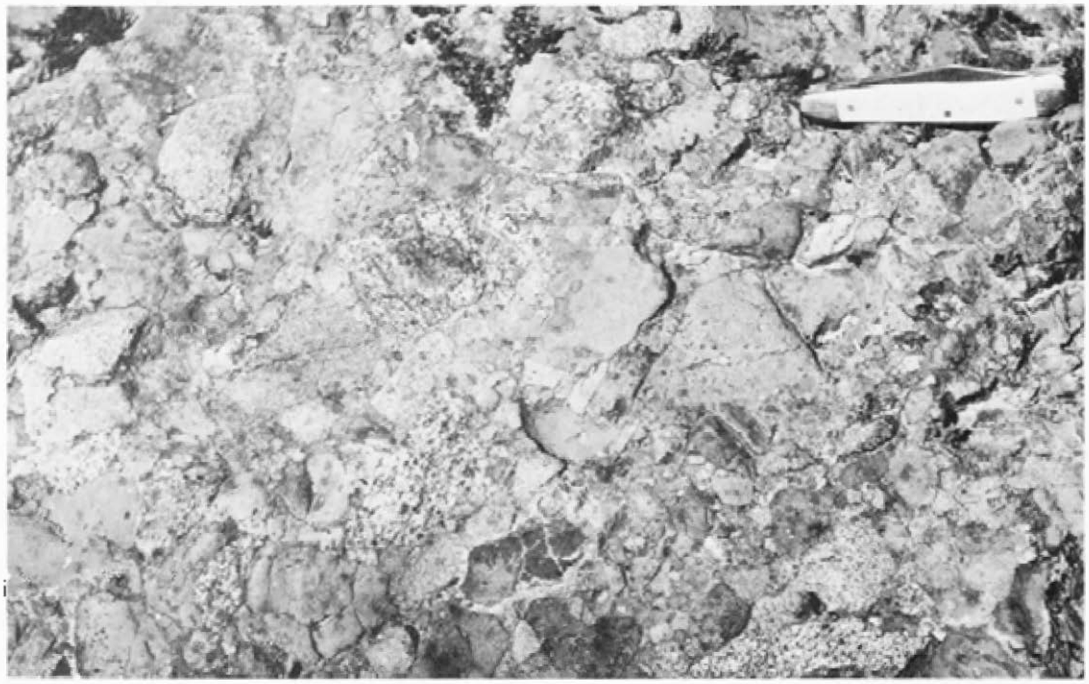


Figure 17. Volcanic breccia closely associated with pillow lavas along Pistol River. Note unsorted angular, closely packed nature of fine "diabasic" fragments mixed with coarser "dioritic" ones. Such breccia is characteristic of most major zones of volcanic rocks in the Otter Point, Colebrooke, and Dothan units, and also is present in the Franciscan of California.

Figure 18. Cape Sebastian and Hunters Cove from the south with the mouth of Myers Creek at right center (taken before new U.S. Highway 101 was built along the shore in middle distance). Massive Cape Sebastian Sandstone forms the Cape headland, and the shaly Hunters Cove Formation underlies the entire ridge to the right of the Cape summit and the north shore of the Cove. Blocks and stacks in the middle ground are Otter Point rocks within the Pistol River shear zone, which passes from the light-gray patch of serpentinite (left of tallest spruce tree) diagonally northwest over the Cape.

Figure 19. Upper Cretaceous strata (Hunters Cover Formation) exposed at low tide in the northwest-plunging Blacklock syncline just northeast of Blacklock Point (W. edge, T. 31 S., R. 15 W.). The thick sandstone units shown are the uppermost part of the Cretaceous section exposed there; more shale and thinner sandstones characterize the lower part. The synclinal axial trace closely parallels the Blacklock Point fault (see inset, Pl. 1). A spectacular angular unconformity with overlying Miocene sandstones ("Empire Formation") occurs in the sea cliff to the right of this view. (Photograph by D. L. Morgridge)

different suite of sedimentary structures. Diller referred the Blacklock strata to his "Myrtle Formation," and, although he never published reports of the Cape Sebastian area, he did collect diagnostic fossils on Myers Creek near the Cape (see Popenoe and others, 1960). Butler and Mitchell (1916) and Wells (1955) erroneously referred the rocks of the latter area to the Eocene. In 1955, H. V. Howe of Louisiana State University, while working for Humble Oil & Refining Co., found Upper Cretaceous Foraminifera in shales in that area, and subsequently Wisconsin geologists found more fossils. Map distribution and descriptions of the Upper Cretaceous rocks have been published by Howard and Dott (1961), Dott and Howard (1962), and Dott (1962, 1965). Two new formations, which were described by Howard (1961) and Howard and Dott (1961), are named herein.

The Upper Cretaceous strata are intensely fractured near steep Cenozoic fault zones such as the prominent Pistol River shear zone, which extends from Cape Sebastian southeast at least to Carpenterville. Northwest-trending folds of varying scales also are prominent within these rocks (Figure 19). Local overturning and thrust faulting characterize the southernmost end of the sequence south of Pistol River, where a few mafic sills have been intruded into the Upper Cretaceous sediments (Plate II, inset B).

Definition of Cape Sebastian Sandstone: A very massive, light-tan-weathering sandstone approximately 800 to 900 feet thick forms the steep Cape Sebastian headland (Figure 18), and underlies a large, faulted synclinal structure that extends southeast from there to the Pistol River. It also may be present in a structurally complex area 4 miles farther south, and in small outliers of faulted sandstone a few miles inland (see Plate II). This formation is not known elsewhere in southwestern Oregon unless it is present on Edson Creek near Sixes River (Lent, 1969). Although named for the cape, the type section measured by Howard (1961) is on the south side of the first headland immediately north of the cape itself (on the line between secs. 25 and 36, T. 37 S., R. 15 W.). The type section was so chosen because the west face at the cape is virtually inaccessible, and it is faulted so that a depositional contact with the overlying

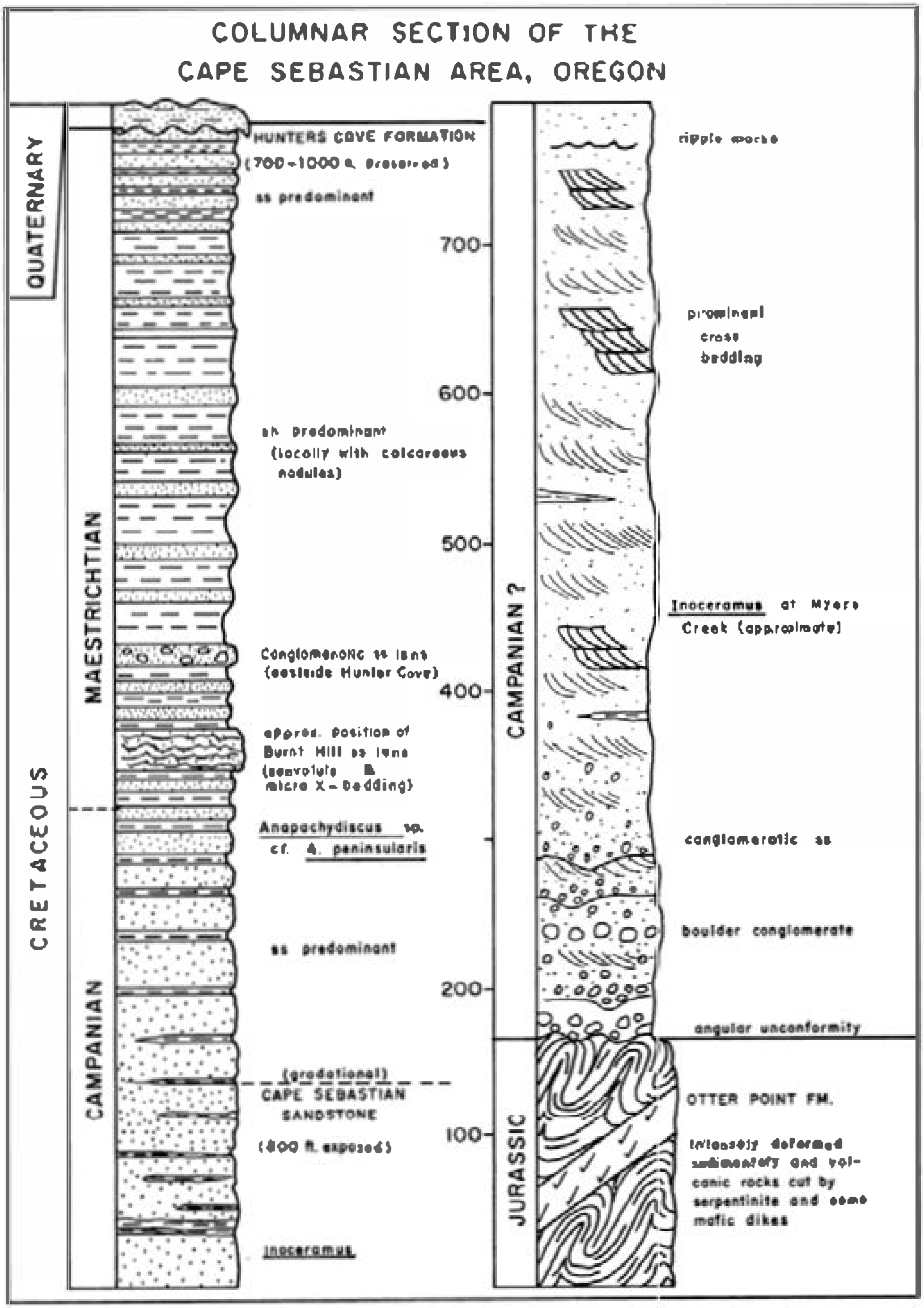


Figure 20. Diagrammatic portrayal of the type sections of the Hunters Cove Formation and Cape Sebastian Sandstone (new names) as measured by J. K. Howard (1961). Inferred positions of a few important features found at nearby localities are included. (See text for location.)

formation is not preserved. The base of the formation lies below sea level, but abundant conglomerate and coarse sandstone in the lower 200 feet of the sea cliffs is interpreted to be very near the basal contact (figure 20). A similar situation exists in Myers Creek below the old U.S. Highway 101 bridge at an abandoned quarry in massive sandstone (NW¼NE¼ sec. 7, T. 38 S., R. 14 W.; Plate II, inset A), which is designated as a reference locality. Strike in mudstones of the Otter Point downstream show a 60° discordance with that of the basal, conglomeratic Cape Sebastian Sandstone in the quarry. The unconformity appears to be exposed in a roadcut on old U.S. Highway 101 a quarter of a mile south of Wildwood Inn (sec. 7, T. 38 S., R. 14 W.; see Plate II). A thin, poorly cemented basal conglomerate with pebbles and cobbles of graywacke, volcanic, and dioritic rocks underlies massive sandstone. At least one doughnut-shaped clast had been bored by a pholad clam, as have many modern beach cobbles. One-eighth of a mile north of the Pistol River store, massive sandstone with coarse conglomerate lenses appears to represent a basal zone resting unconformably upon, and dipping steeply away from, massive, fine conglomerate and graywacke of the Otter Point, which forms the hill by the Pistol River school house. The upper part of the formation grades insensibly into the overlying shaly Hunters Cove Formation (Figure 20).

Lower conglomeratic portion: At all of the above localities, the conglomerate occurs as lenses, which vary from 3 inches to about 3 feet in maximum thickness. They contain a mixture of rounded clasts, and a few units show crude graded bedding (Howard, 1961). In the type section and at the base of the cape proper, several zones of the lower conglomerate consist of up to 80 percent light-gray, oblate calcareous fragments as much as 1 foot long. These presumably came from nodules in certain mudstone sequences of the Otter Point complex. Also associated are rounded clasts of volcanic rocks (some with conspicuous large feldspar phenocrysts typical of certain Otter Point volcanics; see Figure 16), white quartz, rare dioritic clasts, and large, nearly spherical boulders of sandstone identical with typical Cape Sebastian sandstones. The latter are interpreted as concretions formed by localized early diagenetic cementation followed by scour and redeposition. They are characteristic of most Upper Cretaceous conglomerates in the region. Prominent conglomerate of uncertain stratigraphic position within the formation occurs north of the mouth of Houstenaden Creek (NW¼ sec. 9, T. 39 S., R. 14 W.), along U.S. Highway 101 in the NW¼SW¼ sec. 30, T. 37 S., R. 15 W., and in SW¼ sec. 33, T. 37 S., R. 14 W. (Plate II; especially insets A and B.)

A little below the ridge top in the SW¼SE¼ sec. 16, T. 38 S., R. 14 W., a nearly vertical section of unusual breccia that appears to be of sedimentary origin can be seen in contact with black, hard mudstone of the Otter Point Formation. The breccia, which is crudely stratified through an interval of 40 to 50 feet, contains poorly sorted clasts of Otter Point sandstone, fine conglomerate, and mudstone fragments up to 5 feet long set either in a mudstone or coarse sandstone matrix. Some rounded boulders of Cape Sebastian Sandstone type occur near the top. Assuming it is sedimentary, deposition of this unusual material must have been in a relatively more protected environment than that inferred for the other basal deposits. The possibility that this is a tectonic (mélange) breccia cannot be ruled out at this time, however.

Upper massive sandstone: Conglomerate lenses characterize the lower one-third to one-half of the formation, whereas the remainder consists chiefly of moderately well sorted, very massive, fine- to medium-grained sandstone with an average specific gravity of 2.51 (range: 2.37 - 2.75). A very distinctive kind of box-work or honeycomb weathering characterizes the sandstones where exposed in sea cliffs. Festoon cross stratification with amplitudes generally of 5 to 10 inches can be seen sporadically; they are best displayed in the type section and on the southwestern and southeastern faces of Cape Sebastian (Figure 21). Ripple marks also are present. One suspects that cross stratification is more or less universal, but outcrop conditions rarely reveal it. Both thin conglomerate lenses and shale zones also occur.

The sandstones are composed of about 40 to 50 percent quartz, 20 percent plagioclase, 10 to 15 percent K feldspar, 5 to 10 percent volcanic rocks, 2 to 5 percent mica, 2 percent chert, and about 2 percent sandstone and mudstone clasts; matrix generally is less than 10 percent. Grains are subrounded and sorting is moderate.

At least the fossiliferous upper part of the Cape Sebastian Sandstone (Figure 20) clearly was marine, and was formed in a strongly agitated environment. Many features of the formation are similar to those of the Pliocene-Pleistocene marine terrace deposits along the present coast (see Figure 33). It is assumed that practically all of the Cape Sebastian Sandstone represents littoral and neritic deposition. Paleocurrent data show a wide variation; in the type area, currents were toward the southeast, but

Figure 21. Exceptionally well-exposed trough-type cross bedding in the middle part of the Cape Sebastian Sandstone on the southwest face of the Cape. Incipient box-work weathering so typical of all Upper Cretaceous sandstones on the coast can be seen at the bottom center.

Figure 22. Typical Hunters Cove Formation disharmonically folded at the north end of Hunters Cove (NE¼ sec. 1, T. 37 S., R. 15 W.). Note the flysch-like character of alternating shale and sandstone. Additional sedimentary features were illustrated by Dott and Howard (1962).

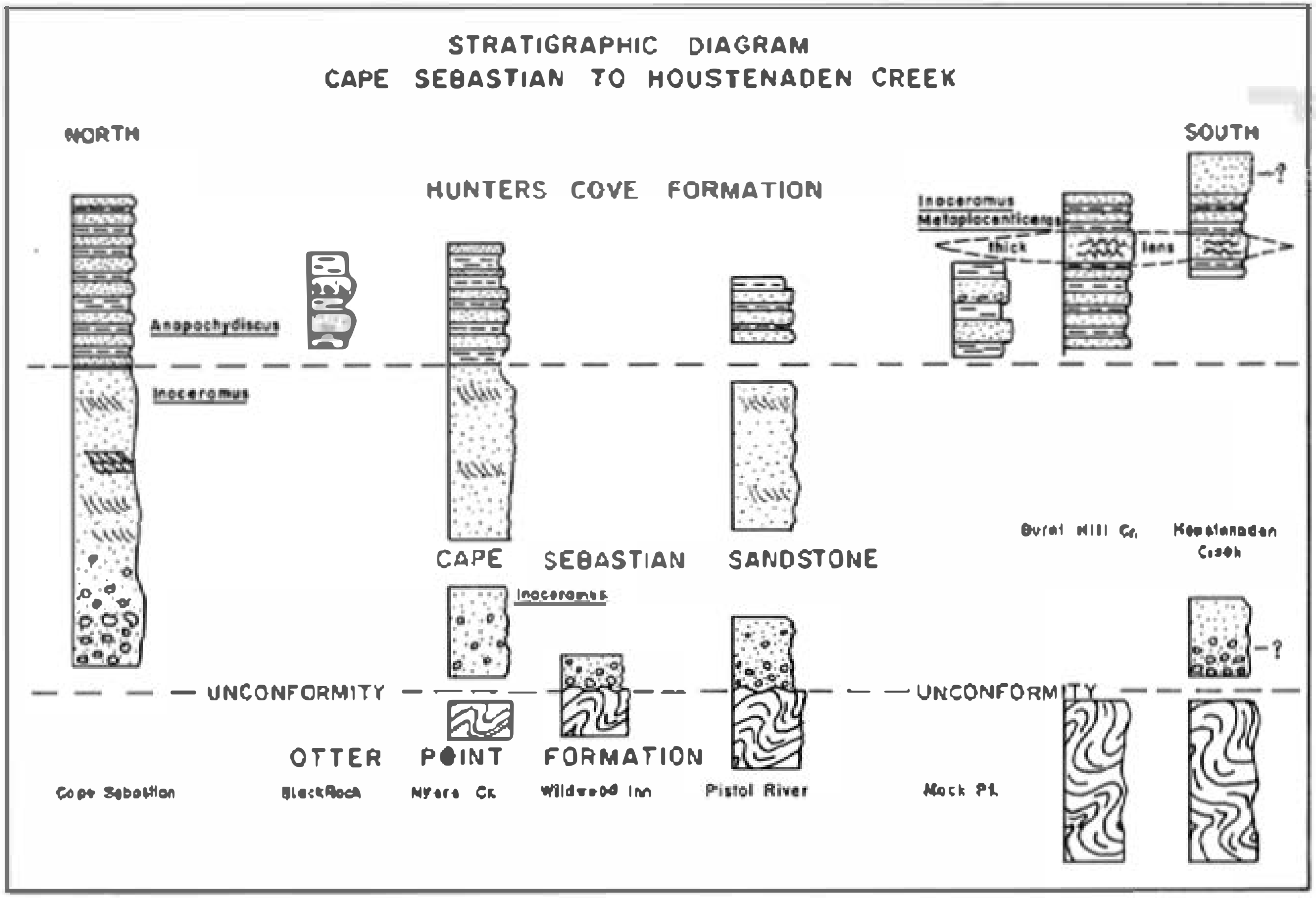


Figure 23. Stratigraphic diagram of inferred lateral relationships among major lithic types in the Cape Sebastian and Hunters Cove formations. Modified after Howard (1961).

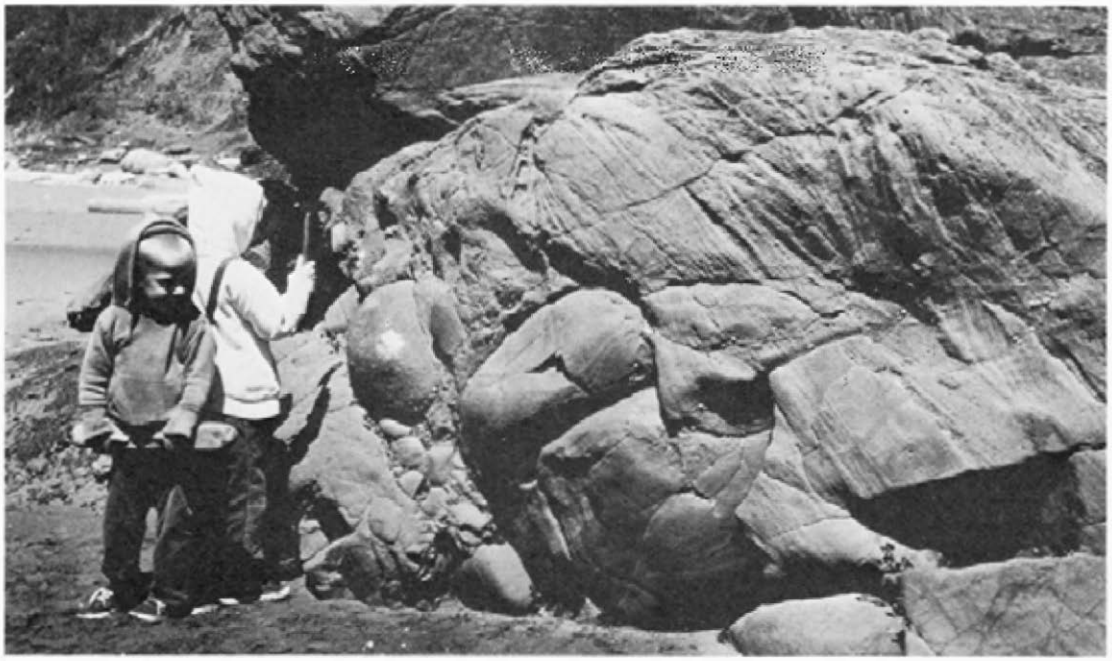


Figure 24. Unusual conglomeratic sandstone mass approximately 20 feet thick within the Hunters Cove Formation south of Crook Point (Mack Point, SE¼ sec. 31, T. 38 S., R. 14 W.; see Plate II). Large rounded boulders are interpreted as eroded concretions formed by local early cementation of Upper Cretaceous sandstones followed by scour in broad channels. Note cross bedding in the coarse sandstone.

elsewhere they were toward the east or locally to the west.

Hunters Cove Formation (new name) (Late Cretaceous)

Definition: A sequence of alternating thin sandstones and mudstones at least 700 to 1,000 feet thick is here named for Hunters Cove on the southeastern side of Cape Sebastian where excellent exposures exist (Figure 22). The sandstones weather to dark gray or brown, while the mudstones weather to a dark olive color. The latter differ from Otter Point mudstones, which they resemble in isolated outcrops, in being softer, and in weathering to a lighter color.

The type area of the formation is designated as the entire neck of Cape Sebastian extending from Black Rock in Hunters Cove north to the first headland north of Cape Sebastian (Plate II). The type section lies directly above that of the underlying Cape Sebastian Sandstone in the latter headland, where the contact relations are well exposed and faults and disharmonic folds are not so prevalent as they are at the cove. Although easily overlooked there, the east boundary fault of the Pistol River shear zone passes diagonally across the cape, producing marked discordances of strike and considerable fracturing of adjacent strata; the Hunters Cove Formation occupies a major synclinal structure just northeast of the shear zone. The original top of the formation is unknown, for everywhere it is overlain unconformably by Quaternary gravels, dune sand, or colluvium. It is very deeply weathered next to the cape and on most ridge crests. Sedimentary structures and lithologic variations are best displayed in sea cliffs south of Pistol River, although its stratigraphic relationships are less clear there than in the type area (Figure 23). Similar strata also assigned to the formation occur near Blacklock Point (Dott, 1962) and north of Sixes River (Lent, 1969).

The Hunters Cove Formation varies greatly in the proportions and relative thicknesses of intercalated fine sandstone and mudstone. Typically, sandstones average 2 to 3 inches and shales about 10 to 12 inches for a sand-shale ratio of 1:3. Rarely is the sand-shale ratio less than 1:3, but it is greater where sandstone units much thicker than the average (up to 10 or 12 feet) contain very thin shale intercalations, for ratios greater than 10:1 (Figures 23, 24). Petrographically the sandstones are identical with those of the Cape Sebastian, except that mica is more prominent. The mudstones are mostly chlorite-vermiculite, with less amounts of montmorillonite, and only traces of illite (as identified by J. B. Hayes). In a few

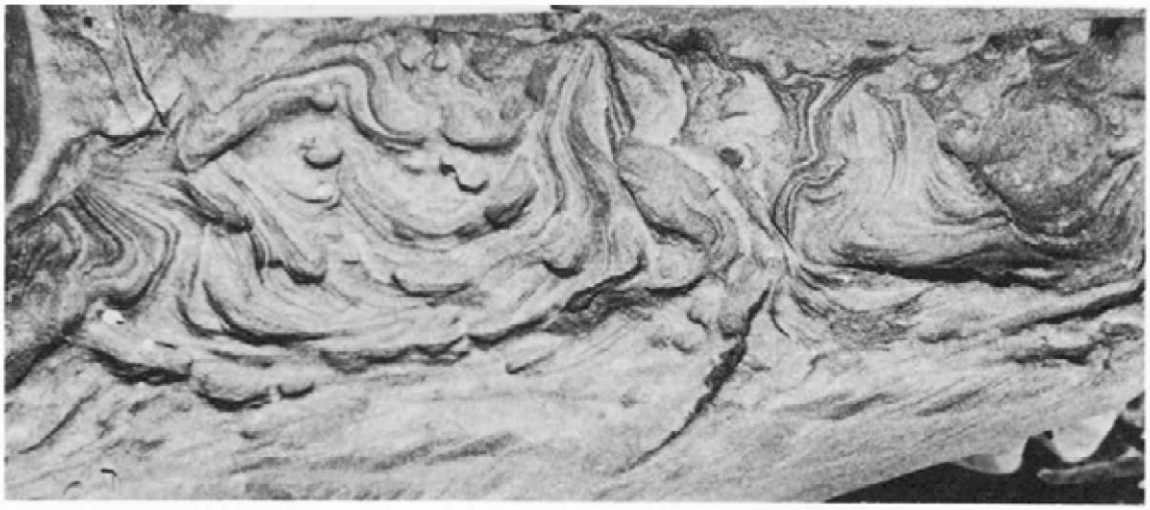


Figure 25. Convolute lamination in fine sandstone within a thick mass interstratified with more normal Hunters Cove strata in Burnt Hill Cove (NW¼ sec. 5, T. 39 S., R. 14 W.; see Plate II). Note small-amplitude cross bedding below and sharp truncation of convoluted zone above. The contortion is interpreted as occurring during a temporary quicksand (liquifaction) state due to an increase of bed shear by a sudden increase of current velocity.

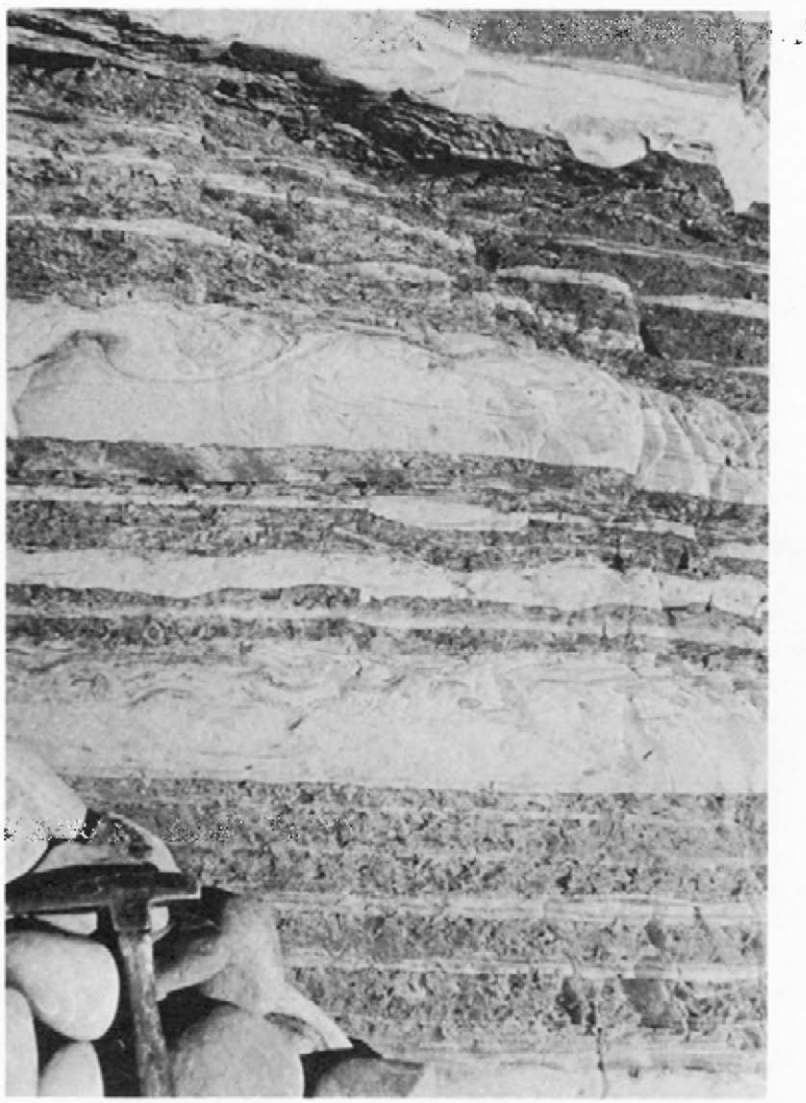


Figure 26. Hunters Cove Formation exposed just north of Blacklock Point (T. 31 S., R. 15 W.), showing convolute lamination and small-amplitude cross laminae. Graded bedding is more common in sandstone beds here than in the Hunters Cove Formation farther south.

areas (notably along U.S. Highway 101, NE¼NW¼ sec. 9, T. 39 S., R. 14 W.) nearly pure mudstone with light gray calcareous nodules occurs.

The lower transition zone is at least 100 feet thick in the type section. Upper Cape Sebastian Sandstone units 2 to 3 feet thick alternate with siltstone and very fine sandstone that weather to form reentrants much as do the mudstones of the Hunters Cove Formation. Rusty iron-oxide staining is common in this interval, as is coarse plant debris; fine cross lamination and burrow structures characterize the finer intervals. Rusty-colored strata, possibly representing the upper Cape Sebastian Sandstone, also are prominently exposed in a creek and headland in the NW¼NW¼ sec. 9, T. 39 S., R. 14 W. The transition zone clearly records a progressive change from strongly agitated depositional conditions to quieter conditions only intermittently interrupted by the introduction of sand. Mudstone increases and sandstone decreases upward in the transition zone until typical Hunters Cove lithology finally prevails. Because of the subtle gradation, formational assignment of isolated outcrops of alternating thin mudstone and thick sandstone beds is very difficult. Noteworthy is thick sandstone involved in thrust faulting in sec. 5, T. 39 S., R. 14 W., which is questionably assigned here to the Hunters Cove Formation (Plate II, inset B), because it is intimately associated with shales typical of that formation. Howard (1961), on the other hand, referred it to the Cape Sebastian Sandstone, with which it is practically identical. Of special interest in an overturned portion of this problematical sequence at the foot of a sea cliff (SE¼ sec. 5, T. 39 S., R. 14 W.) is an unsorted pebbly mudstone -- a lithology not expected within a moderately well-sorted fine sandstone sequence.

The typical Hunters Cove Formation has the superficial appearance of flysch sediments. The sandstones display abundant sole marks (for example, flute, groove and prod marks), fine cross lamination, outstanding convolute lamination (Figure 25), and a variety of burrow structures (see Dott and Howard, 1962). However, they are conspicuously poor in graded bedding; instead, cross lamination generally extends to the base of each unit. It is inferred that intermittent tractive currents of modest competence rather than suspension (turbidity) currents were responsible for the deposition of these sands. No diagnostic bathymetric indicators have been discovered, but the Hunters Cove sediments probably were deposited in gradually deepening water that was always below normal surf agitation, and thus probably was several hundred feet deep. Paleocurrents were toward the east and southeast.

Coarse sandstone boulder conglomerates (Figure 24) are well exposed in light-tan cliffs on the east side of Hunters Cove near Black Rock and at Mack Point (three-quarters of a mile southeast of Crook Point). Both outcrops are interpreted to be lenticular masses within the Hunters Cove Formation. A thick but fine sandstone mass 15 to 20 feet thick also occurs on the headlands on each side of Burnt Hill Creek Cove (sec. 5, T. 39 S., R. 14 W.). The latter is characterized by alternating zones of ripple-drift cross lamination, spectacular convolute lamination (Figure 25), and parallel lamination (see Dott and Howard, 1962). Intensely contorted sandstone balls occur in mudstones beneath. It is inferred that all of these thick, seemingly anomalous sandstone masses within the Hunters Cove Formation are broadly lenticular, channel-like deposits (Figure 23). They may represent deposits seaward of a deltaic complex, or possibly some kind of deeper marine channel sands.

<u>Hunters Cove Formation north of Blacklock Point:</u> In sea cliffs extending for half a mile northeast from Blacklock Point (sec. 19, T. 31 S., R. 15 W.), 1,500 to 2,000 feet of strata tentatively correlated with the Hunters Cove Formation are folded into a broad, northwest-plunging syncline (Figure 19; Dott, 1962). At their south margin, lowest shaly strata are faulted against brecciated serpentinite along a vertical, northwest-trending contact (see inset map on Plate 1). The highest strata are overlain unconformably on the north flank of the syncline by massive, late Cenozoic sandstones and conglomerates, which form high cliffs extending north to Floras Lake. Pleistocene marine terrace deposits in turn truncate all older rocks and cap the sea cliffs above an elevation of 120 feet. Pholad borings characterize the Cretaceous sandstones directly beneath those gravels.

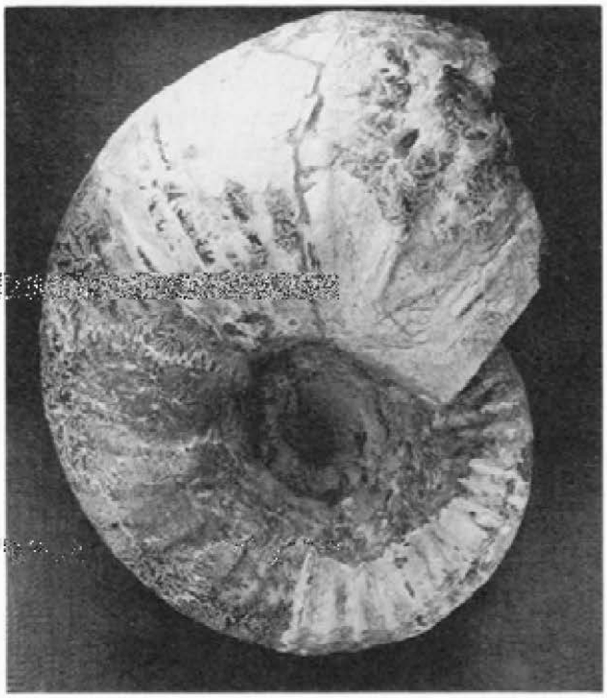
Correlation of the Blacklock strata with the Hunters Cove Formation was first suggested by similarity of induration and structural style, by the alternation of sandstone and mudstone (especially as seen in the valley on the northeast side of Blacklock Point), and by presence of peculiar box-work or honeycomb weathering of sandstones (c.f. Figure 21). Petrographically the sandstones of both sequences proved very similar as well. Unlike the typical Hunters Cove Formation, however, the upper three-quarters of the Blacklock section has more and thicker sandstones, which show considerable graded bedding in units containing coarse sand or granules (Figure 19). Cross lamination typically is of the small-amplitude variety, and is commonly associated with much convolute lamination in the finer zones (Figure 26). But faint, larger amplitude, inclined laminae and scour features also occur in some thick sandstone beds near the top of the section. Many sandstone units are from 3 to 6 feet thick, and several are as much as 8 to 10 feet thick. Whereas the sand-shale ratio in the lower part is about 1:4, in the upper portion of the sequence it averages from 4:1 to 6:1. Fine cross laminae, rare sole marks, and aligned plant debris indicate paleocurrents generally from east to west. Contorted zones, which are rather common, show a statistical north-south orientation of fold "c" axes, suggesting an east-west paleoslope. Turbidity current deposits seem much more common here than in the type Hunters Cove Formation; however, ordinary tractive currents of moderate velocity also reworked much of the finer sand. A mudstone-siltstone sequence on Edson Creek 10 miles east of Blacklock Point (secs. 3, 4, 5, T. 32 S., R. 14 W.) is said to resemble the Blacklock sequence (Lent, 1969); it has yielded only one belemnoid.

Age and regional correlations of Late Cretaceous strata: The Cape Sebastian Sandstone has yielded Inoceramus vancouverensis, I. subundatus (Figure 27), and other clams from a site in lower Myers Creek at the old Highway 101 bridge, and from the southeast tip of Cape Sebastian (Plate II). Several indeterminate clams, oyster fragments, and plant fragments occur at other localities (including a hill in SW¼ sec. 33, T. 37 S., R. 14 W.). Inoceramus also was found in a thick sandstone in the Hunters Cove Formation at Mack Point and at Black Rock in Hunters Cove. The ammonoids Anapachydiscus cf. A. peninsularis (Figure 27) and Baculites sp. were found in the type section of the Hunters Cove by Heward (1961); I later found Metaplacenticeras pacificum (NW¼NW¼ sec. 5, T. 39 S., R. 14 W.), and various clams and echinoid fragments from the northernmost road cut in the formation on U.S. Highway 101 (NW¼ sec. 30, T. 37 S., R. 14 W.). Some other megafaunas collected by Diller and reported by Popenoe and others (1960) apparently were mislocated, and could not be verified. Poorly preserved and rather undiagnostic foraminifers from Hunters Cove mudstones south of Pistol River include Dorothia, Hyperamina, Cribrostomooides, Bathysiphin, Eponides, and Gyroidina (identified by Rex E. Olsen of Humble Oil & Refining Co.; R. M. Touring, written communication, 1961). The Hunters Cove mudstone-sandstone sequence north of Blacklock Point has yielded only a few medial to Late Cretaceous Foraminifera found by J. G. Koch in calcareous nodules near the middle of the sequence, together with a single belemnoid and a single small Baculites cf. B. teres.

David L. Jones of the U.S. Geological Survey (written communication, 1963) interprets the species of Inoceramus to be of late Campanian and/or early Maestrichtian age. Metaplacenticeras pacificum is late Campanian, while the Anapachydiscus probably is early Maestrichtian. This assignment agrees with that of Popenoe and others (1960) based upon the old U.S. Geological Survey collection. The Baculites near Blacklock Point is Coniacian or younger, and is most like Campanian forms, according to Jones. Thus there seems no doubt that at least the upper Cape Sebastian and all of the Hunters Cove formations are latest Cretaceous in age. In the Pistol River area there is no record for the entire interval from the end of the Jurassic to Campanian time. Neocomian strata occur 25 mile to the north, but no record of Aptian to Campanian is known anywhere on the coast. During that interval, major thrust faulting probably was occurring near the present coast, just as is inferred for parts of northern California (Irwin, 1964).

Albion through Maestrichtian faunas occur farther inland, suggesting a gradual Late Cretaceous transgression over most of southwestern Oregon. Widely scattered outliers of relatively little-deformed, "post-orogenic" Cretaceous strata rest with profound unconformity upon older rocks throughout the Klamath region. Onlap occurred at widely differing times within the Late Cretaceous, however, being earliest (Albian) on the eastern side of the Klamath Province in Oregon (Peck and others, 1956; Jones, 1960), and youngest (Campanian) in the present coastal region.

Some probable Campanian fossils have been reported in Franciscan rocks in northern California (Bailey and others, 1964), and in the Gualala Formation, which lies west of the San Andreas fault near Point Arena, California (Popenoe and others, 1960).



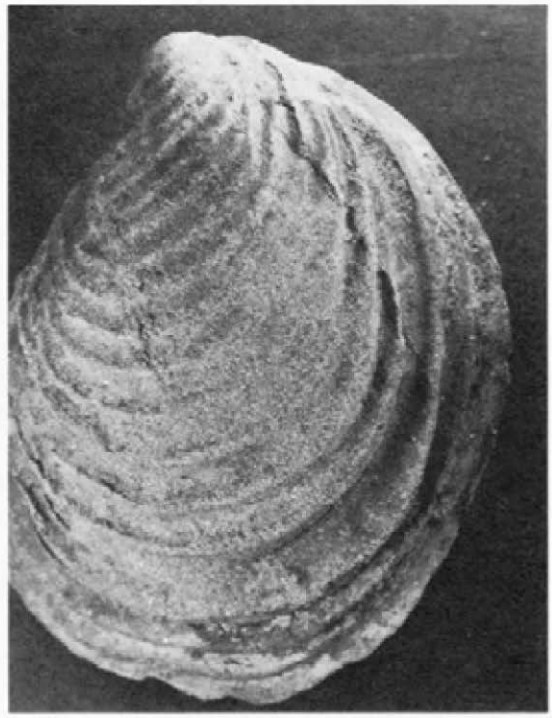


Figure 27. Diagnostic fossils: Left – Anapachydiscus cf. A. peninsularis from the lower part of the Hunters Cove Formation in the type section (see Fig. 20) (X½); Right – Inoceramus subundatus from the middle Cape Sebastian Sandstone at Myers Creek (see Fig. 20) (X1.2). (Photographs by J. K. Howard; identifications by D. L. Jones).

Figure 28. Rainbow Rock (right), a large mass of bedded chert in the Dothan Formation, 3 miles northwest of Brookings and visible from U.S. Highway 101. Metavolcanic rocks directly underlie this chert mass, and are exposed in road cuts to the right of this view.

Dothan (or Franciscan?) Rocks of the Southern Region

Dothan Formation (Jurassic)

Definition and distribution: The Dothan Formation was named by Diller (1907) for a now abandoned post office and railroad station along Cow Creek, 25 miles east of the present map area. Based upon reconnaissance, Diller believed that the formation extended southwest to the coast near the California border, an interpretation supported by Maxson (1933), Wells and others (1949), Wells and Walker (1953) and Ramp (1964). For many years it has appeared that Dothan rocks extended directly into the Franciscan assemblage, a pattern which has produced a long-standing state-line stratigraphic boundary problem. Reconnaissance mapping into California demonstrates that the Dothan can, however, be traced across the border for some miles, and shows that mapping of at least gross subdivisions is possible within seemingly monotonous graywacke terranes.

There is increasing evidence that the Dothan is indeed coextensive with known Franciscan rocks. Volcanic rocks now called the Rogue Formation (Wells and Walker, 1953) separate the type Dothan from Galice strata east of the map area. Although most of the Dothan in the type area and along Rogue River dips steeply eastward, Diller thought that it probably was the youngest of the three formations. But he also recognized that the entire sequence might be overturned, or even that the Galice might have been thrust westward over the Dothan. Recent fossil discoveries by Ramp (1969) in the upper Chetco River drainage area now suggest at least partial age-equivalence with the Otter Point Formation.

Graywacke is the most abundant rock type; much of it shows graded bedding, but thick, massive, ungraded and structureless units also are present. Thick, black mudstone sequences are almost as prominent as graywacke. Locally, pebble and cobble conglomerates occur, as do bedded cherts (Figure 28). Volcanic rocks form substantial volumes of the formation in several areas, especially near the coast. The Dothan is a eugeosynclinal sequence apparently deposited in moderately deep water typified by pelagic muds and occasional radiolarian oozes. Turbidity currents and other gravity-driven processes introduced sand and gravel episodically.

Regional subdivisions: Wells and Walker (1953) distinguished four distinct zones along the Rogue River east of the present map area. The westernmost (4 miles wide), which overlies a thick volcanic mass, is predominantly thinly stratified mudstone and siltstone with some sandstone units up to 5 feet thick and rare conglomerate lenses; volcanic rocks and chert mark the top. The second zone (3 miles wide), which lies east of the first, is dominantly sheared black mudstone with local calcareous nodules and thin conglomerates. Zone 3 (2 miles wide) is massive, cliff-forming graywacke. The fourth or most easterly zone (3 miles wide) is characterized by interstratified mudstone and sandstone with sandstone increasing in abundance eastward. Wells and Walker estimated that the total thickness of the Dothan must be in excess of 18,000 feet, but the true figure is indeterminable.

The last two subdivisions have been traced across the Illinois River (Wells and Walker, 1953) into the eastern edge of the present map area (Ramp, 1964). Zone 4 apparently projects southwest just east of Pollywog Butte (T. 39 S., R. 11 W.), where black mudstones are prominent. Zone 3 may pass from the steep gorge of the Illinois River in T. 37 S., R. 11 W. through Quail Prairie Mountain, thence just east of Mount Emily. Buchia piochii was found in 1968 by Ramp in float at the mouth of Boulder Creek (T. 38 S., R. 11 W.) within this zone, but it is not yet certain if the fossils actually come from Dothan rocks (Ramp, 1969). Possibly corresponding to zones 1 and 2 is a 2- to 3-mile wide zone dominated by black mudstone that was distinguished by Widmier (1962) east of Brookings (here tentatively named Winchuck Member). Northeast of Brookings, the Chetco River meanders for 15 miles over the nonresistant rocks of this member. A dominantly sandstone division with appreciable volcanic rocks and some chert and conglomerate was mapped by Widmier (1962) at the coast (here tentatively named Macklyn Member). The relation of this last zone to those of Wells and Walker is unknown. On a crudely statistical basis, both dip and stratigraphic facing directions suggest that the Dothan rocks may be oldest at the coast, but there must be considerable repetition of strata by many bedding slips and small folds. One might suspect mélange characteristics, which would make any long-range projection of member subdivisions very tenuous. Nonetheless, existing mapping indicates a somewhat surprising gross continuity. Where we have studied it, the Dothan is not so chaotically sheared as is the Otter Point complex, but it tends to be more indurated and very locally -- especially near inferred fault zones -- shows incipient slaty cleavage (just west of the mouth of the Chetco River, at Battery Point in Crescent City, California, and in the upper Winchuck River drainage near the state border). Along the coast near Brookings and at Crescent City the Macklyn Member rocks qualify as a broken formation (Hsu, 1968), being strongly sheared but lacking exotic (non-Dothan) rocks. The coast in both areas appears to have been carved from northwest-trending fault zones. Unlike the Otter Point rocks, the regional strike of the Dothan in Oregon is north-northeast, changing in California to north-northwest.

Macklyn Member: The coastal member consists of about 50 percent gray sandstone, nearly 40 percent mudstone and siltstone, nearly 10 percent volcanic rocks, and less than 1 percent chert and conglomerate. On the average, it dips 50° east, and may be several thousand feet thick (Widmier, 1962). Typical thick graywackes, some with graded bedding, can be seen in all of the headlands around Brookings, but a sequence 200 feet thick at Chetco Point on the south side of Macklyn Cove was taken by Widmier as the type section. The gray sandstones are poorly sorted graywackes, ranging from granules to mud sizes, and they characteristically contain prominent small mudstone chips in at least 50 percent of the sandstone units. Thin mudstone intercalations comprise only about 10 percent of the type section. Some very massive graywackes with only faint stratification, and ranging up to 40 or 50 feet in thickness, can be seen in some headlands and also along the main fork of the Pistol River in Ts.37 and 38 S., R. 13 W. The graywackes vary little except in thickness and in relative proportions of mudstone intercalations.

Petrographically, the sandstones are feldspathic and lithic wackes, as are those of the Dothan inland (Wells and others, 1949). Although heterogeneous, the average sand-grain composition is approximately as follows: quartz-25 percent, chert-10 percent, plagioclase-30 percent, K feldspar-less than 0.1 percent, volcanic rocks-15 percent, plagioclase-30 percent, K feldspar-less than 0.1 percent, volcanic rocks-15 percent, and sedimentary clasts-20 percent. Texturally the grains are angular and poorly sorted, with sericitic matrix averaging from at least 15 to 20 percent by volume.

Sole marks, which are rarely seen (Figure 29), and small-scale cross laminae in siltstones indicate north-to-south paleocurrents for the Macklyn Member (Widmier, 1962). Carbonized plant fragments and two probable worm tubes (Terebellina palachii) are the only fossils found by us in spite of diligent search for both mega- and microfossils.

Local conglomerate zones occur sporadically throughout the member. Clast sizes range from granules to boulders, and shapes are subround to angular. Pebble- to boulder-sized clasts average about 50 to 70 percent volcanic, 25 to 35 percent sedimentary (including chert), and only 5 to 10 percent granitic or dioritic types. Adjacent to volcanic flow rocks, conglomerates tend to be dominated by volcanic clasts, either rounded or angular. At Point St. George near Crescent City, California, occur the coarsest conglomerates assigned to the Macklyn Member (Figure 30). These lie below a series of massive graywackes and black mudstones with isoclinal gravity "slump" folds cut by sandstone dike swarms (Dott, 1966c). Graywacke, chert and some carbonate clasts comprise together about 50 to 60 percent, volcanic rocks 25 to 30 percent, and plutonic rocks about 15 percent, all of which are set in a matrix of sand, granules and fine pebbles (up to 20 percent by volume). Boulders of light-gray granitic types containing up to 20 percent quartz range up to 3 feet in diameter. These rocks are noteworthy in terms of tectonic history, for such rocks are very rare in Dothan, Franciscan, and Otter Point terranes. An attempt to date one of the boulders isotopically yielded 103 ± 10 and 110 ± 25 m.y. (K-Ar on biotite; see Table 3), but the results are not considered reliable because of mineral alteration (Dott, 1965). Coarse conglomerate of uncertain stratigraphic position at Cape Ferrelo north of Brookings has dominantly volcanic clasts and lies next to pillow lavas; it also has fragments of a peculiar myrmekitic quartz-plagioclase plutonic rock. This conglomerate can not be confidently distinguished from heterogeneous, coarse Otter Point conglomerates, which lie only 3 miles to the north; it may be an outlier of that unit rather than part of the Dothan.

Varicolored, rhythmically bedded chert is a rare but important component of the Macklyn Member. It is similar to the Franciscan cherts. Red color dominates, but gray, black, green, white, and yellow also occur. The most conspicuous and accessible example is Rainbow Rock, a sea cliff visible from U.S. Highway 101 (NW¼ sec. 26, T. 40 S., R. 14 W.; Figure 28). Individual beds range from 1 inch to 1 foot thick with thin shale seams between (Widmier, 1962). The cherts occur as lenticular masses generally less than a mile long and up to 75 feet thick. They characteristically are associated closely with volcanic rocks, as in the Franciscan and Otter Point terranes. Microscopically they are cryptocrystalline

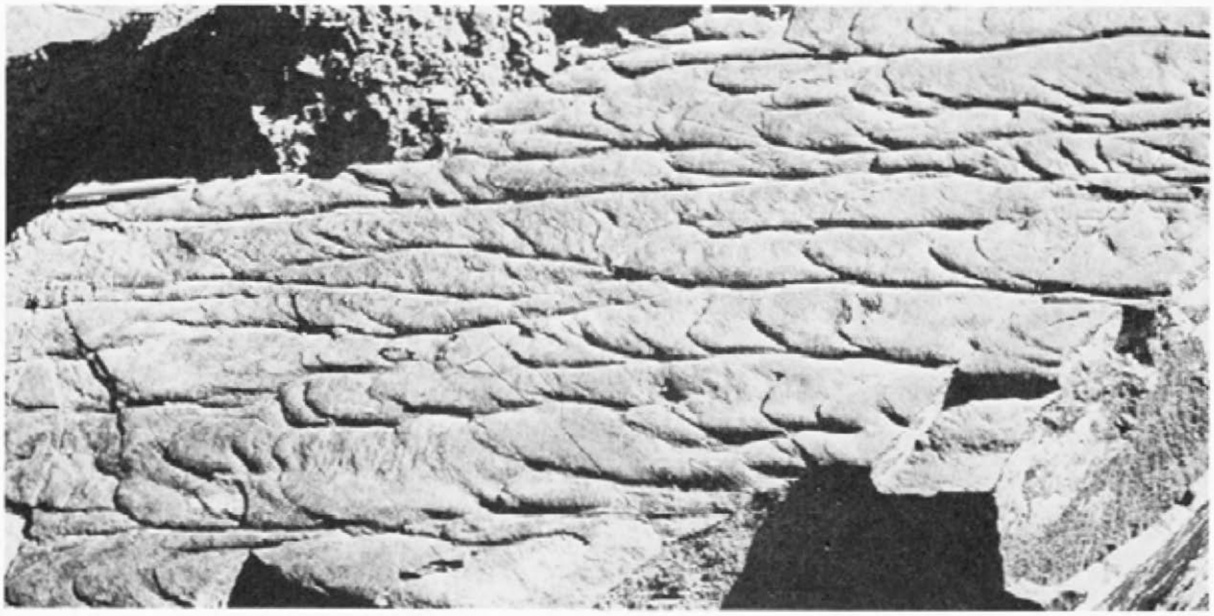


Figure 29. Flute structures on the sole of a Dothan graywacke bed (and flattened by compaction) exposed in Bowman Creek, 6 miles northwest of Brookings (just above the U.S. Highway 101 bridge); pencil at left provides scale. Paleocurrent data indicate that turbidity currents here flowed from north to south, just the opposite of current directions revealed in Otter Point strata only 5 miles to the northwest.

Figure 30. Massive heterogeneous conglomerate assigned to the Dothan Formation at Point St. George, Crescent City, California. This conglomerate contains 5 to 10 percent granite clasts as much as 2 feet in diameter, as well as volcanic and sedimentary ones. It is interstratified with typical Dothan black mudstone and thick graywacke beds.

to microcrystalline, with circular areas of coarser quartz that may represent recrystallized Radiolaria.

Locally amygdaloidal volcanic rocks comprise an important component of the Macklyn, and help to distinguish it from the Winchuck Member. The largest masses occur near the boundary between the two members, but small discontinuous flows also occur throughout the Macklyn. Flow rock, volcanic breccias, and lapilli tuffs all are present. Pillow structures are locally developed notably at the north side of Cape Ferrelo and at Pelican Beach State Park (three-quarters of a mile south of the California border). Compositionally the volcanic rocks vary from porphyritic rhyolite and dacite to andesite and trachyte. Quartz and white feldspar phenocrysts are conspicuous where present. Some vitreous silicic flow rocks resemble chert. Volcanic breccias are variable, and in poor outcrops may be confused with flow rocks. They consist of dacitic and trachytic or dioritic fragments in a fine, greenish matrix (similar to Figure 17). Myrmekitic quartz-plagioclase intrusive rocks are associated with at least one volcanic zone, and they occur as fragments in some breccias as well as in the problematic conglomerate at Cape Ferrelo (Widmier, 1962).

Winchuck Member (probably includes zones 1 and 2 of Wells and Walker, 1953): This member is named for the Winchuck River near the California border, along which typical outcrops occur, especially $1\frac{1}{2}$ miles east of U.S. Highway 101. Although no type section could be measured due to many small folds and faults and to discontinuous outcrops, Widmier (1962) noted that exposures are best from Winchuck Forest Camp (sec. 10, T. 41 S., R. 12 W.) north-northwest along Wheeler Creek for 4 miles toward Mount Emily. This area, however, is riddled with Tertiary dacite dikes related to the Mount Emily stock; also it appears to include only the easternmost strata of the member. Representative exposures occur along the Chetco River road just east of the bridge 2 miles northwest of Mount Emily. The eastern limit of the member has not been fully established, but proportions of sandstone and fine conglomerate appear to increase eastward from Mount Emily. The interval from Long Ridge (where chert and fine conglomerate occur near the fire lookout) east to Pollywog Butte probably represents zone 3 of Wells and Walker (1953).

The Winchuck Member is composed of more than 60 percent black mudstone and siltstone. Some dark, poorly sorted sandstone beds several feet thick are present, and are almost identical petrographically with those of the Macklyn; chert and volcanic fragments are less common, and white mica more common. Graded bedding and small-scale cross laminae are occasionally observed. Conglomerate is rare, and generally is similar to that of the Macklyn Member (Widmier, 1962). An unusual boulder and cobble conglomerate occurs on the Chetco River 200 yards east of Wilson Creek (sec. 30, T. 39 S., R. 12 W.). Bedded chert and the only volcanic rocks known within the Winchuck Member occur at a prominent bend of the Chetco River in secs. 29 and 32, T. 38 S., R. 12 W. They extend north 5 miles to Mineral Hill (T. $37\frac{1}{2}$ S., R. 12 W.), where they are faulted against serpentinite.

Age and relationships with the Franciscan and Otter Point complexes: In certain areas (South Forks of Hunter Creek and on Pistol River near Deep Creek), graywackes mapped as Otter Point are difficult to distinguish with confidence from those of the Dothan Formation. Very possibly the two units are of similar age, as is implied by the discovery of Buchia piochii within the Dothan outcrop area on upper Chetco River (Ramp, 1969). However, presence of a narrow, discontinuous zone of Colebrooke-type schists from Pistol River to Whalehead, as well as intensely sheared rocks (including serpentinite) from Carpenterville to Whalehead, led Widmier (1962) to infer a major fault between Otter Point and Dothan rocks. Structural and lithologic contrasts between the two formations also are most pronounced from Whalehead to Carpenterville. Northwest of the fault occur intensely sheared and veined conglomerates with minor graywacke and mudstone; the dominant strike of these Otter Point rocks and the trends of tight folds within them are northeasterly, which is markedly discordant with the northerly trends in adjacent Dothan rocks. Southeast of the Whalehead fault, the Dothan Formation is much less sheared, and its lighter colored rocks include only minor conglomerate and much more sandstone as well as volcanics and bedded chert of the Macklyn Member.

Petrographically the Otter Point graywackes tend to be slightly darker than Dothan ones, reflecting both a dark matrix and a greater percentage of volcanic rock fragments. Over-all, the Otter Point is more sheared and heterogeneous, has far more conglomerate, more pillow lavas (which are of more mafic composition) and more fossils than the Dothan. Moreover, the Dothan graywackes are more highly indurated, having an average specific gravity of 2.67 as compared to 2.61 for the Otter Point. Therefore, whether coeval or not, the Dothan and Otter Point are distinctive, mappable entities over much of the map area. In small or isolated out-crops of graywacke or mudstone, however, one may be hard pressed to distinguish them.

Taliaferro (1942) argued that the Dothan in its type region was older than both the Rogue volcanics and the Galice Formation. He correlated the Dothan and Rogue rocks with the sandy and volcanic Amador (now Cosumnes and Logtown Formations) and the Galice with the Mariposa Formations, all in the Sierra Nevada. Wells and Walker (1953) also tentatively regarded the Dothan as the oldest. Largely because of our failure to find fossils in coastal Dothan rocks and the apparent continuity of outcrops from the coast inland to Rogue River, we assumed the Dothan to be older than the Otter Point complex. This implied that it pre-dated the Nevadan orogeny. A whole-rock K-Ar date of 149 ± 4 m.y. for a dacite (erroneously reported previously as "rhyolite") in an area of the Mocklyn Member of the Dothan 9 miles north of Brookings seemed to confirm such an age assignment (Dott, 1965; see Table 3). Seemingly consistent also with a postulated pre-Otter Point (early Late Jurassic) age were the greater induration, development of local slaty cleavage, and the presence of small patches of Colebrooke-type phyllite and schist within areas of Dothan rocks (Widmier, 1962*).

Opinions on the age relationship of the Dothan to other Jurassic formations in southwestern Oregon have been fluctuating ever since Diller first proposed that the Dothan was younger than the Galice and Rogue Formations. Diller thought that either the sequence was overturned or the Galice was thrust over the Dothan.

Taliaferro (1942) and Wells and Waters (1953) regarded the Dothan as older than the Galice and Rogue Formations. In our work on the coast we assumed the Dothan to be older than the Otter Point, thus pre-Nevadan in age. An apparent gradation northward of Dothan strata into the main region of Colebrooke Schist led us to infer that the Dothan, as well as the Galice, might have been a forerunner of the Colebrooke. But Coleman (1969) now has evidence for a thrust rather than a metamorphic facies relationship between the Colebrooke Schist and the Dothan Formation.

Irwin (1964) suggested a Tithonian (post-Nevadan) age for the Dothan and its correlatives in California, and postulated that the Rogue and Galice Formations had been thrust over the Dothan. Recently, Hotz (1969) found evidence for such a thrust relationship along the Rogue River east of our map area. Discovery of Tithonian fossils in the area of rocks mapped as Dothan by Ramp (1969) supports these views.

Baldwin (1969), although agreeing with the thrust interpretation, argues that the Dothan and Galice may merely represent different coeval (and pre-Nevadan) facies juxtaposed by thrusting. In summary, concepts regarding the stratigraphic position of the Dothan are still in a flux and somewhat contradictory, but an early resolution seems probable.

In the Dothan controversy, several contradictory petrologic characteristics should be kept in mind. First, Dothan volcanic rocks seem, on the average, to be more silicic than are typical Franciscan ones (compare Wells and others, 1949; Wells and Walker, 1953; and Widmier, 1962 with Bailey and others, 1964). Second, although the Otter Point complex is more like the Franciscan both structurally and in its volcanic petrology, the graywacke densities and K feldspar contents of the Dothan are more Franciscan-like than are those of the Otter Point. The work of Gluskoter (1964) and Hsu and Ohrbom (1969) in the type region of the Franciscan, however, indicates that K-feldspar distributions can be somewhat deceptive. Finally, if the Dothan does, in fact, prove to be of the same age as the Otter Point rocks, as now seems likely, then the petrologic and structural differences of the two units as well as opposite paleocurrent orientations in the two coeval sequences at localities only 5 miles apart (see Figure 29) still will require

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*Widmier found blue-gray carbonaceous phyllite or schist identical with the Colebrooke within the Dothan outcrop area on Long Ridge (sec. 34, T. 38 S., R. 12 W.), along the Pistol River-Carpenterville shear zone on old Highway 101 just south of the Bosley Butte road junction (SE¼NE¼ sec. 14, T. 39 S., R. 14 W.) and 50 yards north of the junction of the main forks of Whaleshead Creek (NE¼NE¼ sec. 3, T. 40 S., R. 14 W.), along a fault zone on Cape Ferrelo (NW¼ sec. 22, T. 40 S., R. 14 W.), and in the first roadcut south of Ram Creek on new U.S. Highway 101 (NE¼ sec. 22, T. 40 S., R. 14 W.). On the Pistol River just west of a jeep-trail crossing in the southwestern part of sec. 19, T. 38 S., R. 13 W., Widmier (1962, p. 38) observed what seemed to be a continuous gradation from Colebrooke phyllite eastward into Dothan mudstone, and he reported (p. 58-59) a similar apparent gradation in a gully south of the new Highway 101-Ram Creek phyllite locality noted above. If these phyllite patches are not gradational with Dothan rocks, then they probably represent erosional remnants of a thrust sheet.

explanation. Possibly the differences between the Dothan and Otter Point terranes reflect two distinct but coeval mélange complexes of slightly different structural and environmental origin.

Cenozoic Rocks

Eocene strata (undifferentiated)

Distribution and lithology: Diverse Eocene and possible Paleocene sedimentary rocks occur in the northern part of the map area and were studied superficially. Bandy (1944, 1950), Baldwin (1965), and Lent (1969) have given more attention to them. Marine megafaunas and microfaunas provide dating criteria, and prove that early Cenozoic seas were extensive in the map area even though the preserved record is very scattered (Dott, 1966b). The early Cenozoic strata represent post-orogenic transgressive deposits that rest unconformably upon widely differing Mesozoic rocks. They are slightly folded and extensively faulted, especially along the vertical Coquille River fault in the northeast corner of the area.

Petrographically the Eocene sediments are heterogeneous, and in general reflect the nearest pre-Cenozoic basement. They are comparable to the Upper Cretaceous sandstones in terms of mica and K-feldspar content, but differ in other respects (Dott, 1965; 1966b). North of the present map area they tend to be rich in volcanic detritus. Except for a distinctive graded sequence exposed near Agness, the oldest known Cenozoic exposure in the area (T. 34 S., R. 11 E.; Figure 31), coarse, cross-stratified

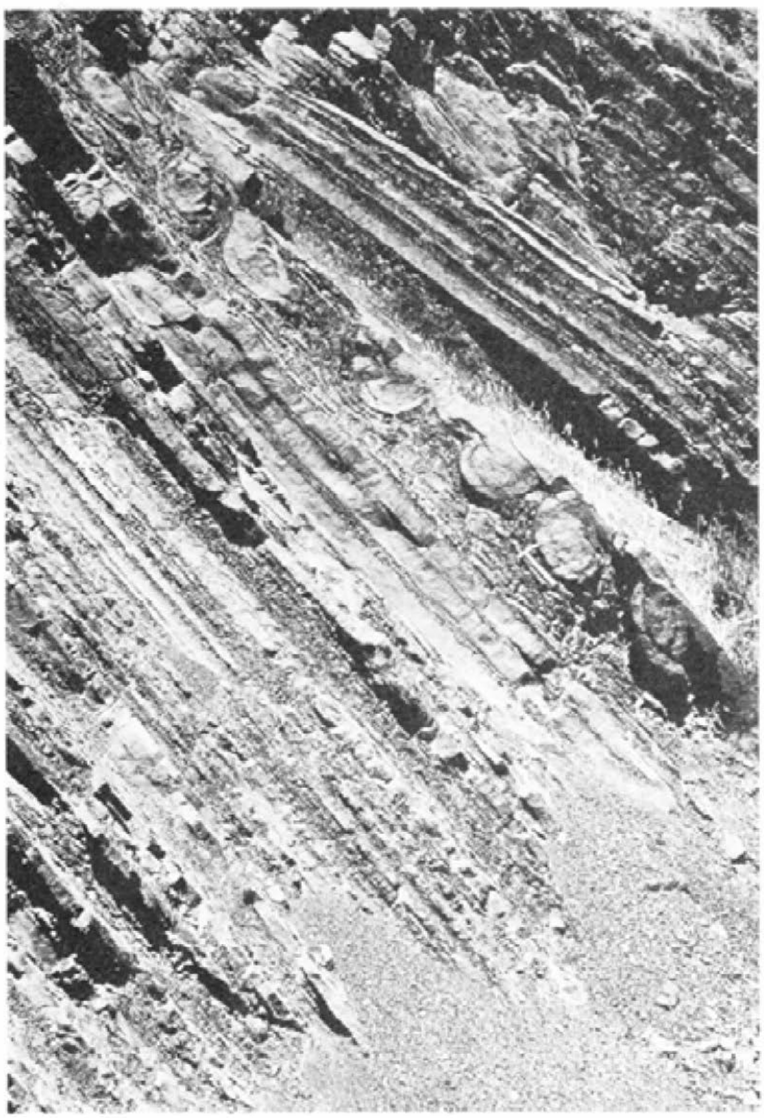

Figure 31. Paleocene or Lower Eocene flysch sequence exposed in the locally famous "Mason's Wall" along the Agness-Powers road overlooking Rogue River (SW part of T. 34 S., R. 11 W.). The graded graywackes, which are rich in volcanic rock fragments, dip steeply east away from the Coquille River fault toward the axis of the Eden Ridge syncline. Note deformational structures near center formed by differential gravitational loading following sudden deposition from a turbidity current of sand upon unstable mud.

Figure 32. Eight-feet-long rounded boulder of Cretaceous (?) conglomerate within an Eocene conglomerate adjacent to the Coquille River fault (the vertical fault here separates conglomerate in foreground from lighter colored diorite in background). Note hammer for scale. (Exposed in road cut along Powers-Agness road, sec. 36, T. 33 S., R. 12 W.).

sandstones and conglomerates (Figure 32) are the most prominent rock types and mudstone is of secondary importance in several areas. Coal occurs locally. In the absence of fossils, many Eocene conglomerates and graywackes are difficult to distinguish from Lower Cretaceous ones.

Structural and stratigraphic relationships: The Eocene rocks are of interest principally for the evidence they provide for dating structural events. An angular unconformity between gently dipping Eocene conglomerate and vertical graywackes of latest Jurassic or Early Cretaceous age is well exposed on Salmon Creek southwest of Powers (SE¼ T. 31 S., R. 12 W.). Several widely scattered Eocene conglomerate and sandstone outliers contain serpentinite detritus (near Iron Mountain in NW¼ sec. 4, T. 34 S., R. 12 W.; SE¼ sec. 33, T. 33 S., R. 12 W.; and NW¼ sec. 23, T. 33 S., R. 12 W.) proving that much serpentinite was emplaced by Eocene time. Baldwin (1968) interprets detrital black-sand deposits near Horse Sign Butte (8 miles south of Agness) as Eocene rather than Cretaceous, suggesting that adjacent mafic and ultramafic rocks were emplaced and undergoing erosion there by Eocene time. A few miles to the east along Illinois River, Eocene sediments apparently were deposited widely upon both ultramafic rocks and amphibole gneisses. Although Wells and others (1949) report ultramafic pebbles in Cretaceous as well as Eocene conglomerates in the Kerby quadrangle (east of the present map area), no such pebbles have been identified in pre-Eocene conglomerates of the coastal region. Gabbroic pebbles and a few serpentine sand grains are known, however, in Jurassic and Cretaceous sediments, and probably at least small amounts of ultramafic rocks were emplaced in the crust by Late Jurassic time.

Eocene conglomerates also contain fragments of schist like that of the Colebrooke formation at widely scattered localities. Lent (1969) reports them in the Sixes River area, and they occur in an important unfossiliferous outlier on Lobster Creek (sec. 24, T. 34 S., R. 13 W.) generally believed to be Eocene. The latter rests unconformably upon the Colebrooke. Coleman feels that this outlier dates the overthrusting of both the Colebrooke and underlying serpentinite as pre-Eocene.

It is clear that large masses of Colebrooke and ultramafic rocks had been emplaced and were being eroded by Eocene time, therefore the thrust faulting is regarded as pre-Eocene. Because the Upper

Cretaceous strata are structurally more akin to the Eocene than to older rocks, it is probable that much of the thrusting actually occurred during medial Cretaceous time. By no means all of the serpentinite reached its present position in pre-Eocene time, however, for late Cenozoic vertical fault zones have intensely sheared serpentinite pods along them, and several of these pods are today in fault contact with Eocene strata. Coleman has found calcium silicate contact alteration zones (rodingites) in Eocene sediments and older rocks adjacent to the serpentinite, indicating that the two rocks were in contact for a considerable time at relatively great depth (1967, and oral communication, 1968). Apparently the serpentinized peridotites underwent diapiric intrusion episodically during the Cenozoic.

Mount Emily dacitic intrusives (medial Cenozoic)

East and north of Brookings, dikes and sills of light tan-weathering dacite and some rhyolite porphyry have intruded the Dothan Formation ("Tad" on Plate 1). Mount Emily appears to be a stock or volcanic neck of varied composition, including locally mineralized diorite and syenite (Butler and Mitchell, 1916). Noteworthy is the fact that abundant dacitic to rhyolitic dikes radiate outward into the Winchuck Member of the Dothan. Fresh rock is light gray with quartz and feldspar phenocrysts in a vitreous, glossy groundmass. The feldspar is chiefly oligoclase with minor K feldspar; amphibole, zircon, an opaque iron mineral, and graphite are accessories (Widmier, 1962).

It is readily apparent in the field that the dacite and rhyolite postdate the major deformation of the region, and a K-Ar whole-rock determination for a sample from Harris Beach State Park just north of Brookings yielded a date of 30 ± 1 m.y. (near the Oligocene-Miocene boundary) (Table 3). That a significant episode of silicic intrusive activity may be widely represented in the Coast Ranges is suggested by the presence of nearly identical dacitic volcanic necks or plugs intrusive into Franciscan rocks in the Morro Bay area of southern California; the latter have been dated as 24 to 27 m.y. (Turner and others, 1970).

Mafic dikes between Whalehead and Crook Point (medial Cenozoic)

A series of 8 or 10 east-west-trending dark gray, dioritic to gabbroic dikes cut Otter Point strata along the coast between Horse Prairie Creek and the Thomas Creek bridge (secs. 21 and 28, T. 39 S., R. 14 W.). They are best exposed in sea cliffs, but several also are exposed in roadcuts on the Coast Highway. Most are vertical and they range from 8 inches to 10 feet wide. They show either porphyritic or diabasic textures, and contain chiefly twinned and zoned plagioclase (An_{40-65}) and clinopyroxene, with accessory hornblende, biotite, opaque grains, apatite, and zircon. A dark gabbroic dike from 1 to 2 feet thick and composed of plagioclase and pyroxene also has intruded the Hunters Cove Formation in the first road cut south of Burnt Hill Creek on U.S. Highway 101 (NE¼ sec. 5, T. 39 S., R. 14 W.). Soon after the cut was made, a fresh sample was dated by the whole-rock K-Ar method as 28 ± 1 m.y. (Table 3), which places it with the silicic Emily intrusives very near the Oligocene-Miocene boundary.

On the east side of Crook Point just southeast of "Clay" triangulation station (NW¼ sec. 31, T. 38 S., R. 14 W.), a black mafic sill from 2 to 3 feet thick and showing columnar jointing has intruded the Hunters Cove Formation next to a major fault contact with the Otter Point complex, which forms the point itself (Plate II, inset B). This unusual rock can be traced for a quarter of a mile. It consists of andesine, clinoenstatite, and minor olivine (Howard, 1961). It is presumed to be closely related to the medial Cenozoic sills and dikes. Snavely and Wagner (1961) dated gabbroic and alkalic intrusives in the central Coast Ranges of Oregon as post-Eocene and pre-middle Oligocene. Possibly the more southerly mafic intrusives are related.

Miocene and Pliocene sediments (undifferentiated)

In the northwest corner of the map area around Cape Blanco and at the southern end around Crescent City occur shallow-marine sands, gravels and some mudstones with Miocene and Pliocene faunas. Most of these were recognized by Diller to be of late Cenozoic age (1902, 1903a). Those in the north generally have been mapped as the "Empire Formation," while the southern ones are termed "Wymer Formation" (inland) and "St. George Formation" (coastal). Diller (1902) interpreted these strata as

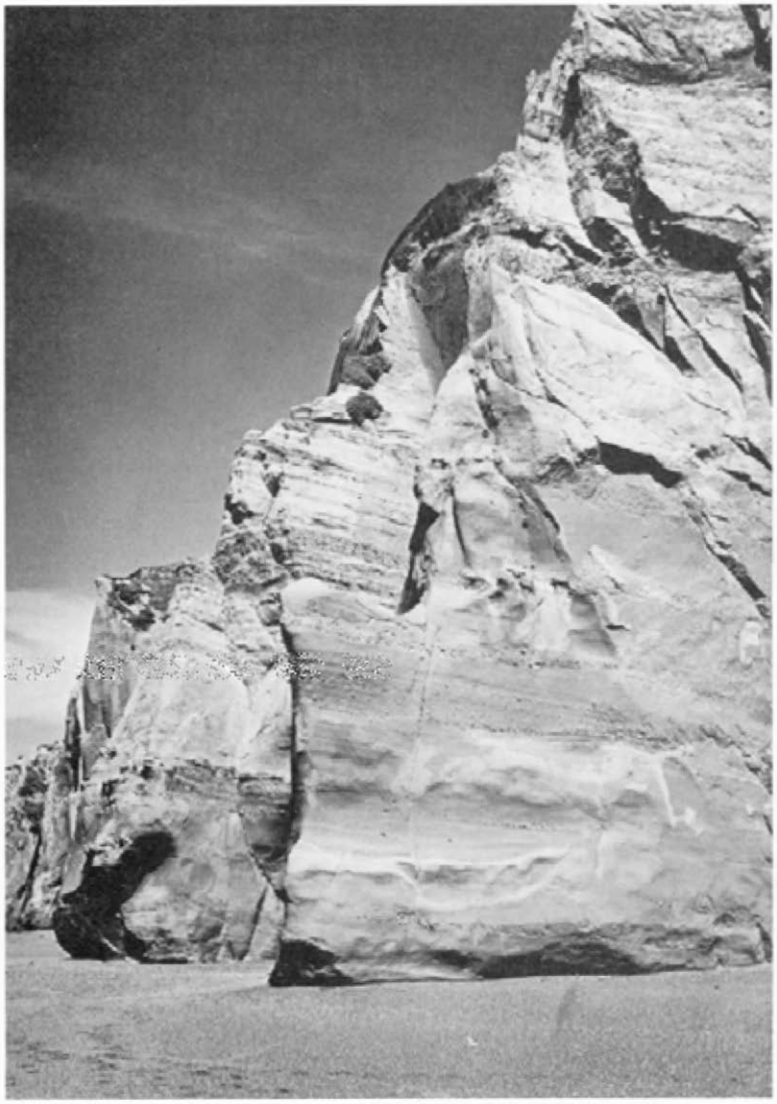

Figure 33. Imposing cliffs of shallow-marine Miocene sands and gravels ("Empire Formation") just north of the Blacklock syncline of Figure 19. Such sands extend in similar cliffs for 3 miles north to Floras Lake at the map edge. Note dark gravel lenses and broad scour truncations. Layers of mollusk shells and wood also are common.

evidence of a major Miocene peneplanation of the Klamath region. While his inference was too generalized, the strata certainly do reflect a major physiographic and tectonic change.

Durham (1953) recognized an unconformity within the "Empire Formation" of Diller southeast of Cape Blanco; middle Miocene faunas occur below and lower Pliocene ones above. Middle Miocene sands and gravels also extend north from Blacklock Point to Floras Lake (Addicott, personal communication, 1969; see Figure 33). The top of Cape Blanco is capped by lower Pliocene sands and gravels, which rest unconformably upon overturned Otter Point strata and are, in turn, overlapped by Pleistocene marine terrace deposits (Figure 34). Both the Pliocene and Jurassic rocks have been faulted at the east side of that headland against Eocene mudstones, proving that at least some of the vertical faults in the region are relatively young. Koch collected lower Pliocene mollusks (identified by Addicott) from sands and gravels 1.5 miles southeast of Port Orford near the mouth of Hubbard Creek. These beds are mapped with the Quaternary on Plate I.

The Miocene Wymer Formation comprises scattered patches of flat-lying marine and nonmarine fine conglomerate, sandstone, and shale in the hills east of Crescent City, which rest unconformably upon a variety of Mesozoic rocks. According to preliminary mapping (see Weed Sheet, 1963, of the California State Geologic Map), they straddle the Klamath boundary fault, thus placing a definite younger limit to westward thrusting in this area. At Crescent City and almost certainly beneath the flat plain to the north, richly fossiliferous Pliocene mudstone and fine sandstone (St. George Formation) unconformably overlie Dothan strata (Maxson, 1933; Back, 1957). They appear to represent lagoonal deposits.

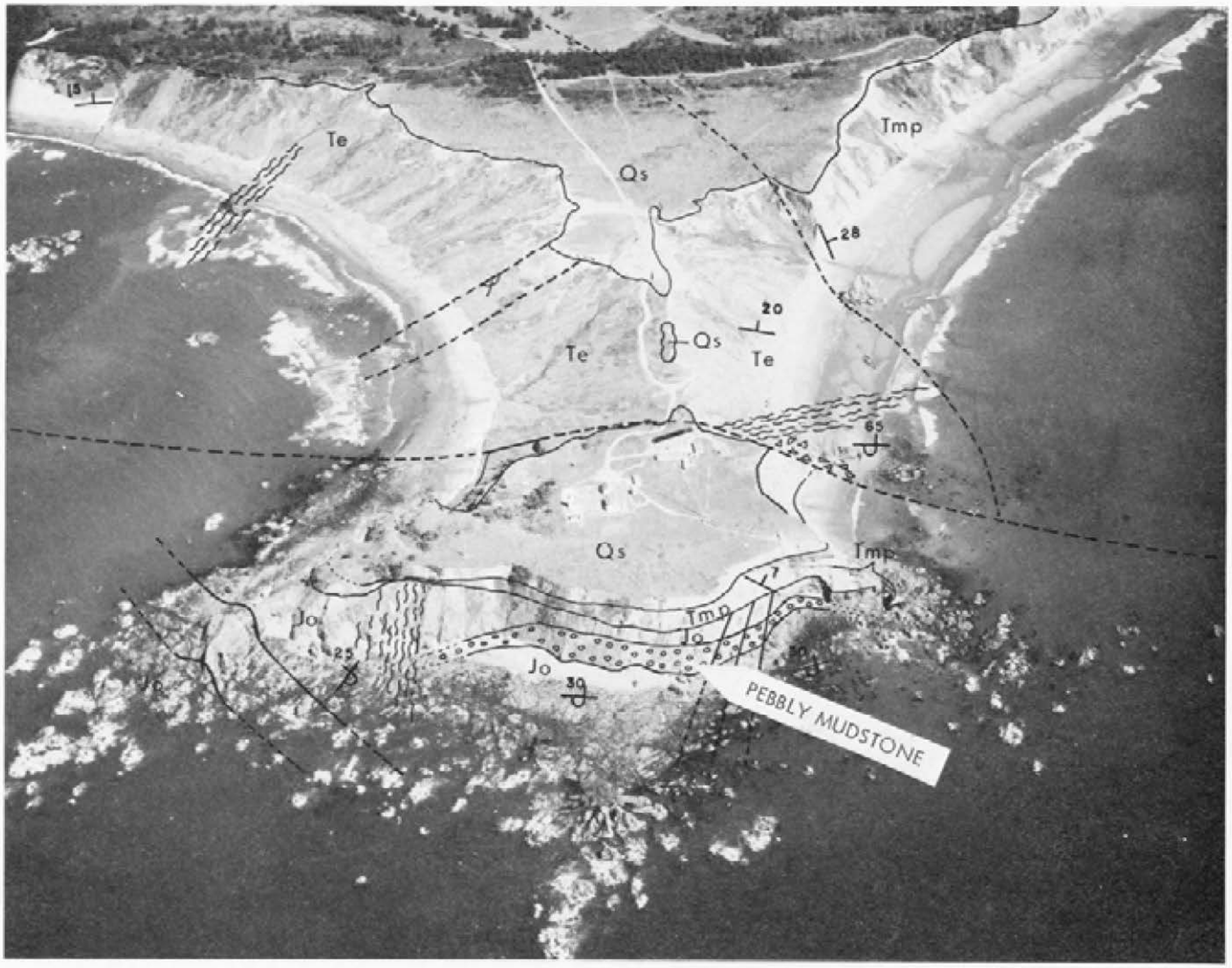

Figure 34. Oblique air photograph of Cape Blanco showing flat Pleistocene marine terrace deposits unconformable upon Tertiary and Jurassic rocks. The light-colored Cenozoic strata suggested the Cape's name to early Spanish mariners. Note very youthful faulting, which has displaced units at least as young as Pliocene (compare inset map on Plate I).

Quaternary deposits

Elevated Pleistocene marine-terrace deposits are especially prominent in the northwest and southern parts of the map area, although patches occur all along the coast. Several distinct terraces have been recognized in the flat belt extending north from Port Orford for nearly 40 miles to Coos Bay. Poorly consolidated sands and gravels from a few feet to 100 feet thick characterize the terraces, which have been dissected by major streams. The most extensive terraces lie at elevations between 200 and 300 feet (several have been warped differentially). In the vicinity of Cape Blanco (Figure 34), isotopic dates from shells of at least 33,000 years ago (Richards and Thurber, 1966) and of shells 25,000 years ago and wood and cones of 45,000 years ago indicate a late Pleistocene age for materials on the youngest terrace (Janda, 1969). Remnants of older terraces occur at still higher elevations, for example in the areas along the Elk and Sixes Rivers northeast of Port Orford, which Janda (1969) regards as probably dating back to early Pleistocene time. Lent (1969) reports one remnant just north of the present map at an elevation of 1,200 feet. Prominent terraces also occur on the narrow coastal plain extending north from the Rogue River to

Ophir (for example, at Otter Point; Figure 13). Southern terraces occur at an elevation of 30 feet near Crescent City, but are near 80 feet around Brookings. Higher ones (up to 800 feet) occur north of Brookings (T. 40S., R. 14W.).

Several wide beach areas are mapped as "Quaternary," as is a large area of partially stabilized sand dunes just south of the mouth of Pistol River. Other small areas of dunes are not mapped. River alluvium is shown for the lower ends of river valleys only. The texture and composition of modern beach, dune, and river sands were studied by Loudon (1967) to determine what differences, if any, could be related to distinct source rocks. In general, all of the sands are so heterogeneous that it is difficult to prove any significant patterns. On the average, the beach sands are medium grained, subrounded, and well sorted. They are very immature compositionally, containing predominantly rock fragments, many of which are unstable (Table 4). It is apparent from both textural and compositional studies that most of the beach sand is derived from coastal outcrops; only the Rogue and Chetco Rivers regularly supply significant sand to the coast. Because headlands partition the coast so strongly, it was not possible to use the sand to determine the net longshore drift along the coast. It is assumed that southerly drift is dominant, at least in the summer, but some northerly drift also must occur during severe winter storms. Beaches between major headlands are so isolated that they show distinctive textures and compositions related almost exclusively to local geology and local wave regimes. In short, the geologically heterogeneous nature of the coastal mountains and the rugged and irregular coast produce extremely complex local patterns of sand types.

Indian shell middens occur along the coast at a number of places. Notable examples are situated

Table 4. Characteristics of southwestern Oregon beach sands (after Loudon, 1957).

Textural summary (phi units)

	Median diameter	Mean diameter	Sorting	Skewness	Kurtosis
Beaches (N=44)	1.59φ (-.13 to 2.31)	1.60φ (-.13 to 2.29)	0.39 (0.24 to 1.02)	+0.08 (-.60 to +.35)	0.77 (0.42 to 1.33)
Dunes (N= 7)	1.38φ (0.57 to 1.74)	1.46φ (0.76 to 1.83)	0.48 (0.35 to 0.97)	0.09 (-.21 to +.71)	0.72 (0.45 to 0.83)
Rivers (N=23)	1.98φ (0.30 to 3.03)	2.02φ (0.30 to 3.11)	0.57 (0.35 to 1.19)	0.06 (-.18 to +.26)	0.81 (0.63 to 1.72)

Compositional summary (N=27 slides with an average of 581 points per slide):

Rock fragments:		Minerals:	
Volcanic	38%	Plain quartz	13%
Sedimentary	13	Polycrystalline quartz	13
Metamorphic	7	K feldspar	1
Serpentinite	3	Plagioclase	3
Chert	1	Epidote	1
Other	6	Hornblende	1
		Pyroxene	1

(from north to south) between Blacklock Point and the mouth of the Sixes River, on the southern tip of Cape Sebastian, three-quarters of a mile south of Myers Creek (NE¼ sec. 18, T. 38 S., R. 14 W.), and above coves in sec. 16, T. 39 S., R. 14 W. Some middens (especially that near Myers Creek) have yielded artifacts, which include a large variety of tools made from bones and antlers.

Implications of the New Global Tectonics to Southwestern Oregon

Late Jurassic and Early Cretaceous of the Klamath Province

The Galice Formation was deposited during Oxfordian and Kimmeridgian time (circa 140 to 160 m.y. ago) upon an undetermined basement. The fact that the entire region lies west of the quartz diorite line of Moore (1959) suggests that it lay at or near the Late Jurassic continental margin. The abundance of andesitic and rhyolitic volcanic rocks with relatively low K_2O and TiO_2 and some sodium and Al_2O_3 enrichment within the Galice and associated Rogue Formation (perhaps also the Dothan) of the Klamath Province point to development within a volcanic arc setting (Dickinson, 1969; see also discussion in Dott, 1965). Significantly, blueschists have not been reported within known Galice terranes either of the Klamath proper or of the outlying Klamath terrane in the northern part of the map area.

During latest Jurassic time, the Nevadan orogeny affected the northwestern Klamath Province. The Galice and Rogue rocks were deformed and metamorphosed to greenschist and higher grades. Widely scattered quartz diorite plutons (for example, the Pearse Peak and Bray Mountain) formed within Klamath terranes and within some of the large ultramafic complexes between 135 and 150 m.y. ago in Oregon and in northern California (Lanphere and others, 1968). Meanwhile, mixed blueschist and greenschist metamorphism was occurring in presumed Galice-age rocks somewhere west of the main Klamath Province between 125 and 140 m.y. ago --probably in close association with an oceanic trench. The resulting Colebrooke Schist was later thrust upon the presently juxtaposed late Mesozoic sedimentary and ultramafic complexes (Coleman, 1969).

Erosion quickly exposed the Galice metamorphic terrane and associated diorite plutons, and in Early Cretaceous time a marine transgression of the northwest side of the Klamath Province, represented by the Humbug Mountain and Rocky Point formations and, farther east, the Myrtle Group, produced a nonvolcanic, clastic sedimentary sequence almost identical with that of the northern Sacramento Valley of California. In both states this history is reflected in an increase of detrital K feldspar and mica in progressively younger formations.

Late Jurassic of the coastal province

The Dothan Formation for years was assumed to be a part of the pre-Nevadan Klamath Jurassic succession and either pre-Galice, coeval with Galice, or perhaps even post-Galice. Recently, a post-Nevadan age and an origin outside the Klamath tectonic province (in the strict sense) has been suggested as previously discussed. The Otter Point (of equivalent age and very similar to the Franciscan assemblage) lies entirely west of the Dothan, and formed largely, if not entirely, during Tithonian time. It has no known basement, but the presence of pillowed basalt and keratophyre, together with widespread ultramafic rocks, suggests that it probably formed on oceanic crust. The Dothan, on the other hand, while possessing many similarities to the Otter Point, was characterized by somewhat more silicic volcanism (see Table 2), less conglomerate, and less mélange development.

Recently proposed Mesozoic models for California, based upon the concept of "plate tectonics," invite some speculations about the origin of the Otter Point and Dothan rocks. Dickinson (1969), Hamilton (1969), and Ernst (1970), although arguing from somewhat different viewpoints, all conclude that a late Mesozoic arc or tectonic land characterized by calc-alkaline volcanism lay along and east of the site of the present Sierra Nevada, which was then near the margin of the continental crust. At the present site of the California Coast Ranges, there was a complementary deep oceanic trench wherein the Franciscan Complex formed. Between lay a narrow continental shelf and slope characterized by rapid clastic sedimentation (the present Great Valley region). Sea-floor spreading and underthrusting of the eastern Pacific crust beneath the continental margin presumably carried oceanic basalts and abyssal sediments (including bedded cherts) eastward to be thrust beneath, and tectonically mixed with, the toe of the continental slope sequence as well as with slivers of oceanic basement and mantle peridotite. Rapid depression of the rocks beneath the trench, followed soon by rapid elevation along thrust faults, presumably led to the high-pressure but low-temperature blueschist metamorphism characteristic of the Franciscan terrane and many other regions located on the oceanic sides of island arcs.

Much additional work will be required before the analogy with the California model can be fully tested in Oregon. As was suggested above, the Klamath region (like the Sierra) apparently lay along the western side of a Late Jurassic volcanic arc and tectonic land. A postulated complementary deep trench lay to the west with its axis slightly beyond the present coast. The sheared or mélange nature of much of the Otter Point rocks, together with glaucophane schists found along the thrust boundary between them and the overriding Colebrooke Schist, are consistent with a trench origin in which Pacific crust was being actively thrust beneath newly formed Klamath continental crust. While the Otter Point has much in common with the Franciscan, it is far more conglomeratic, suggesting an origin nearer to islands rather than to the deepest part of a trench. It is probable that much of the conglomerate finally accumulated on deep sea fans miles from land in a manner similar to that of the thick, coarse Mesozoic conglomerates of the Sacramento Valley of California (Aalto and Dott, 1970). The Otter Point and Dothan assemblages probably represent accumulations transitional between trench-axis and arc-axis deposits and having characteristics of both. California's Great Valley nonvolcanic continental shelf sedimentary sequence of late Mesozoic age has little preserved counterpart on the west-central side of the Klamath arc between the inferred volcanic arc and the trench. Apparently the undifferentiated Jurassic-Cretaceous strata ("JK" of Plate I) in the east-central part of the map area around Agness (T. 35 S., R. 11 E.) are the only possible analogues; thrust faulting may have concealed most of them.

The several geologic subprovinces near the coast, which have been distinguished formally in the preceding discussion, appear to have been telescoped by faulting in Oregon even more than in northern California. The Great Valley counterpart, especially, is almost unrecognizable. The major map units of Plate I reveal what is left of the now-jumbled subprovinces. Even though details of structural interpretation shown therein will be superseded, it is thought that those tectonic divisions are sufficiently delineated to aid further unraveling of the very complex structural history of the region (see Medaris and Dott, 1970). As Dickinson (1969) noted, in such cases features like the volcanic arc and trench themselves have been destroyed by structural processes. Most of their character in Oregon, therefore, must be deduced by very detailed sedimentological studies.

Cretaceous thrust faulting

Eastward underthrusting of oceanic crust is presumed to have continued during Cretaceous time, resulting in broad folding and some faulting of the Cretaceous strata and continuing intense shearing of Otter Point and Dothan rocks. Deformation culminated in extensive low-angle thrust faulting certainly before middle Eocene time, but most likely in medial Cretaceous time as inferred in northern California and by Misch (1966) in northern Washington. Some underthrusting of Upper Cretaceous beneath Otter Point rocks is indicated, but of a lesser magnitude.

Although it seemed incredible when Irwin suggested immense thrusting in 1964, it now appears that the coastal outlier of Klamath-type greenschists and diorites overlain by Sacramento Valley-like Cretaceous sediments in the northern part of the present map area almost certainly is either a very large allochthon or a block displaced more than 25 miles westward by strike-slip faulting. The distinctly different Otter Point rocks lie both to the north and south of the outlier as do blueschist rocks of the Colebrooke Schist. This Klamath-Great Valley-type outlier has no nearby counterparts and is totally anomalous in its present position. The Colebrooke Schist clearly is allochthonous upon the Otter Point and also upon the southern side of the Klamath-Valley outlier, suggesting large-scale imbrication of several thrust sheets resulting from the culmination of Mesozoic oceanic underthrusting. The analogies with the gross structure and history of northern California and northern Washington as they have come to be understood in recent years are truly striking. That the underthrusting involved profound displacements of upper mantle material is suggested by the discovery by Medaris of high-pressure minerals in ultramafic rocks closely associated with the Colebrooke allochthon as well as by the presence within these same rock masses of at least two plutons that yield Paleozoic dates; these are interpreted as old masses carried up into the crust during culminating thrusting (Medaris and Dott, 1970).

Late Cretaceous and early Cenozoic tectonic quiescence

Southwestern Oregon became relatively stable by latest Cretaceous time when erosion had reduced much of the terrain to sea level, allowing partial marine inundation during the Late Cretaceous world-wide transgression. No contemporaneous volcanism is known, and the sediments reflect deep erosion of plutonic as well as older sedimentary and metamorphic rocks. They have a high K-feldspar content (up to 20 percent) and appreciable mica (Dott, 1965; 1966). The rocks are totally different from all older strata, and are more akin structurally to early Cenozoic ones. Different areal distributions of Upper Cretaceous and lower Cenozoic strata, however, imply some epeirogenic warping in Paleocene time followed by widespread marine transgression and unconformable overlap by variable Eocene deposits upon the Mesozoic complex (Baldwin, 1965; Dott, 1966a).

Late Cenozoic tectonism

Post-Eocene vertical faults and shear zones have affected much of the coastal region (figure 35). Where they were overprinted on older mélanges and thrust sheets, structural history is almost impossible to decipher. North-northwest-trending shear zones characterize the coastal margin much as in the California Coast Ranges (Figure 2). These structures have been traced onto the continental shelf off northern California by Silver (1969a), but they do not extend to the abyssal realm. Northerly trending faults also occur farther inland in Oregon. That faulting continues today is suggested by seismic activity along the present coast (Figure 2), by clear offsets of Pliocene strata (Figure 34), and by warping and probable faulting of elevated Pleistocene marine terraces. The onset of the faulting is thought to have been in medial Cenozoic time (Oligocene-Miocene, or 25 to 30 m.y. ago), but this date is inferred from somewhat

Figure 35. Northwest toward Crook Point and Mack Reef (in distance) from Deer Point along the exceptionally rugged coast in T. 39 S., R. 14 W. Line of stacks in the reef is a series of igneous tectonic blocks along the Cenozoic Crook Point fault zone; Upper Cretaceous strata bound the fault on the east in right distance (see Plate II, inset B). Stacks in the foreground are very massive Otter Point conglomerates, which lie in thrust contact with the Upper Cretaceous strata at Houstenaden Creek to the right of photograph (in sec. 9, T. 39 S., R. 14 W.).

Figure 36. Simplified tectonic map of southwestern Oregon illustrating the thrust hypothesis of Coleman (1969), relations between the major tectonic sub-provinces discussed in the text, and the relation of southwestern Oregon to the offshore Gorda lithosphere plate (see inset map). Roman numerals are inferred thrust blocks; arabic numbers indicate mantle-derived peridotite studied by Medaris. (After Medaris and Dott, 1970; compare Fig. 3.)

circuitous reasoning. First, the faults affect Eocene and Upper Cretaceous strata more or less equally, and scattered dikes, sills, and volcanic rocks dating from 28 to 30 m.y. ago are assumed related to the faulting. Secondly, the development of the north-south-trending Coos synclinorium north of the present map area and also a major change of structural patterns in eastern Oregon and Washington (Figure 2) occurred in Miocene time (Dott, 1965). Finally, on a still larger scale, it is clear that the entire Cordillera suffered a profound tectonic change reflected in extreme fragmentation of the crust and by a very widespread change to basaltic volcanism beginning in most areas either in Oligocene or Miocene time, about 25 to 30 m.y. ago (Dott, 1969; Christiansen and Lipman, 1970). This pervasive change apparently reflected collision of southwestern North America with the East Pacific Rise, and it is assumed that the change of tectonic style in southwestern Oregon was essentially synchronous with those better dated phenomena elsewhere.

According to analyses of oceanic magnetic anomalies and of active seismicity, sea-floor spreading is continuing from the Gorda Ridge west of southern Oregon (Tobin and Sykes, 1968; Silver, 1969b). The Blanco Fracture (McManus, 1965), like the Mendocino Fracture Zone, apparently is a transform fault that displaces the Gorda and Juan de Fuca Ridges (Figure 2). Moore (1970) suggests that the Blanco Fracture may be one extension of the San Andreas fault. The spreading Gorda oceanic lithosphere plate (Figure 36) east of the ridges apparently is decoupled from the continental plate as suggested by crumpling of continental-rise sediments detected by Silver (1969a, 1969b), by the lack of clear continuity of structures on the continent and adjacent shelf with those of the oceanic plate, and by evidence of about 1,000 meters of uplift of Miocene-Pliocene sediments on the shelf and slope west of central Oregon (Byrne and others, 1966). Decoupling of the Gorda from the continental plate would explain why the Blanco Fracture has no direct continuity with onshore structures. Silver (1969a) concluded from vector analysis of lithosphere plate movements that the Gorda Plate is underthrusting the continent toward the northeast, which could produce a significant right-lateral slip component along the continental margin. Such seems borne out by earthquake first-motion studies (McEvilly, 1968), and suggests at least some strike-slip motion along the late Cenozoic coastal shear zones as was postulated by Koch (1966). Thus the strain suffered by California south of the Mendocino fracture zone seemingly has been propagated for at least 200 miles farther north along the continental margin.

Although spreading still seems to be occurring off Oregon and Washington, the absence of a modern deep trench and of a proven Benioff zone with deep-focus earthquakes east of the present Cascade volcanic arc have been puzzling. The apparently rapid rate of spreading indicated for the Gorda oceanic plate of about 5 cm. per year, together with rapid sedimentation resulting from the Columbia and other large rivers, may account for the lack of a trench, and the paucity of deep-focus earthquakes may reflect only a temporary period of relatively little seismicity. If spreading and oceanic underthrusting are indeed continuing, then the present geologic state of the southwestern Oregon coast is ephemeral, and future episodes of orogenesis seem inevitable. But there would be major discontinuities between future structures and older ones just as the present shelf and coast are discordant with the old Klamath structural arc. As I have argued elsewhere (1969), apparently major discontinuities are characteristic of the sea-floor spreading process.

Economic Geology

Placer and vein gold, especially in the Sixes River and Johnson Creek drainage basins, were actively being mined at the turn of the century. Gold Beach acquired its name from placer gold worked during the winter season when storm waves shifted most of the beach sand offshore to expose gold-bearing gravels. In the northern part of the map area, black beach sands used to be worked for gold, platinum, and to some extent chromite and manganese. During World War II and again in the recent years the federal government has undertaken extensive evaluation programs of the placer sand potential for commercial reserves of heavy metals. With the abundance of ultramafic rocks in the region, there is a natural expectation of chromite, nickel, and platinum deposits, and extensive prospecting for these has occurred over the years. A rather unusual residual red soil developed at Red Flat on the southern end of the Signal Buttes ultramafic mass has been prospected for traces of nickel that are present. An unusual borate mineral (priceite) occurs in serpentinite at Lone Ranch Creek near Cape Ferrelo, but it is not abundant enough to be of commercial value.

Coal was mined on a limited scale from Eocene rocks in the northern part of the area at the turn of the century, but the Coos Bay coal fields still farther north contained vastly greater reserves. Coal mining ceased even at Coos Bay in 1923. Sedimentary materials of present economic importance are confined to gravels, which are readily available from river beds, and stone for riprap and fill, which are quarried locally. Diorite, volcanic rocks, and well-indurated older sedimentary rocks are best suited for the latter purposes; the choice of massive Cape Sebastian Sandstone for riprap along the new U.S. Highway 101 south of Gold Beach may have been an unfortunate choice, although it seems to have survived the elements rather well for the past 6 years. Offshore petroleum potential has received considerable attention in recent years, especially north of Cape Blanco. If Upper Cretaceous and Cenozoic strata are well developed offshore from the map area, there may be some significant potential.

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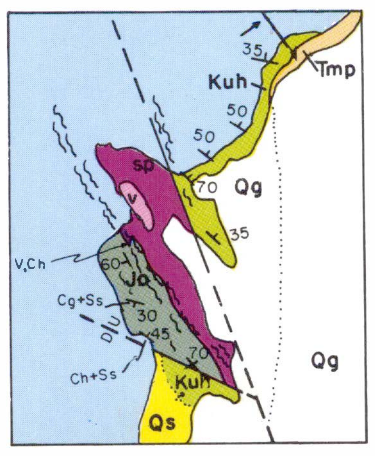
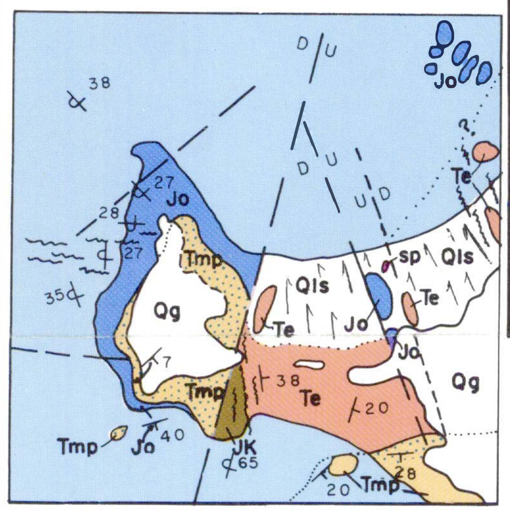
GEOLOGIC COMPILATION MAP OF WESTERN CURRY COUNTY, OREGON

Blacklock Point



Cape Blanco



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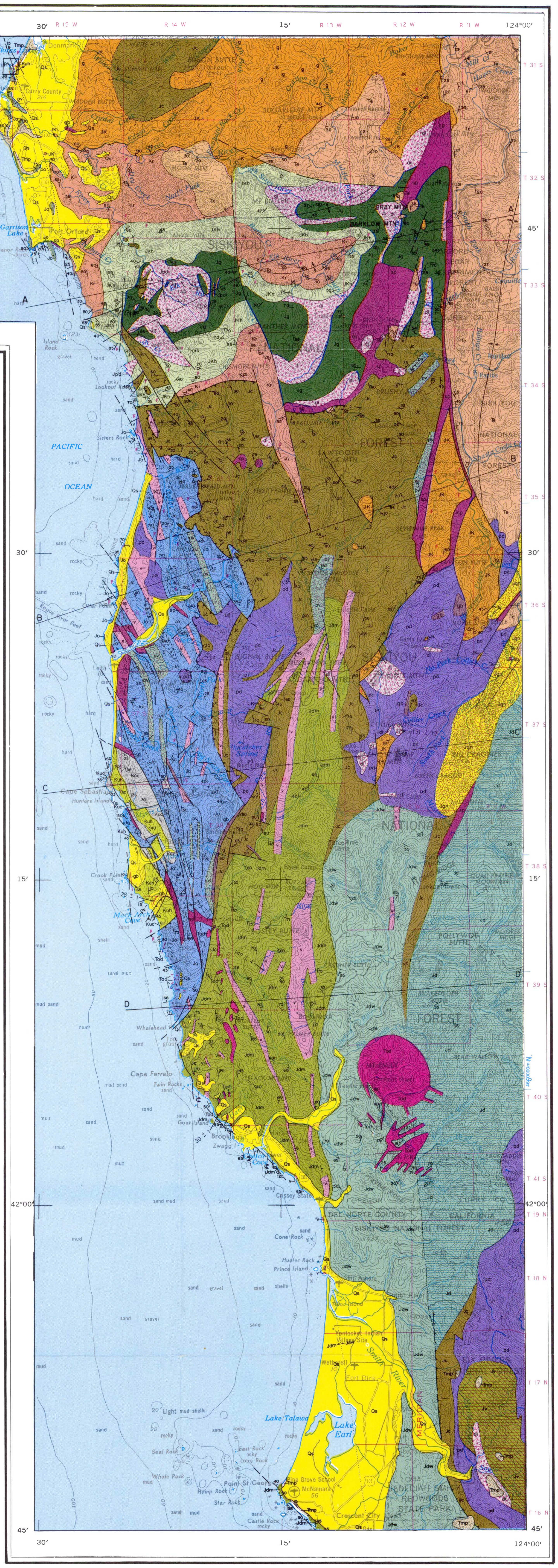
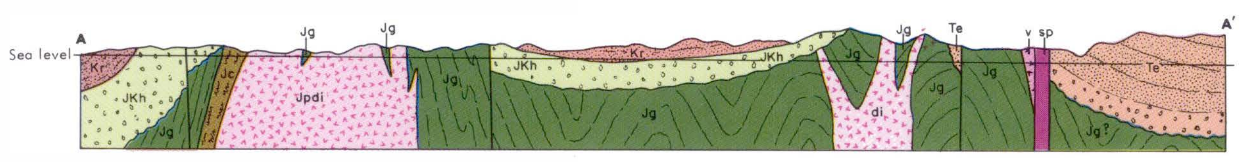


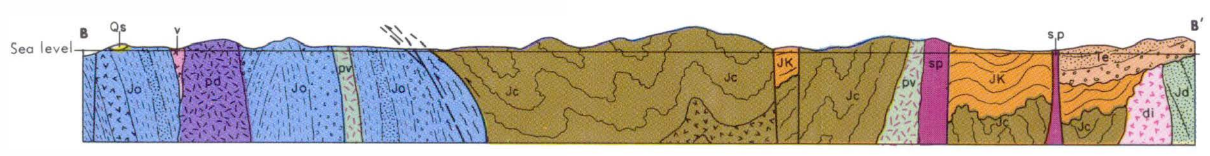
SECTIONIZED TOWNSHIP

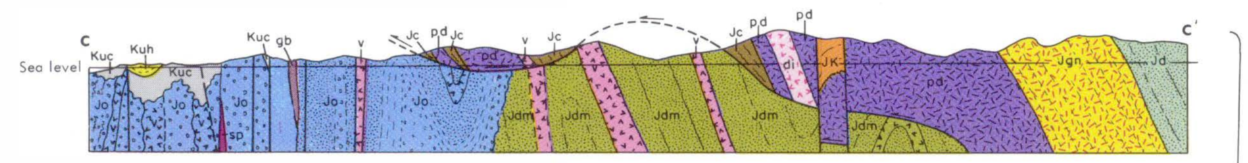
6	5	4	3	2	1
7	8	9	10	11	12
18	17	16	15	14	13
19	20	21	22	23	24
30	29	28	27	26	25
31	32	33	34	35	36

TOWNSHIP OR RANGE LINE

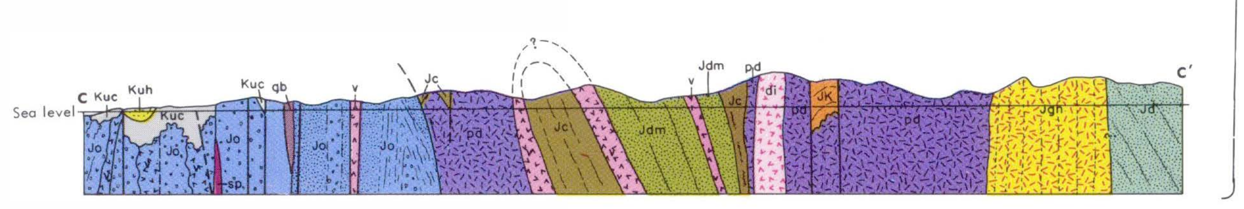
LAND GRANT BOUNDARY



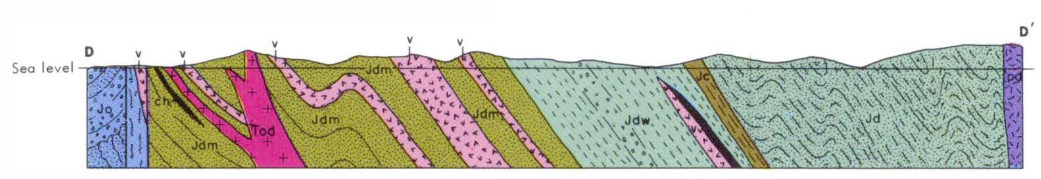




LARGE-SCALE THRUST INTERPRETATION



METAMORPHIC FACIES INTERPRETATION



EXPLANATION

QUATERNARY

Qs — Sands
Quaternary dune and beach sands (and some marine terrace deposits)

UNCONFORMITY

TERTIARY

(Mio-Pliocene)

Tmp — *Undifferentiated Upper Tertiary (Mio-Pliocene) marine deposits (includes "Empire Fm." of Diller)*

UNCONFORMITY

(Oligocene)

Tod — dikes and sills
Dacite dikes and sills of Brookings area (includes Mt. Emily intrusive)

(Eocene)

Te — Undifferentiated Eocene Sediments
non-marine and marine sediments (sandstone, shale, conglomerate and coal)

UNCONFORMITY

UPPER CRETACEOUS

(Campanian-Maestrichtian)

Kuh — Hunter Cove Formation (new name)
(dominantly shale with thin sandstone beds; local lenses of coarse sandstone and conglomerate up to 30 feet thick)

Kuc — Cape Sebastian Sandstone (new name)
(cross stratified, massive fine sandstone with local coarse conglomerate, especially near base)

UNCONFORMITY

LOWER CRETACEOUS

(Neocomian)

Kr — Rocky Point Formation
(graded sandstone and mudstone)

JKh — Humbug Mountain Conglomerate
(coarse, massive conglomerate with local thin sandstones)

JK — *Undifferentiated uppermost Jurassic and Lower Cretaceous strata of inland and northern areas (sandstone, shale and conglomerate) (Includes rocks equivalent in age to the Myrtle Group of inland regions)*

JURASSIC

(Portlandian)

Jo — Otter Point Formation
(Black mudstone, graded sandstone, massive pebble conglomerates; possibly a lateral facies equivalent of lower Humbug Mtn. conglomerate; contains important volcanic zones and minor bedded chert)

Massive conglomerate zones.

UNCONFORMITY

JURASSIC?

(Callovian?-Oxfordian-Kimmeridgian)

Jg — Galice Formation
(Slightly metamorphosed black, slaty mudstones and thin sandstones; typically displays conspicuous lamination)

Jd — Dothan Formation (undifferentiated)
(Sandstone, shale, minor conglomerate and bedded chert; includes important volcanic zones; may show incipient metamorphism). Age uncertain; commonly considered pre-Galice, but recent studies suggest possible contemporaneity with Otter Point Formation. Commonly mapped with the Franciscan Complex in California.

Jdw — Winchuck Member
(Black mudstone and thin, fine sandstones)

Jdm — Macklyn Member
(Massive sandstone, mudstone, bedded chert, conglomerate and volcanic rocks)

Jv — Undifferentiated Meta-Volcanics
Located principally in outcroppings along Smith River in northern California of assumed Jurassic age.

Jgn — Gneissic Rocks
Found along Illinois River (closely associated with peridotite and serpentinite masses; also reported from Big Craggies; presumed of Jurassic age).

Jc — Colebrooke Schist
(chiefly quartz-mica phyllite and schist of greenschist facies with minor blue schist minerals locally; includes meta-volcanics;)

g — *Principal localities of prominent glaucophane-bearing blueschists.*

130±10 Isotopic Dates. (Numbers in Millions of years)

GEOLOGICAL SYMBOLS

Approximate contact of Colebrooke Schist with Dothan; here assumed to be a metamorphic gradation, but perhaps a structural contact

Broad zones of intense shearing

F — Fossil localities

Faults
Dashed where approximately located or indefinite.

Thrust or reverse fault, barbs on side of upper plate.

Contacts
Dashed where approximately located, dotted where concealed;

Anticlinal axis

Synclinal axis
Showing trace of axial plane and bearing and plunge of axis; dashed where approximately located.

Approximate strike and dip of beds or flows.

Approximate strike and dip of foliation.

IGNEOUS ROCKS OF DIVERSE AGES:

di — Diorite
Quartz diorite and minor granodiorite stocks and dikes (apparently all are late Jurassic)

gb — Gabbroic dikes
(commonly associated with peridotite masses; probably Jurassic in age largely, but locally of Tertiary age)

pd — Peridotite
(Massive, dark ultramafic rocks with variable serpentinization; assumed to be largely of Jurassic age, but may include younger masses)

sp — Serpentinite
(light to dark green, intensely sheared serpentinized ultramafic rocks; assumed to be altered Jurassic peridotites)

pv — Pillow (ellipsoidal) lavas
(found in Otter Point, Macklyn member of Dothan and Colebrooke Formations)

v — Non-ellipsoidal volcanic rocks
including lavas and volcanic breccias and conglomerates (found in Otter Point, Galice, Macklyn Member of Dothan and Colebrooke Formations)

Geology
By R. H. Dott, Jr. 1967 (revised 1968)

Base Map from U.S. Army Map Service 1: 250,000 Topographical Series

Cartography by C. J. Newhouse & S. R. Renoud

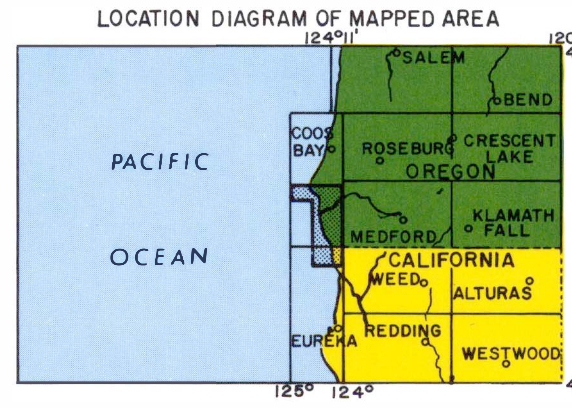
Scale 1:250,000

5 0 5 10 15 Statute Miles
5 0 5 10 15 20 Kilometers
5 0 5 10 Nautical Miles

CONTOUR INTERVAL 200 FEET
WITH SUPPLEMENTARY CONTOURS AT 100 FOOT INTERVALS

TRANSVERSE MERCATOR PROJECTION

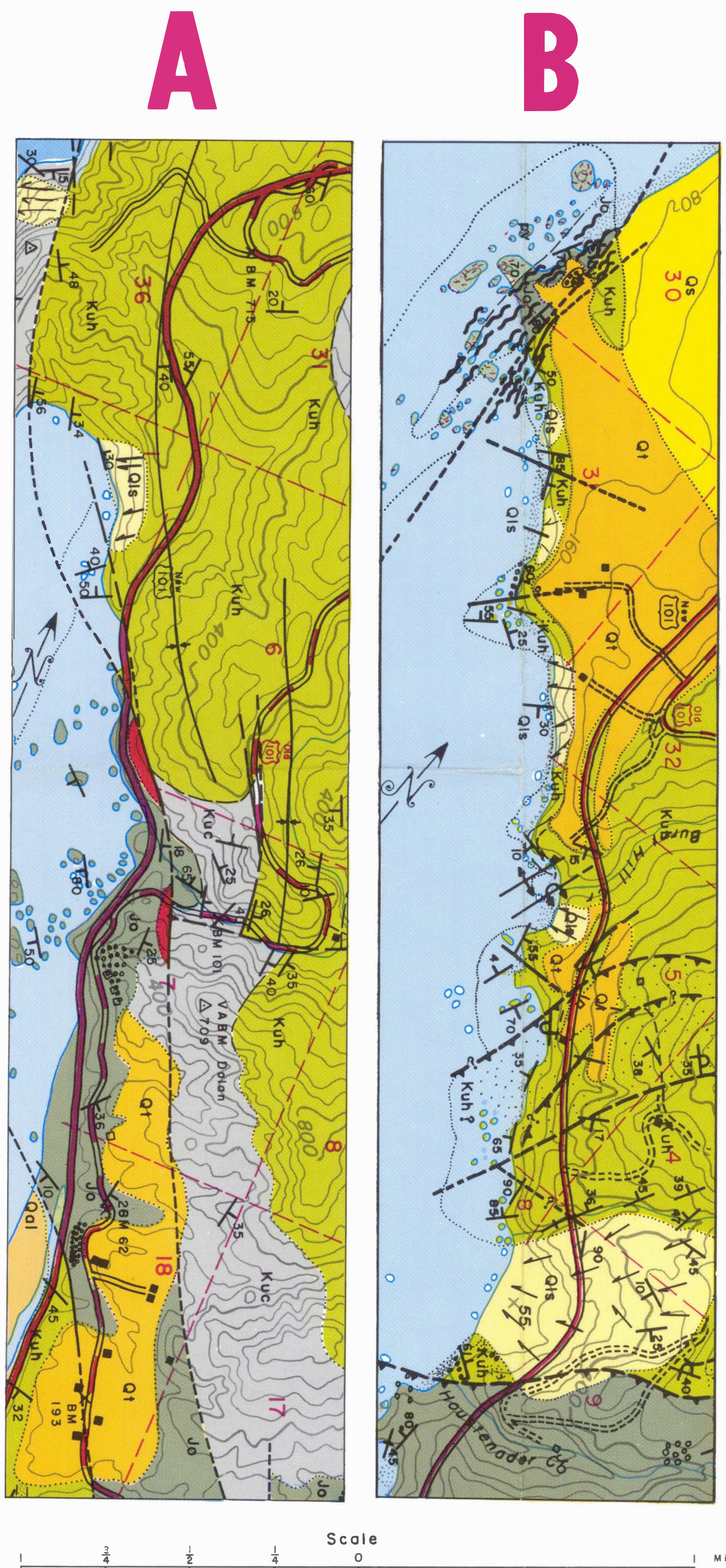
LOCATION DIAGRAM OF MAPPED AREA



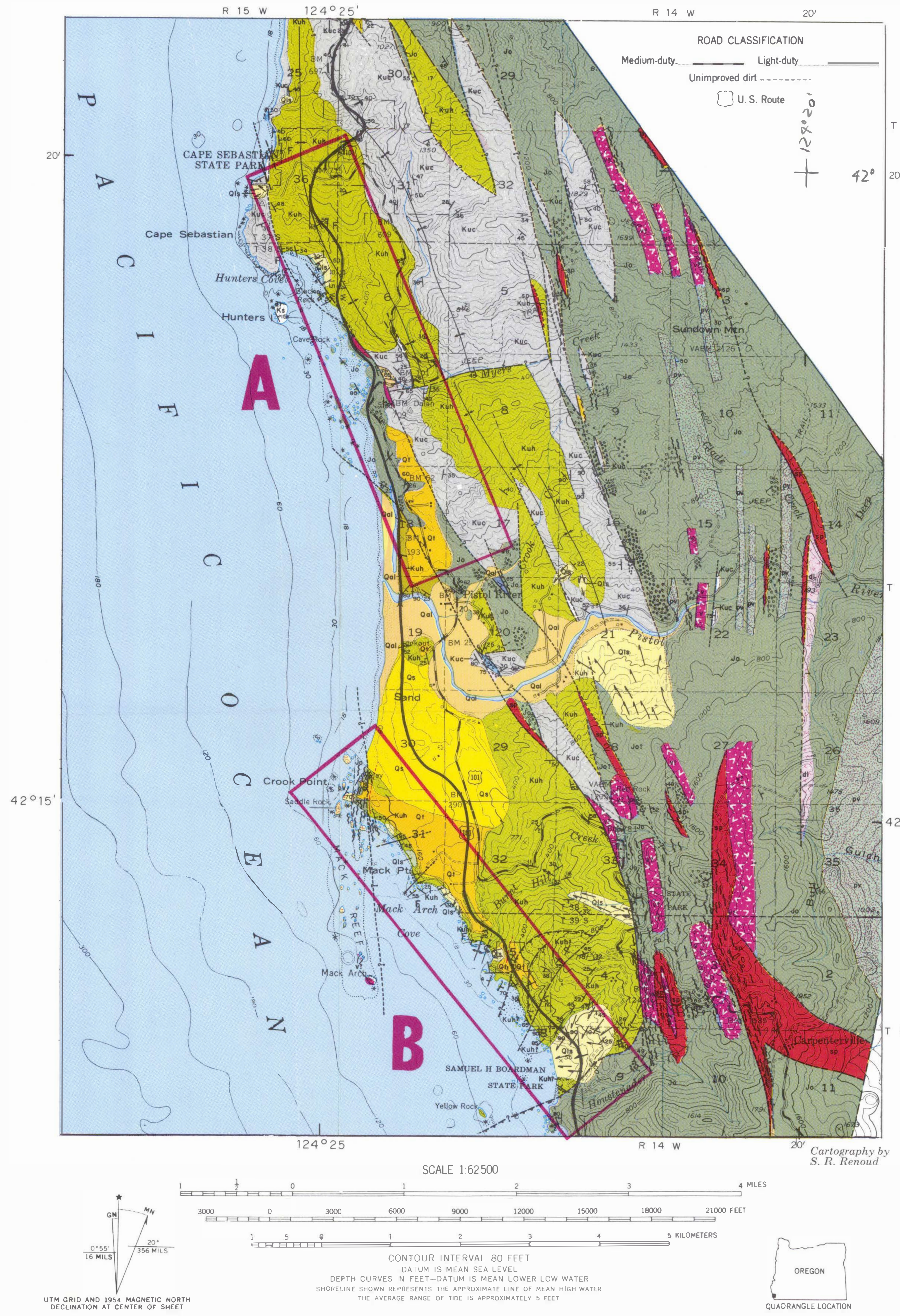
STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES
R. E. CORCORAN, STATE GEOLOGIST

GEOLOGIC MAP OF CAPE SEBASTIAN

STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES
R. E. CORCORAN, STATE GEOLOGIST



Base Map from U.S. Geological Survey



Geology
By R. H. Dott, Jr. 1967 (revised 1968)

EXPLANATION

QUATERNARY

Qal — River alluvium (*Chiefly gravel*)

Qls — Major landslides

Qs — Sands
Quaternary dune and beach sands (and some marine terrace deposits)

Qt — Pleistocene marine terrace deposits
(Sands and gravels mostly 150-200 feet above sea level.)

CRETACEOUS

Kuh — Hunter Cove Formation (new name)
(dominantly shale with thin sandstone beds; local lenses of coarse sandstone and conglomerate up to 30 feet thick)

Kuc — Cape Sebastian Sandstone (new name)
(cross stratified, massive fine sandstone with local coarse conglomerate, especially near base)

JURASSIC

Jo — Otter Point Formation
(Black mudstone, graded sandstone, massive pebble conglomerates; possibly a lateral facies equivalent of lower Humbug Mtn. conglomerate; contains important volcanic zones and minor bedded chert) Massive conglomerate zones

IGNEOUS ROCKS OF DIVERSE AGES:

di — Diorite
Quartz diorite and minor granodiorite stocks and dikes (apparently all are late Jurassic) (commonly associated with peridotite masses; probably Jurassic in age largely, but locally of Tertiary age).

Serpentinite
(light to dark green, intensely sheared serpentinized ultramafic rocks; assumed to be altered Jurassic peridotites)

Jpl — Pillow (ellipsoidal) lavas
(found in Otter Point, Macklyn member of Dothan and Colebrooke Formations)

Non-ellipsoidal volcanic rocks
including lavas and volcanic breccias and conglomerates (found in Otter Point, Galice, Macklyn Member of Dothan and Colebrooke Formations)

UNCONFORMITY

GEOLOGICAL SYMBOLS

Gabbroic dikes

Broad zones of intense shearing

Faults
Dashed where approximately located or indefinite.

Thrust or reverse fault, barbs on side of upper plate.

Contacts
Dashed where approximately located, dotted where concealed;

Anticlinal axis

Synclinal axis
Showing trace of axial plane and bearing and plunge of axis; dashed where approximately located.

Approximate strike and dip of beds or flows.

F — Fossil localities