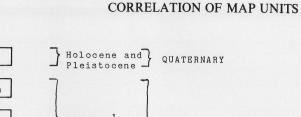


DEPARTMENT OF THE INTERIOR

THERMAL-ALTERATION SYMBOLS

2/2+ OUTCROP--Showing thermal-alteration index of kerogen

3b) SAMPLE GROUP--See text for discussion of area



Tnn Tnm Tpn Tpm PRE-TERTIARY

Units shown included by age brace consist primarily of Neogene rocks ²Units shown included by age brace consist primarily of Paleogene rocks

DESCRIPTION OF MAP UNITS

SURFICIAL DEPOSITS (HOLOCENE AND PLEISTOCENE) NEOGENE NONMARINE SEDIMENTARY ROCKS (TERTIARY)

NEOGENE MARINE SEDIMENTARY ROCKS (TERTIARY) IGNEOUS ROCKS (TERTIARY) PALEOGENE NONMARINE SEDIMENTARY ROCKS (TERTIARY)

PALEOGENE MARINE SEDIMENTARY ROCKS (TERTIARY) MARINE SEDIMENTARY ROCKS (EOCENE TO UPPER CRETACEOUS) SEDIMENTARY ROCKS (UPPER CRETACEOUS) -- Marine. Locally divided

Nonmarine redbed facies MARINE SEDIMENTARY ROCKS (LOWER CRETACEOUS AND UPPER JURASSIC) FRANCISCAN ASSEMBLAGE (CRETACEOUS OR LATE JURASSIC) OPHIOLITIC ROCKS (JURASSIC) -- Locally includes:

Serpentinized peridotite GRANITIC ROCKS (PRE-TERTIARY) PRE-BATHOLITHIC METAMORPHOSED PLUTONIC ROCKS (PRE-TERTIARY)

METAMORPHOSED SEDIMENTARY ROCKS (PRE-TERTTARY)

GEOLOGY SYMBOLS

THRUST FAULT -- Dashed where approximately located; dotted where concealed. Sawteeth on upper plate AAA_____DETACHMENT FAULT--Dotted where concealed

STUDIES RELATED TO WILDERNESS

The Wilderness Act (Public Law 88-577, September 3, 1964) and related acts require the U.S. Geological Survey and the U.S. Bureau of Mines to survey certain areas on Federal lands to determine their mineral resource potential. Results must be made available to the public and be submitted to the President and the Congress. This report presents the results of a study on thermal alteration of organic matter in rocks of the Santa Lucia Wilderness and 22 roadless areas, which consist of the Sespe-Frazier, Garcia Mountain, Black Mountain, La Panza, Machesna Mountain, Los Machos Hills, Big Rocks, Stanley Mountain, Miranda Pine, Horseshoe Springs, Tepusquet Peak, La Brea, Spoor Canyon, Fox Mountain, Diablo, Matilija, Dry Lakes, Sawmill-Badlands, Cuyama, Antimony, Quatal and Little Pine Roadless Areas. All the roadless areas are in the Los Padres National Forest, Kern, Los Angeles, San Luis Obispo, Santa Barbara, and Ventura Counties, California. The Santa Lucia Wilderness was established by Public Law 95-237, 1978. The twenty-two roadless areas were classified as further-planning areas during the Second Roadless Area Review and Evaluation (RARE II) by the U.S. Forest Service,

This map shows thermal-alteration indices (TAI's), based on colors of pollen grains, of 115 outcrop and 20 conventional core samples from Mesozoic and lower Tertiary rocks in the southern Coast and western Transverse Ranges, Southwestern California. The TAI's have been calibrated against previously determined vitrinite reflectance values from some of the same sample localities.

South of the Santa Ynez fault, the TAI's of exposed rocks near the fault are mainly between 2+ and 3- (2+/3-) to 3 and are generally in the early stage of thermal maturity with respect to the possible generation of oil. North of the Santa Ynez fault, the exposed rocks have TAI's mostly of 2 to 2+ and are mainly immature or transitional from immature to mature. However, Jurassic(?) and Lower Cretaceous samples from the

INTRODUCTION

The purpose of this map is to present data on thermal alteration of kerogen in 35 outcrop (map) and conventional core (fig. 2) samples of Mesozoic and lower Tertiary ocks in the southern Coast and western Transverse Ranges. Thermal-alteration indices (TAI's) shown on this map are based on colors of pollen grains isolated from the rock samples, using the TAI scale of Staplin (1969) and Pearson (1982). The geologic map used here is from Frizzell and Vedder (in press); the location of the Santa Ynez fault in southwestern Santa Barbara County is from Dibblee (1950, 1966). A petroleum potential map of the region, based mainly on organic geochemistry, porosity and permeability, and structure, has been prepared by Frizzell and Claypool (1983). Location and accessibility

Coast Ranges and the western part of the Transverse Ranges of California and totals approximately 1,336 square miles (fig. 1). It forms an elongate curve between U.S. Highway 101 on the west and Interstate Highway 5 on the east. California State Highways 33, 58, and 166 provide paved approaches to numerous secondary and unimproved roads that generally allow access to within a quarter mile of the borders of the various roadless areas. Trails provide entry into many parts of most roadless areas.

were certrifuged in a 1.45-specific-gravity solution of ZnBr₂ to separate the pollen grains from remaining mineral matter and from some of the dark woody material. Color determinations were made on the basis of pollen grains, which provide more consistent and reliable TAI's than dinoflagellates and acritarchs (Staplin, 1969; Batten, 1980). Some variation in pollen colors exists among grains on each slide. Darker specimens generally either have thick exines, such as many spores and some large pollen grains, or they are reworked older spores and pollen. I observed little obvious evidence of reworking in the present material, although occasionally a taxon such as Classopollis is seen that is probably reworked from the Cretaceous. At the other extreme are pale grains that usually have thin exines; however, specimens seemingly having a normal exine thickness, but which are very pale and appear bleached (probably weathered), are also found. I chose pollen grains of average exine thickness for the color measurements, and within any one slide most of these grains have approximately the same color. Staplin (1982, p. 8) reported that "palynologists at Esso Resources (Canada) interpret the thermal alteration index from the bladders of bisaccate gymnosperm pollen." During this study I recorded separate measurements of conifer grain sacci and of angiosperm pollen grains of medium exine thickness, and I found little or no variation between colors of the two groups of pollen in any one slide. In order to observe as true colors as possible, I used a 12-volt halogen light source and blue filter, which together produced nearly white light.

specimens retaining the original exine thickness had the same colors as well preserved grains in adjacent samples. Moderate oxidation during weathering or slight oxidation during sample processing may not change the colors significantly as long as these chemical effects do not reduce the exine thickness (Correia, 1967; Batten, 1981). TAT's less than 2+ or 2+/3- are difficult to determine accurately from pollen colors because the changes are so small (Staplin, 1977; Jones and Edison, 1978; Fisher and

others, 1980). Under the most favorable conditions it may be possible to determine TAT's to an accuracy of ± 0.1 within the range of approximately 2+/3- to 3/3+ (Jones and Edison, 1978, p. 6). Such accuracy is not attained in the present study. The TAI scale I used suggests an apparent resolution of about ± 0.15-0.2. Normal operational errors of TAI determinations in any one sample are perhaps on the order of 0.2-0.3 (P. F. Wesendunk, written commun., 1983) to 0.3-0.5 (Batten, 1981, fig. 1). On the other hand, the outcrop and core samples examined in this study are free of contamination due to cavings and mud additives, which causes difficulties in determining TAI's of cuttings samples often studied by oil company palynologists.

index of 2 is assigned to rather deep yellow grains, whereas an index of 2+ is assigned to yellow-orange specimens. I found the best way to distinguish between the two colors was to look at grains of normal exine thickness that were folded or had a thick portion (arci, for example); in grains indicating an index of 2, the thick part of the grain is dark yellow, appearing gray-yellow, whereas in grains indicating an index of 2+, the thick part of the

Acknowledgments I wish to thank P. L. Miller, Jr., of Chevron U.S.A. Inc., for permission to sample

cores from the Gerber No. 1 well, and R. E. Malloy of Union Oil Company for processing some of the samples from State Highway 33. K. P. Helmold of Cities Service Company provided unpublished data on locations of samples in his dissertation area. R. L. Pierce, Mobil Oil Corp.; P. R. Wesendunk and P. L. Miller, Jr., of Chevron U.S.A. Inc.; and V. A. Frizzell, Jr., U.S. Geological Survey, reviewed the first draft of this map with its accompanying diagrams and text and made many helpful suggestions for its improvement.

SAMPLES INVESTIGATED

This traverse includes 58 samples collected along Highway 33 from Ojai to the Cuyama River. The traverse crosses five major faults, from south to north the Santa Ynez, Tule Creek, Munson Creek, Pine Mountain, and Big Pine faults. Most of the rocks along the traverse are Cretaceous or early Tertiary in age, and the samples studied for this map are from an unnamed Upper Cretaceous unit and from the following Eocene ormations (in ascending order, not differentiated on the geologic map): Juncal Formation, Matilija Sandstone, Cozy Dell Shale, and Coldwater Sandstone. Some variation is apparent in TAI's within individual outcrops and within individual formations of a

Sample group 1 - Highway 33 traverse

given fault block, but the variations are mainly small and probably do not significantly affect interpretations of the TAI trends along the traverse. Upper Cretaceous and Eocene rocks just south of the Santa Ynez fault have darker pollen colors than most rocks on the traverse north of that fault. No pollen was found south of the fault in the predominantly sandstone and redbed strata of the Sespe Formation and Coldwater Formation, but rocks throughout the Cozy Dell Shale along this part of the highway have TAI's of about 3-. Two samples from the upper part of the Matilija Sandstone at its type locality have a TAI of 3. No pollen was found south of the

Santa Ynez fault in the middle and lower parts of the Matilija Sandstone, in the Juncal Formation, or in the unnamed Upper Cretaceous unit. All of the kerogen found in these barren samples is black woody material. Because pollen is commonly found in the Matilija and Juncal Formations north of the Santa Ynez fault, the lack of pollen in these formations south of the fault on Highway 33 appears to be due to thermal destruction of Between the Santa Ynez and Tule Creek faults, the Cozy Dell and the Coldwater mainly have a TAI of 2+. The TAI of 2 from the Cozy Dell sample just south of the Tule Creek fault may be slightly too low. The two samples from the Coldwater just north of

lighter in color than samples from the Cozy Dell, which is stratigraphically lower; it is possible that the darker colors in the Coldwater are due to thermal effects caused by fluids or movement of the Santa Ynez fault. Between the Tule Creek and Munson Creek faults, the Coldwater and perhaps the upper part of the Cozy Dell may have slightly lower TAI's (2, 2, 2/2+) than the Matilija (2/2+) or the Juncal (2/2+, 2+, 2+, 2+), but the evidence is weak because of the small number of samples examined. However, it is interesting that the change in TAI from the Coldwater to the Juncal should be so small through thousands of feet of section. Between the Munson Creek and Pine Mountain faults, nearly all the samples are from the Cozy Dell and show TAI's of 2/2+ to 2+/3-. Between the Pine Mountain and Big Pine

the Santa Ynez fault that have TAI's of 2+/3- are difficult to interpret; they should be

faults, samples were only available from the Matilija and Cozy Dell, and these two formations have the same TAI, 2 to 2+. About the same TAI is found in the rocks from this traverse sampled north of the Big Pine fault; these are from the Juncal Formation. The TAI data from the Highway 33 traverse suggest that two major blocks can easily be distinguished on the basis of pollen colors: kerogen in the Cretaceous and lower Tertiary rocks south of the Santa Ynez fault has undergone greater catagenesis than in nearly all of the lower Tertiary rocks between that fault and the Cuyama River. Lower Tertiary rocks north of the Santa Ynez fault mainly have TAI's between 2 and 2+; within this area, little variation is obvious in TAI's from the top of the preserved lower Tertiary sequence to its base, through a stratigraphic section 17,000 ft thick. Thus, the lower Tertiary rocks north of the Santa Ynez fault have a low thermal gradient in spite of folding and faulting. Similar very low rates of increasing thermal alteration with depth have also been found in other regions of North America (L. B. Magoon and P. R. Wesendunk, written commun., 1983). Furthermore, little or no variation is evident

Sample group 2 - east of Highway 33 This group includes 11 samples from the Juncal Formation from central Ventura

among rocks of the different fault blocks. The TAI evidence from Highway 33 and from

the other sample localities in the study region supports the laumontite distribution data of McCulloh and others (1978) and McCulloh (1981; see also Frizzell and Claypool, 1983), which suggested to McCulloh that a regional thermal event affected rocks in the southern part of the study region prior to large scale left-lateral movement on the Santa

County to westernmost Los Angeles County. A fair amount of scatter exists in the TAI's determined from each of these areas. Three samples just north of the Pine Mountain fault and not far north of the Santa Ynez fault, in eastern Ventura County, have TAI's of 3-; these values are higher than in the Pine Mountain fault zone along Highway 33 but as high as TAI's in sample gauth of the Santa Venz fault in high as TAI's in some samples south of the Santa Ynez fault in sample groups 1, 3a, and

Sample group 3 - southern Santa Barbara County These samples may be divided into two subgroups - those from south of the Santa

Ynez fault and those north of the fault. In the first subgroup are samples from four areas, from east to west (3a) Gibralter Road northeast of Santa Barbara, (3b) northwest of Santa Barbara, (3c) Refugio Road, and (3d) near Gaviota Pass. Samples from Gibralter Road (sample group 3a) consist of five samples of the Cozy Dell Shale and four samples of the Juncal Formation; they have rather high TAI's of 3- to 3, the same as most samples from the Cozy Dell and the upper part of the Matilija Sandstone south of the Santa Ynez fault on Highway 33. The Juncal Formation seems to have a higher TAI on Highway 33 than on Gibralter Road because no pollen was preserved below the upper part of the Matilija on Highway 33 south of the fault. A single sample from the Cozy Dell from northwest of Santa Barbara (3b) has a TAI of 2+/3-, the same as two samples from this formation south of the Santa Ynez fault on Highway 33. Eleven samples were examined from Refugio Road (3c), from (in ascending order) the Anita Shale of Kelley (1943), Cozy Dell Shale, Sacate Formation of Kelley (1943), and Gaviota Formation of Effinger (1935) as used by Dibblee (1950). A rather rapid change in TAI's occurs in this sequence. TAI's in the Anita (probably Juncal age) just south of the Santa Ynez fault are mainly 3-; the TAI's decrease upsection (southward) and have a value of only 2 in the Gaviota (probably Coldwater age). The sample of Sacate Formation from U.S. Highway 101 near Gaviota Pass (3d) has a TAI of 2/2+, about the same as the Cozy Dell and the overlying Sacate on Refugio Road.

Samples north of the Santa Ynez fault in southern Santa Barbara County include one sample of the Cozy Dell Shale (middle Eocene) from Highway 101 (3e; TAI 1+/2-), four samples of the Espada Formation of Dibblee (1950) (probably Lower Cretaceous Highway 101 just south of Buellton (3f; TAI's of 2 to 2+), and two samples of the Espada Formation south-southeast of Lompoc (3g; TAI's of 1+ and 1+/2-). The low TAI's of probable Lower Cretaceous rocks of the Espada Formation in this area are

Sample group 4 - central San Rafael Mountains Ten samples were examined from this area. These rocks were mapped by Vedder and others (1967) as the Espada(?) Formation of Jurassic and Early Cretaceous age. Because the dip is to the northeast, older rocks are exposed in the southwestern part of the traverse and younger rocks in the northeastern part. Few differences were observed among TAI's of these rocks except that the southernmost two samples appear to be thermally slightly less mature (TAI of 2+/3-) than the remaining samples (3- to 3). This is

anomalous because pollen of these older rocks would be expected to be darker and more

Sample group 5 - southeastern San Luis Obispo County and north-central Santa Barbara County

mature than the pollen of the younger rocks.

Seven scattered samples were examined from this area. All these samples but one have TAI's of 1+ to 2. The exactness of these values is questionable, as Jones and Edison (1978, p. 5) pointed out that "TAI values less than 2.3 [= approximately 2+] are difficult to determine accurately." The six samples are early Tertiary in age according to my sporomorph analyses. The exception is the sample from the Rinconada fault zone; rocks on the northeast side of the fault were mapped by Dibblee (1976, fig. 8) as unnamed lower Tertiary sedimentary rocks, whereas those on the southwest side were mapped as unnamed Upper Cretaceous sedimentary rocks. Because preservation of pollen in this sample is very poor, the age cannot be determined on the basis of these fossils. lowever, from several bisaccate gymnosperm specimens and from fragments of other spores and pollen grains, it is clear that this sample is much more mature than the others examined from this area, probably 3-/3. It is not known whether the slight metamorphism of kerogen in this sample is due to the burial and prefaulting history of these rocks or whether they might have undergone slight catagenesis as a result of

THERMAL-ALTERATION INDICES VERSUS VITRINITE REFLECTANCE

TAI values have limited significance unless they can be correlated with geochemical and other parameters linked to particular thermal stages in the generation and destruction of oil and gas. More has been published about the relation of vitrinite reflectance to maturation stages than about the relation of TAI's to these stages. Therefore, it was important in this study to calibrate my TAI values against previously determined R_o values from parts of the same region. Three sets of samples were available for this comparison: (1) conventional cores from the Standard Oil Company Gerber No. 1 well near Point Conception in southwesternmost Santa Barbara County (fig. 2); (2) the Gibralter Road section between Santa Barbara and the Santa Ynez fault (map, sample group 3a; fig. 3); and (3) the Highway 33 section between Ojai and the Santa Ynez fault (map, sample group 1; fig. 4). Figure 5 summarizes these comparisons. In each figure (figs. 2-4), the R_O value corresponding to each TAI sample was found by drawing a ontal line from each TAI sample to the Ro regression line. Correlations among TAI's and Ro's are more consistent for the Gerber well samples than for the outcrop samples from Gibralter Road and Highway 33. Probably this is partly due to the much closer spacing of samples from the Gerber well. However, it is also noticeable that TAI values fluctuate more in the outcrop sections than in the well section, possibly in part

The onset of oil generation generally takes place at Ro's of about 0.5 to 0.7 (Tissot and Welte, 1978; Heroux and others, 1979; Waples, 1981), an interval which corresponds to TAI's of 2+ to 3- (fig. 5). On the basis of TAI's (map and fig. 5), the exposed lower Tertiary rocks south of the Santa Ynez fault are generally in the mature thermal facies with respect to the possible generation of oil. The exposed Mesozoic and lower Tertiary rocks north of the Santa Ynez fault in the study area are mostly immature or transitional from immature to mature.

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Organic matter in sedimentary rocks that is insoluble in ordinary organic solvents. Mean percent vitrinite reflectance as measured in immersion oil.