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PRELIMINARY DATA ON ROCK SAMPLES (KG-1 TO KG-24) IN THE COOPERATIVE MONTEREY ORGANIC GEOCHEMISTRY STUDY, SANTA MARIA AND SANTA BARBARA-VENTURA BASINS, CALIFORNIA

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INTRODUCTION

This chapter of the report provides preliminary geologic data on the individual rock samples being analyzed in the Cooperative Monterey Organic Geochemistry Study (CMOGS). CMOGS, its purposes and participants, are more generally described in the *Preface* (Chapter A, this report).

The samples reported here are all from (1) the Naples Beach section near Goleta, California, in the Santa Barbara-Ventura basin, or (2) the Lions Head section near Lompoc, California, in the Santa Maria basin. Geologic background on these sections is discussed in *Preliminary Geologic Background* (Chapter B, this report). More details on the collection and stratigraphic position of the samples are given in *Preliminary Correlation and Age* (Chapter D, this report). **Bold-faced words** are defined and discussed in *Geology Handbook* (Chapter E, this report).

EXPLANATION OF HEADINGS FOR SAMPLES

Purpose of sample: the intention in selecting the sample and which other samples were intended to be closely compared with the sample in exploring questions about the organic matter. (See also "Purpose of sample set" under Naples and Lions Head in *Preliminary Geologic Background*, Chapter B, this report.)

Questions: outline of questions posed for the sample.

Lithology: rock name commonly used by local geologists (see also discussion of rock classification systems under **rock** in *Geology Handbook*, Chapter E, this report).

ODP-equivalent sediment: the name in the current ODP classification that the rock would have had prior to lithification (Mazzullo and others, 1988) based on inorganic composition only. KG-18 and KG-19 (dolostones) are not named because they do not likely represent original composition.

Stow-Piper-Dean-equivalent sediment: the name in Dean and others' (1984) classification scheme introduced to handle sediments that are mixtures of detrital mud, biogenic carbonate, and biogenic silica. By analogy with the term "marl" for muddy calcareous sediment, they introduce "sarl" for muddy siliceous sediment, and "smarl" for muddy calcareous siliceous sediment. The sediment name is given according to this scheme as formalized by Stow and Piper (1984).

Lithostratigraphic position: the formation or member (see also discussion of **formation** and **member** in *Geology Handbook*, Chapter E, this report). For exact measured positions in each section, see *Preliminary Correlation and Age* (Chapter D, this report).

Typicalness: representativeness of the sample in reference to lithologies generally found in the member; see also Figures 11-15 in *Preliminary Geologic Background* (Chapter B, this report).

Inorganic composition:

By XRF: values for sedimentary components derived from major oxide analyses by a partitioning scheme developed for the Monterey Formation in the Santa Barbara coastal area (Isaacs, 1980). Values are normalized on an organic-free-basis (and excluding pyrite) to 100%. Components are **calcite, dolomite, apatite, aluminosilicate minerals** (including **clay minerals**), **detrital quartz**, and **biogenic and diagenetic silica.**

The XRF (X-ray fluorescence) analyses are quantitative, and reproducibility of duplicate blind splits is <2% of analyzed values of major oxides, except Na_2O, which has an average standard deviation of 3% of analyzed values (0.04 wt% Na_2O). The *reproducibility* of the derived sediment components is excellent, with average standard deviations of 0.5 wt% detrital minerals (aluminosilicate minerals + detrital quartz), 0.4 wt% biogenic silica, 0.1 wt% dolomite, 0.2 wt% calcite, and 0.01 wt% apatite (Isaacs and others, 1989). Regarding accuracy, the partition between dolomite and calcite is not quite accurate due to excess Ca in dolomite, but the sum of dolomite + calcite is quite accurate (Isaacs and others, 1989). Due to variability in the composition of the clay fraction, small calculated amounts of biogenic and diagenetic silica (< 10%) may not actually be present.

By XRD: values for all minerals identifiable by X-ray Diffraction analysis. These include calcite, dolomite, apatite, clay minerals, feldspars, quartz, pyrite, and gypsum. (Gypsum is present as an evaporative product of the seawater in the samples when collected.)

XRD is generally semi-quantitative, but the analysis here is based on a careful calibration of the Monterey in this area, including extraction of specific minerals and development of calibration curves, etc., so these value are more quantitative than most. The method used to calibrate the standards is modified from Schultz (1964). Note that the detection threshold for certain poorly crystallized materials is rather high, particularly opal-A and opal-CT which may not be detected unless present in abundances >10-20%. Also, values for minerals at low abundance (<5%) such as apatite and pyrite are not very precise.

XRD analysis of <2μ clay fraction: relative abundances in the clay mineral fraction only.

Faunal and floral analysis:

Foraminifera: age determinations are based on the zonation of Kleinpell (1938, 1980). Interpretation of oxygen conditions is based on the general principles of Ingle (1980, 1981); see also **oxygen-minimum zone, anoxic** and discussion under **aerobic**, Chapter E, this report. **Fish debris** and other materials in the residue are also noted.

Calcareous nannofossils (see **calcareous nannoplankton**): age determinations are based on the zonation of Okada and Bukry (1980).

Siliceous microfossils (see **diatom, silicoflagellate, radiolarian, sponge spicule**): age determinations are based on the zonation of Barron (1981, 1986). Estimates of productivity are based on indicators proposed by Barron and Keller (1983) together with evidence on preservation and downslope transport (as indicated by the abundance of benthic or shelf-dwelling taxa).

Tentative absolute age: from Chapter D, this report; based on Barron's (1981, 1986) **biostratigraphy** framework.

Isotope ratios of benthic forams: values reported relative to PDB (see also **oxygen isotope stratigraphy** and **bottom water temperature**).

Silica diagenesis: silica phase (opal-A, opal-CT, or diagenetic quartz); seafloor **dissolution** can greatly affect the floral assemblage, and **silica diagenesis** generally destroys all diatom frustules.

PRELIMINARY SAMPLE DATA

Naples Beach Section

Overall

Bottom-water oxygen (see also under **aerobic** in *Geology Handbook*, Chapter E, this report):

From trace elements in KG samples (interpreted by D.Z. Piper): oxygen was generally low in the bottom-water but present; denitrifying conditions are indicated for all KG samples except those from the Sisquoc Formation (KG-12 and KG-13). For these latter samples, no conclusions can be drawn due to the low abundances of minor elements.

From **benthic foraminifera** faunas in KG samples (interpreted by M.L. Cotton): for KG-1, KG-2, KG-4, and KG-11, very low oxygen conditions, possibly "oxygen-minimum" (<0.2 ml/L) conditions but most likely in the range 0.2-1.0 ml/L. For all other samples with faunas, fairly low oxygen conditions, generally in the range 0.2-1.0 ml/L.

Thermal exposure: Although concretions and isolated beds of opal-CT may form at varying temperatures, bedded strata of broad compositional range in which all biogenic silica has transformed to opal-CT are probably confined to burial temperatures exceeding 48°C (Keller and Isaacs, 1985). Only very rare occurrences of diatom fragments are observed in the lower 300 stratigraphic feet of the Monterey Formation at the Naples Beach section (Arends and Blake, 1986). In overlying strata, opal-A in siliceous microfossils is common throughout the sequence though some opal-CT beds are present as much as 880 stratigraphic feet (270 m) higher. Assuming a thermal gradient of 30°C/km as found in the offshore Hondo field (U.S. Geological Survey, 1974), the opal-A/opal-CT transitional zone represents a range in maximum temperature exposure of about 8°C, and the entire sequence sampled (from KG-3 to KG-12) a range of about 14°C.

KG-12

Purpose of sample: this sample was intended to be a representative Sisquoc siliceous mudstone for comparison with the Monterey strata in the Naples section which, although more TOC-rich, are thought to represent slower organic matter sedimentation and lower overall productivity (Figure 7 in *Preliminary Geologic Background*, Chapter B, this report).

Questions: Is the organic matter similar to Monterey organic matter, or is it distinctive as to source or environment? Is its low abundance due to unusually rapid sedimentation (high preservation of inorganic constituents) or seafloor dissolution? Are there any indications of the very high productivity inferred?

Lithology: siliceous mudstone

ODP-equivalent sediment: diatomaceous mud

Stow-Piper-Dean-equivalent sediment: mud or sarl

Lithostratigraphic position: Sisquoc Formation

Typicalness: a common lithology in this formation and well within the range of sample compositions generally present.

Inorganic composition:

by XRF (C. M. Isaacs; normalized to 100% w/o pyrite): 0% calcite, 3% dolomite, 0.2% apatite, 49% aluminosilicate minerals, 16% detrital quartz, 32% biogenic and diagenetic silica.

by XRD (R. M. Pollastro; normalized to 100%): 0% calcite, 0% dolomite, 0% apatite, 48% aluminosilicate minerals (including 38% total clay, 8% plagioclase feldspar, 2% potassium feldspar), 20% quartz, 29% opal-CT, 1% pyrite, 2% gypsum.

XRD analysis of $<2\mu$ clay fraction (R. M. Pollastro): 15% illite, 47% interstratified illite/smectite, 6% kaolinite, 3% chlorite, 29% aluminum hydroxy-interlayered illite/smectite.

Faunal and floral analysis:

Foraminifera and washed residue (M. L. Cotton): barren of foraminifera including arenaceous foraminifera; fish remains - rare. Age assignment: indeterminate.

Calcareous nannofossils (M. V. Filewicz): barren.

Siliceous microfossils (R. G. Arends): Age assignment: *Nitzschia reinholdii* zone, subzone b.

Siliceous microfossils (J. A. Barron): good preservation, some fragmentation, very little dissolution, some downslope transport. Productivity is estimated to have been excellent.

Tentative absolute age: estimated within the range 5.1-6.1 Ma (Chapter D, this report).

Silica phase: biogenic silica (opal-A) is present by microfossil analysis, and opal-CT by XRD analysis, so the silica in the sample may be in the opal-A/opal-CT phase transformation. If so, indications of dissolution and lack of microfossil diversity *for the siliceous microfossils* would not necessarily be signficant in terms of original depositional state.

KG-13

Purpose of sample: see discussion under KG-12.

Questions: see discussion under KG-12.

Lithology: siliceous shale

ODP-equivalent sediment: diatomaceous mud

Stow-Piper-Dean-equivalent sediment: mud or sarl

Lithostratigraphic position: Sisquoc Formation

Typicalness: a common lithology in this formation and well within the range of sample compositions generally present.

Inorganic composition:

by XRF (C. M. Isaacs; normalized to 100% w/o pyrite): 0% calcite, 2% dolomite, 0.0% apatite, 45% aluminosilicate minerals, 15% detrital quartz, 38% biogenic and diagenetic silica.

by XRD (R. M. Pollastro; normalized to 100%): 0% calcite, 0% dolomite, 0% apatite, 49% aluminosilicate minerals (including 40% total clay, 6% plagioclase feldspar, 3% potassium feldspar), 20% quartz, 29% opal-CT, 0% pyrite, 2% gypsum.

XRD analysis of <2μ clay fraction (R. M. Pollastro): 18% illite, 41% interstratified illite/smectite, 5% kaolinite, 5% chlorite, 31% aluminum hydroxy-interlayered illite/smectite.

Faunal and floral analysis:

Foraminifera and washed residue (M. L. Cotton): barren of foraminifera including arenaceous foraminifera; fish remains - rare. Age assignment: indeterminate.

Calcareous nannofossils (M. V. Filewicz): barren.

Siliceous microfossils (R. G. Arends): Age assignment: *Nitzschia reinholdii* zone, subzone b.

Siliceous microfossils (J. A. Barron): moderate preservation, more seafloor dissolution than in KG-12. Productivity is estimated to have been very good.

Tentative absolute age: estimated within the range 5.1-6.1 Ma (Chapter D, this report).

Silica phase: biogenic and diagenetic silica (opal-A) is present by microfossil analysis, and opal-CT by XRD analysis, so the silica in the sample may be in the opal-A/opal-CT phase transformation. If so, indications of dissolution and lack of microfossil diversity *for the siliceous microfossils* would not necessarily be signficant in terms of original depositional state.

KG-7

Purpose of sample: this sample was intended to represent a typical laminated porcelanite as a pair to KG-8 (a massive more clay-rich bed) within the non-calcareous strata of the clayey-siliceous member. The pair was also intended to be contrasted with the pair KG-6 & KG-7 from the calcareous-siliceous strata of the upper calcareous-siliceous member, and the pair KG-10 & KG-11 from the massive calcareous-siliceous strata of the lower calcareous-siliceous member.

Although the choice of KG-7 was reasonably good, KG-8 does not actually represent the most massive clay-rich contrast possible, and in fact KG-8 is partly laminated and has only a small compositional contrast with KG-7.

Questions: see under KG-5.

Lithology: porcelanite

ODP-equivalent sediment: diatomaceous muddy mixed sediment

Stow-Piper-Dean-equivalent sediment: *sarl* (= mixture of detrital mud and biogenic silica with < 17% biogenic carbonate)

Lithostratigraphic position: Monterey Formation, clayey-siliceous member (of Isaacs, 1984)

Typicalness: a common lithology in this member and well within the range of sample compositions generally present (Figure 15 in *Preliminary Geologic Background*, Chapter B, this report).

Inorganic composition:

By XRF (C. M. Isaacs; normalized to 100% w/o pyrite): 0% calcite, 1% dolomite, 0.1% apatite, 43% aluminosilicate minerals, 14% detrital quartz, 42% biogenic and diagenetic silica.

by XRD (R. M. Pollastro; normalized to 100%): 0% calcite, 0% dolomite, 0% apatite, 31% aluminosilicate minerals (including 21% total clay, 7% plagioclase feldspar, 3% potassium feldspar) 11% quartz, 57% opal-CT, 1% pyrite, < 1% gypsum.

XRD analysis of <2μ clay fraction (R. M. Pollastro): 31% illite, 38% interstratified illite/smectite, 5% kaolinite, 1% chlorite, 25% aluminum hydroxy-interlayered illite/smectite.

Faunal and floral analysis:

Foraminifera and washed residue (M. L. Cotton): the sample contains rare calcareous foram fragments and arenaceous forams apparent along bedding planes. The microlithology is mottled and appears to have been bioturbated. Dolomite, tan and microsucrosic - rare. Age assignment: indeterminate due to lack of diagnostic species.

Calcareous nannofossils (M. V. Filewicz): barren.

Siliceous microfossils (R. G. Arends): barren.

Siliceous microfossils (J. A. Barron): barren.

Tentative absolute age: estimated within the range 6.1-7.0 Ma (Chapter D, this report).

Silica phase: opal-CT.

KG-8

Purpose of sample: see discussion under KG-7.

Questions: see discussion under KG-5 and KG-6.

Lithology: siliceous mudstone

ODP-equivalent sediment: mud with diatoms

Stow-Piper-Dean-equivalent sediment: mud

Lithostratigraphic position: Monterey Formation, clayey-siliceous member (of Isaacs, 1984)

Typicalness: a common lithology in this member and well within the range of sample compositions generally present (Figure 15 in *Preliminary Geologic Background*, Chapter B, this report).

Inorganic composition:

By XRF (C. M. Isaacs; normalized to 100% w/o pyrite): 2% calcite, 3% dolomite, 2% apatite, 58% aluminosilicate minerals, 19% detrital quartz, 16% biogenic and diagenetic silica.

By XRD (R. M. Pollastro; normalized to 100%): 0% calcite, 0% dolomite, 4% apatite, 52% aluminosilicate minerals (including 35% total clay, 14% plagioclase feldspar, 3% potassium feldspar), 14% quartz, 25% opal-CT, 2% pyrite, 2% gypsum.

XRD analysis of $<2\mu$ clay fraction (R. M. Pollastro): 17% illite, 31% interstratified illite/smectite, 2% kaolinite, 3% chlorite, 47% aluminum hydroxy-interlayered illite/smectite.

Faunal and floral analysis:

Foraminifera and washed residue (M. L. Cotton): the sample contains rare calcareous foram fragments and arenaceous forams apparent along bedding planes. The microlithology is mottled and appears to have been bioturbated. Fish remains - common; sponge spicules - rare; phosphatic material - rare. Age assignment: indeterminate due to lack of diagnostic species.

Calcareous nannofossils (M. V. Filewicz): barren.

Siliceous microfossils (R. G. Arends): Age assignment: indeterminate.

Siliceous microfossils (J. A. Barron): poor preservation; abundant sponge spicules, common diatom fragments and quartz grains indicate extreme dissolution and post-depositional transport.

Tentative absolute age: estimated within the range 6.1-7.0 Ma (Chapter D, this report).

Silica phase: biogenic and diagenetic silica (opal-A) is present by microfossil analysis, and opal-CT by XRD analysis, so the silica in the sample may be in the opal-A/opal-CT phase transformation. If so, indications of dissolution and lack of microfossil diversity *for the siliceous microfossils* would not necessarily be significant in terms of original depositional state.

KG-5

Purpose of sample: this sample was intended to represent a laminated silica-rich bed in the upper calcareous-siliceous member (1) for contrast with other parts of the sequence thought to represent much lower organic matter influx and productivity (cf. Figure 7 in *Preliminary Geologic Background*, Chapter B, this report); and (2) as a pair to KG-6, a massive clay-rich bed speculated to represent lower productivity and much slower sedimentation (cf. Figure 15 in *Preliminary Geologic Background*, Chapter B, this report) within the calcareous-siliceous strata. The pair was also intended to be contrasted with the pair KG-7 & KG-8 from the non-calcareous clayey-siliceous strata overlying, and the pair KG-10 & KG-11 from the lower calcareous-siliceous member. Although KG-6 does represent a clay-rich massive end-member, KG-5 does not represent the most silica-rich or most-laminated choice possible. The reason was that the silica in the more extremely silica-rich beds in this interval at Naples has converted to opal-CT, which makes sampling fresh material difficult and would have made paleontologic analysis impossible.

Questions: Is the organic matter distinctively different from that in the carbonaceous marl (KG-1, KG-2, KG-4) as to source or environment? Is the organic matter primarily derived from diatoms as generally believed, or did calcareous plankton or other sources make significant contributions? Compared to KG-6, does the lower abundance of organic matter reflect poorer organic matter preservation, different organic matter composition, a different seafloor environment, or merely greater preservation of inorganic components in the sediment? Compared to the pair KG-7/8, are there any similarly paired differences that would reflect contrasts in siliceous vs. terrigenous sediment components, or massive vs. laminated layering, differences in organic matter preservation or composition? Compared to the pair KG-7/8, are there any joint differences that would reflect ubiquitous vs. absent calcite? Etc.

Lithology: calcareous diatomaceous rock

ODP-equivalent sediment: muddy diatomaceous mixed sediment with calcite

Stow-Piper-Dean-equivalent sediment: *smarl* (= mixture of biogenic silica, biogenic calcite, and detritus, each in proportions between 17-67%)

Lithostratigraphic position: Monterey Formation, upper calcareous-siliceous and transitional marl-siliceous members (of Isaacs, 1984) undifferentiated

Typicalness: a common lithology in this member and well within the range of sample compositions generally present (Figure 14 in *Preliminary Geologic Background*, Chapter B, this report).

Inorganic composition:

By XRF (C. M. Isaacs; normalized to 100% w/o pyrite): 13% calcite, 2% dolomite, 2% apatite, 32% aluminosilicate minerals, 11% detrital quartz, 41% biogenic and diagenetic silica.

By XRD (R. M. Pollastro; normalized to 100%): 18% calcite, 0% dolomite, 2% apatite, 25% aluminosilicate minerals (including 20% total clay, 5% plagioclase feldspar), 15% quartz, 37% opal-A, 2% pyrite, 1% gypsum.

XRD analysis of $<2\mu$ clay fraction (R. M. Pollastro): 22% illite, 47% interstratified illite/smectite, 2% kaolinite, 0% chlorite, 29% aluminum hydroxy-interlayered illite/smectite.

Faunal and floral analysis:

Foraminifera and washed residue (M. L. Cotton): Diatoms, radiolarians, and sponge spicules are all common. The microlithology appears mottled. Based on the fauna, a fairly low-oxygen setting, in the range 0.2-1.0 ml/L. Age assignment:

Delmontian to late Mohnian age based on *Rotalia garveyensis*, *Uvigerina segundoensis*, *Bolivina barbarana*, and *Eponides healdi*.

Calcareous nannofossils (M. V. Filewicz): species are common, moderately preserved, and include *Reticulofenestra pseudoumbilica*, *Dictyococcites* sp., *Calcidiscus* cf. *leptoporus*, and *Coccolithus pelagicus*. Age assignment: Miocene to early Pliocene undifferentiated; species diversity is extremely low.

Siliceous microfossils (R. G. Arends): Age assignment *Denticulopsis hustedtii* zone.

Siliceous microfossils (J. A. Barron): very good preservation, little or no bioturbation or post-depositional transport. The assemblage is dominated by planktonic taxa, productivity is estimated to have been excellent.

Tentative absolute age: estimated within the range 6.7-7.6 Ma, probably 7.0-7.6 Ma (Chapter D, this report).

Isotope ratios of benthic forams (on upper part of originally sampled bulk material; analysis by B. P. Flower): $\delta^{18}O$ = 1.59; $\delta^{13}C$ = -0.63.

Silica phase: opal-A.

KG-6

Purpose of sample: see discussion under KG-5.

Questions: see under KG-5. Does the sample represent lower productivity, higher dilution by detritus, or more seafloor dissolution relative to KG-5?

Lithology: siliceous mudstone

ODP-equivalent sediment: mud with diatoms

Stow-Piper-Dean-equivalent sediment: mud

Lithostratigraphic position: Monterey Formation, upper calcareous-siliceous and transitional marl-siliceous members (of Isaacs, 1984) undifferentiated

Typicalness: a common lithology in this member but somewhat more clay-rich than samples that are generally present.

Inorganic composition:

By XRF (C. M. Isaacs; normalized to 100% w/o pyrite): 5% calcite, 2% dolomite, 1% apatite, 60% aluminosilicate minerals, 20% detrital quartz, 12% biogenic and diagenetic silica.

By XRD (R. M. Pollastro; normalized to 100%): 6% calcite, 0% dolomite, 5% apatite, 51% aluminosilicate minerals (including 35% clay, 10% plagioclase feldspar, 6% potassium feldspar), 20% quartz, 10% opal-CT, 3% pyrite, 4% gypsum.

XRD analysis of $<2\mu$ clay fraction (R. M. Pollastro): 30% illite, 40% interstratified illite/smectite, 2% kaolinite, 2% chlorite, 26% aluminum hydroxy-interlayered illite/smectite)

Faunal and floral analysis:

Foraminifera and washed residue (M. L. Cotton): Fish remains, diatoms, radiolarians, and sponge spicules are all common. The microlithology appears mottled. A fairly low-oxygen setting, in the range 0.2-1.0 ml/L. Age assignment: Late Mohnian based on *Bolivina hughesi*, and *Bolivina* sp. cf. *Bolivina cuneiformis*.

Calcareous nannofossils (M. V. Filewicz): barren.

Siliceous microfossils (R. G. Arends): Age assignment *Thalassiosira antiqua* zone, subzone a.

Siliceous microfossils (J. A. Barron): similar to KG-5 but showing some bioturbation or post-depositional transport. Productivity estimated to have been very good.

Tentative absolute age: estimated within the range 7.0-7.6 Ma, probably about 7.4-7.5 Ma (Chapter D, this report).

Isotope ratios of benthic forams (on nearly identical material resampled from the same bed; analysis by B. P. Flower): $\delta^{18}O$ = 1.69; $\delta^{13}C$ = -0.46.

Silica phase: biogenic silica (opal-A) is present by microfossil analysis, and opal-CT by XRD analysis, so the silica in the sample may be in the opal-A/opal-CT phase transformation. If so, indications of dissolution and lack of microfossil diversity *for the siliceous microfossils* would not necessarily be significant in terms of original depositional state.

KG-1:

Purpose of sample: this sample was intended to represent a typical TOC-rich highly calcareous foram-rich bed to contrast with (1) other rock types in the phosphatic organic-rich carbonaceous marl member, namely KG-2 (a representative TOC-rich calcareous shale with blebby apatite) and KG-4 (a rare TOC-rich massive calcite-poor mudstone); and (2) other less TOC-rich parts of the sequence in which organic matter influx and productivity are thought to have been higher (cf. Figure 7 in *Preliminary Geologic Background*, Chapter B, this report).

Questions: Is the organic matter primarily derived from diatoms as generally believed, or did calcareous plankton (which dominate the preserved sediment) or other sources make significant contributions? Does the high abundance of organic matter reflect unusually high preservation, different organic matter composition, an unusual seafloor environment, or merely greater dissolution of inorganic components in the sediment?

Lithology: phosphatic foraminite (= rock composed largely of foraminifera tests)

ODP-equivalent sediment: muddy calcareous mixed sediment

Stow-Piper-Dean-equivalent sediment: marl (=mixed detritus and calcite, both in proportions 17-67%)

Lithostratigraphic position: Monterey Formation, carbonaceous marl member (of Isaacs, 1984)

Typicalness: a common lithology in this member and well within the range of sample compositions generally present (Figure 13 in *Preliminary Geologic Background*, Chapter B, this report).

Inorganic composition:

By XRF (C. M. Isaacs; normalized to 100% w/o pyrite): 47% calcite, 2% dolomite, 6% apatite, 30% aluminosilicate minerals, 10% detrital quartz, 4% biogenic and diagenetic silica.

By XRD (R. M. Pollastro; normalized to 100%): 48% calcite, 0% dolomite, 7% apatite, 33% aluminosilicate minerals (including 16% clay, 4% plagioclase feldspar, 2% potassium feldspar, 11% heulandite [a zeolite]), 11% quartz, 1% pyrite, < 1% gypsum.

XRD analysis of <2μ clay fraction (R. M. Pollastro): 13% illite, 28% interstratified illite/smectite, 0% kaolinite, 0% chlorite, 59% aluminum hydroxy-interlayered illite/smectite.

Faunal and floral analysis:

Foraminifera and washed residue (M. L. Cotton): Nearly the entire washed residue is composed of forams. Also present are rare fish remains and common phosphatic material. Poorly preserved foram fragments and cavities are commonly filled with dolomite cement. The fauna (as indicated by common *Bolivina decurtata*, *Uvigerina* spp., and buliminids) indicates very low oxygen conditions, possibly oxygen-minimum (<0.2 ml/L) conditions, but most likely in the range 0.2-1.0 ml/L. Age assignment: Mohnian or older, undifferentiated, based on *Bolivina hughesi*, and *Bolivina* sp. cf. *Bolivina cuneiformis* (as in KG-6), with *Baggina californica*, *Bolivina californica*, and *Eponides rosaformis*.

Calcareous nannofossils (M. V. Filewicz): common moderately preserved species include *Reticulofenestra pseudoumbilica*, *Reticulofenestra* sp. (5μ or less), *Dictyococcites* sp., *Coccolithus pelagicus*, *Sphenolithus neoabies*, *Coccolithus miopelagicus*, *Discolithina multipora*, and *Discoaster exilis*. Age assignment: definitely middle Miocene, probably CN5 zone.

Siliceous microfossils (R. G. Arends): barren.

Siliceous microfossils (J. A. Barron): barren.

Tentative absolute age: estimated within the range 13.7-15.0 Ma but possibly as young as 8.9 Ma (Chapter D, this report).

Isotope ratios of benthic forams (on nearly identical material resampled from the same bed; analysis by B. P. Flower): $\delta^{18}O$ = 1.43; $\delta^{13}C$ = -2.59. Values on lower part of bed only: $\delta^{18}O$ = 1.44; $\delta^{13}C$ = -2.64.

Silica phase: biogenic silica (opal-A) is absent; diagenetic silica is indeterminate as to presence or phase due to low abundance.

KG-4

Purpose of sample: this sample was intended to represent a rare TOC-rich massive calcite-poor mudstone (rumored to be one company's favorite source-rock) to contrast with (1) other rock types in the phosphatic organic-rich carbonaceous marl member, namely KG-1 (a representative TOC-rich highly calcareous foram-rich bed) and KG-2 (a representative TOC-rich calcareous shale with blebby apatite); and (2) other less TOC-rich parts of the sequence in which organic matter influx and productivity are thought to have been higher (cf. Figure 7 in *Preliminary Geologic Background*, Chapter B, this report).

Questions: Is the organic matter distinguished in terms of source or depositional environment from KG-1 or KG-2? Is the predominant sediment composition (clay) reflected in the organic matter? See also questions under KG-1.

Lithology: mudstone

ODP-equivalent sediment: mud with diatoms

Stow-Piper-Dean-equivalent sediment: *sarl*

Lithostratigraphic position: Monterey Formation, carbonaceous marl member (of Isaacs, 1984)

Typicalness: an unusual lithology, outside the range of compositions previously collected in this member (Figure 13 in *Preliminary Geologic Background*, Chapter B, this report) in being highly detritus-rich, almost barren of calcareous microfossil debris, and internally massive. There are altogether about 3 similar beds at Naples, roughly 6-12" thick.

Inorganic composition:

By XRF (C. M. Isaacs; normalized to 100% w/o pyrite): 4% calcite, 2% dolomite, 2% apatite, 63% aluminosilicate minerals, 21% detrital quartz, 8% biogenic and diagenetic silica.

By XRD (R. M. Pollastro; normalized to 100%): 5% calcite, 0% dolomite, 0% apatite, 60% aluminosilicate minerals (including 49% total clay, 8% plagioclase feldspar, 3% potassium feldspar), 7% quartz, 25% opal-CT, 2% pyrite, 1% gypsum.

Note: in the discrepancy between XRF-interpreted values for biogenic and diagenetic silica at 8%, and XRD values for opal-CT at 25%, the XRD values are undoubtedly correct and show that the sample has anomalously low detrital quartz in the detritus fraction.

XRD analysis of $<2\mu$ clay fraction (R. M. Pollastro): 25% illite, 34% interstratified illite/smectite, 2% kaolinite, 1% chlorite, 42% aluminum hydroxy-interlayered illite/smectite.

Faunal and floral analysis:

Foraminifera and washed residue (M. L. Cotton): common fish remains and phosphatic material. The fauna (as indicated by common *Bolivina decurtata*, *Uvigerina* spp., and buliminids) indicates very low oxygen conditions, possibly oxygen-minimum (<0.2 ml/L) conditions, but most likely in the range 0.2-1.0 ml/L. Age assignment: Mohnian or older, undifferentiated, based on on *Bolivina hughesi*, and *Bolivina* sp. cf. *Bolivina cuneiformis* (as in KG-6), with *Baggina californica*, *Bolivina californica*, and *Eponides rosaformis*.

Calcareous nannofossils (M. V. Filewicz): barren.

Siliceous microfossils (R. G. Arends): Age assignment *Denticulopsis lauta* zone.

Siliceous microfossils (J. A. Barron): fragmented, poorly preserved assemblage representing extreme dissolution; abundant sponge spicules and quartz grains indicated transported and winnowed sediment.

Tentative absolute age: estimated within the range 13.7-14.0 Ma (Chapter D, this report).

Isotope ratios of benthic forams (on nearly identical material resampled from the same bed; analysis by B. P. Flower): $\delta^{18}O$ = -0.48; $\delta^{13}C$ = -12.77.

Silica phase: biogenic silica (opal-A) is present by microfossil analysis, and opal-CT by XRD analysis, so the silica in the sample may be in the opal-A/opal-CT phase transformation. If so, indications of dissolution and lack of microfossil diversity *for the siliceous microfossils* would not necessarily be significant in terms of original depositional state.

KG-2:

Purpose of sample: this sample was intended to represent a typical TOC-rich calcareous shale with blebby apatite to contrast with (1) other rock types in the phosphatic organic-rich carbonaceous marl member, namely KG-1 (a representative TOC-rich highly calcareous foram-rich bed) and KG-4 (a rare TOC-rich massive calcite-poor mudstone); and (2) other less TOC-rich parts of the sequence in which organic matter influx and productivity are thought to have been higher (cf. Figure 7 in *Preliminary Geologic Background*, Chapter B, this report).

Questions: Is the organic matter distinguished in terms of source or depositional environment from KG-1 or KG-4? See also questions under KG-1.

Lithology: phosphatic marl

ODP-equivalent sediment: calcareous muddy mixed sediment with apatite and diatoms

Stow-Piper-Dean-equivalent sediment: marl

Lithostratigraphic position: Monterey Formation, carbonaceous marl member (of Isaacs, 1984)

Typicalness: a common lithology in this member and well within the range of sample compositions generally present (Figure 13 in *Preliminary Geologic Background*, Chapter B, this report).

Chapter B, this report).

Inorganic composition:

By XRF (C. M. Isaacs; normalized to 100% w/o pyrite): 22% calcite, 4% dolomite, 12% apatite, 39% aluminosilicate minerals, 13% detrital quartz, 10% biogenic and diagenetic silica.

Faunal and floral analysis:

Foraminifera and washed residue (M. L. Cotton): Fish remains, sponge spicules, and phosphatic material are all common. The fauna (as indicated by common *Bolivina decurtata*, *Uvigerina* spp., and buliminids) indicates very low oxygen conditions, possibly oxygen-minimum (<0.2 ml/L) conditions, but most likely in the range 0.2-1.0 ml/L. Age assignment: Luisian, based on *Anomalina salinasensis* and *Bolivina conica*.

Calcareous nannofossils (M. V. Filewicz): species are frequent, moderately preserved, and include *Reticulofenestra pseudoumbilica*, *Dictyococcites* sp., *Coccolithus pelagicus*, *Sphenolithus neoabies*, *Discoaster exilis*, *Sphenolithus heteromorphus*, *Calcidiscus floridanus*, and *Helicosphaera carteri*. Age assignment: probable middle Miocene, probable CN4 (possible CN3) zone; the absence of *Helicosphaera ampliaperta* suggests correlation to CN4.

Siliceous microfossils (R. G. Arends): Age assignment *Denticulopsis lauta* zone, subzone a.

Siliceous microfossils (J. A. Barron): Fragmented, poorly preserved assemblage representing extreme dissolution.

Tentative absolute age: estimated within the range 14.0-16.0 Ma (Chapter D, this report).

Isotope ratios of benthic forams (on nearly identical material resampled from the same bed; analysis by B. P. Flower): $\delta^{18}O = 0.74$; $\delta^{13}C = -1.48$.

Silica phase: opal-A.

KG-11

Purpose of sample: see discussion under KG-10.

Questions: see discussion under KG-10.

Lithology: calcareous-siliceous rock

ODP-equivalent sediment: calcareous diatomaceous ooze with mud

Stow-Piper-Dean-equivalent sediment: smarl

Lithostratigraphic position: Monterey Formation, lower calcareous-siliceous member (of Isaacs, 1984)

Typicalness: a common lithology in this member and well within the range of sample compositions generally present (Figures 11-12 in *Preliminary Geologic Background*, Chapter B, this report).

Inorganic composition:

by XRF (C. M. Isaacs; normalized to 100% w/o pyrite): 27% calcite, 4% dolomite, 0.3% apatite, 15% aluminosilicate minerals, 5% detrital quartz, 50% biogenic and diagenetic silica.

By XRD (R. M. Pollastro; normalized to 100%): 28% calcite, 3% dolomite, 0% apatite, 16% aluminosilicate minerals (including 14% total clay, 2% plagioclase feldspar), 9% quartz, 44% opal-CT, 1% pyrite, 1% gypsum.

XRD analysis of $<2\mu$ clay fraction (R. M. Pollastro): 33% illite, 29% interstratified illite/smectite, 0% kaolinite, 11% chlorite, 27% aluminum hydroxy-interlayered illite/smectite.

Faunal and floral analysis:

Foraminifera and washed residue (M. L. Cotton): sample contains abundant free foraminifera as well as foram casts and molds, possibly some silicified foram tests. Radiolarians - rare. Very low oxygen conditions, possibly oxygen-minimum (<0.2 ml/L) conditions, but most likely in the range 0.2-1.0 ml/L. Age assignment: Middle to early Miocene undifferentiated, based on a nondiagnostic fauna which includes *Valvulineria williami*, *Valvulineria miocenica*, and *Valvulineria depressa*, and species as in KG-2.

Calcareous nannofossils (M. V. Filewicz): species vary from frequent to very rare, are poorly preserved, and include *Reticulofenestra pseudoumbilica*, *Coccolithus pelagicus*, and *Helicosphaera carteri*.

Siliceous microfossils (R. G. Arends): barren.

Tentative absolute age: estimated within the range 17.6-17.7 Ma (Chapter D, this report).

Isotope ratios of benthic forams (on nearly identical material resampled from the same bed; analysis by B. P. Flower): $\delta^{18}O$ = 0.12; $\delta^{13}C$ = -0.78.

Silica phase: opal-CT.

KG-10

Purpose of sample: this sample was intended to represent a typical silica-poor calcareous mudstone as a pair to KG-11 (a typical silica-rich calcareous mudstone) within the massive part of the lower calcareous-siliceous member. The pair was also intended to be contrasted with (1) the pair KG-5 & KG-6 from the calcareous-siliceous strata of the upper calcareous-siliceous member, (2) the pair KG-7 & KG-8 from the non-calcareous strata of the clayey-siliceous member, (3) the similarly layered Rincon mudstones (KG-3 & KG-9), (4) other parts of the sequence which are laminated, and (5) the overlying carbonaceous marl member (KG-1, KG-2, KG-4) which is thought to represent much lower productivity.

Questions: Is the massive layering that is characteristic of this lower part of the Monterey reflected in any environmental feature of the organic matter? Is the organic matter a potential source of (actual) oils? How does the organic matter differ from that in the Rincon samples (KG-3, KG-9)? See also discussion under KG-5.

Lithology: siliceous-calcareous mudstone

ODP-equivalent sediment: muddy calcareous ooze with diatoms

Stow-Piper-Dean-equivalent sediment: smarl

Lithostratigraphic position: Monterey Formation, lower calcareous-siliceous member (of Isaacs, 1984)

Typicalness: a common lithology in this member and well within the range of sample compositions generally present (Figures 11-12 in *Preliminary Geologic Background*, Chapter B, this report).

Inorganic composition:

by XRF (C. M. Isaacs; normalized to 100% w/o pyrite): 36% calcite, 6% dolomite, 0.7% apatite, 25% aluminosilicate minerals, 8% detrital quartz, 23% biogenic and diagenetic silica.

By XRD (R. M. Pollastro; normalized to 100%): 35% calcite, 7% dolomite, 0% apatite, 19% aluminosilicate minerals (including 13% total clay, 2% plagioclase feldspar, <1% potassium feldspar, 4% heulandite [a zeolite]), 8% quartz, 30% opal-CT, 1% pyrite.

XRD analysis of $<2\mu$ clay fraction (R. M. Pollastro): 17% illite, 18% interstratified illite/smectite, 0% kaolinite, 9% chlorite, 56% aluminum hydroxy-interlayered illite/smectite.

Faunal and floral analysis:

Foraminifera and washed residue (M. L. Cotton): Pyrite - rare. A fairly low-oxygen setting, in the range 0.2-1.0 ml/L. Age assignment: Saucesian based on rare *Siphogenerina transversa*, *Lenticulina simplex*, and *Valvulineria williami*.

Calcareous nannofossils (M. V. Filewicz): species vary from frequent to very rare, are poorly preserved, and include *Reticulofenestra pseudoumbilica*, *Coccolithus pelagicus*, *Helicosphaera carteri*, *Reticulofenestra gartneri*, and *Helicosphaera intermedia*.

Siliceous microfossils (R. G. Arends): barren.

Tentative absolute age: estimated within the range 17.6-17.7 Ma (Chapter D, this report).

Isotope ratios of benthic forams (on nearly identical material resampled from the same bed; analysis by B. P. Flower): $\delta^{18}O$ = 0.48; $\delta^{13}C$ = -1.02. Replicate: $\delta^{18}O$ = 0.40; $\delta^{13}C$ = 0.36.

Silica phase: opal-CT.

KG-9

Purpose of sample: this sample was intended to represent a typical Rincon mudstone for comparison with the Monterey strata in the Naples section.

Questions: See discussion under KG-3.

Lithology: mudstone

ODP-equivalent sediment: mud with dolomite

Stow-Piper-Dean-equivalent sediment: mud

Lithostratigraphic position: Rincon Shale

Typicalness: a common lithology in this formation and well within the range of sample compositions generally present.

Inorganic composition:

by XRF (C. M. Isaacs; normalized to 100% w/o pyrite): 3% calcite, 11% dolomite, 3% apatite, 59% aluminosilicate minerals, 20% detrital quartz, 4% biogenic and diagenetic silica.

By XRD (R. M. Pollastro; normalized to 100%): 4% calcite, 10% dolomite, 4% apatite, 58% aluminosilicate minerals (including 45% total clay, 11% plagioclase feldspar, 2% potassium feldspar), 22% quartz, 2% pyrite, <1% gypsum.

XRD analysis of $<2\mu$ clay fraction (R. M. Pollastro): 21% illite, 40% interstratified illite/smectite, 0% kaolinite, 5% chlorite, 34% aluminum hydroxy-interlayered illite/smectite.

Faunal and floral analysis:

Foraminifera and washed residue (M. L. Cotton): fish remains - rare to common; phosphatic material (as sporbo) - common; white and gray, medium to fine-grained sand - rare; arenaceous foraminifera - present; pyrite - common. Based on the fauna, a fairly low-oxygen setting, in the range 0.2-1.0 ml/L. Age assignment: Saucesian based on rare *Siphogenerina transversa*, *Lenticulina simplex*, and *Valvulineria williami*.

Calcareous nannofossils (M. V. Filewicz): species vary from frequent to very rare, are poorly preserved, and include *Discoaster adamanteus*. Age assignment: Early to Middle Miocene.

Tentative absolute age: estimated within the range 17.7-24 Ma (Chapter D, this report).

Silica phase: biogenic silica (opal-A) is absent; diagenetic silica is indeterminate as to presence or phase due to low abundance.

KG-3

Purpose of sample: this sample was intended to represent a typical Rincon mudstone for comparison with the Monterey strata in the Naples section.

Questions: Is the organic matter in the Rincon Shale distinctive as to source or environment from organic matter in the Monterey? Are there organic matter features that eliminate Rincon organic matter as an actual oil source? Are there organic matter features that suggest different bottom or early diagenetic environments?

Lithology: mudstone

ODP- equivalent lithology: mud

Stow-Piper-Dean-equivalent sediment: mud (= detritus > 67%)

Lithostratigraphic position: Rincon Shale

Typicalness: a common lithology in this formation and well within the range of sample compositions generally present, but a little unusual in having some distinct lamination in part of the sample, and obvious apatite pellets.

Inorganic composition:

By XRF (C. M. Isaacs; normalized to 100% w/o pyrite): 0% calcite, 8% dolomite, 8% apatite, 59% aluminosilicate minerals, 19% detrital quartz, 6% biogenic and diagenetic silica.

By XRD (R. M. Pollastro; normalized to 100%): 0% calcite, 6% dolomite, 9% apatite, 56% aluminosilicates (including 45% total clay, 9% plagioclase feldspar, 2% potassium feldspar), 25% quartz, 3% pyrite, < 1% gypsum.

XRD analysis of <2μ clay fraction (R. M. Pollastro): 20% illite, 38% interstratified illite/smectite, 0% kaolinite, 5% chlorite, 37% aluminum hydroxy-interlayered illite/smectite.

Faunal and floral analysis:

Foraminifera and washed residue (M. L. Cotton): fish remains - rare to common; phosphatic material (as sporbo) - common; white and gray, medium to fine-grained sand - rare; arenaceous foraminifera - present. Based on the fauna, a fairly low-

oxygen setting, in the range 0.2-1.0 ml/L. Age assignment: Saucesian based on rare *Siphogenerina transversa*, *Lenticulina simplex*, and *Valvulineria williami*.
Calcareous nannofossils (M. V. Filewicz): barren.
Siliceous microfossils (R. G. Arends): barren.
Tentative absolute age: estimated within the range 17.7-24 Ma (Chapter D, this report).
Silica phase: biogenic silica (opal-A) is absent; diagenetic silica is indeterminate as to presence or phase due to low abundance.

LIONS HEAD SECTION

Overall

Bottom-water oxygen (see also under **aerobic** *Geology Handbook*, Chapter E, this report):

From trace element distributions in KG samples (interpreted by D.Z. Piper): oxygen was generally low in the bottom-water but present; denitrifying conditions are indicated for all KG samples. (See also Geology Handbook under **anoxia.**) KG-22 contains megafossils of mud-dwelling organisms that were almost certainly living in situ (see also faunal analysis under KG-22).

From benthic foram faunas (interpreted by M.L. Cotton): fairly low oxygen conditions, generally in the range 0.2-1.0 ml/L, for all samples with faunas. None of the numerous samples analyzed from this section over the years have had "oxygen-minimum" (< 0.2 ml/L) faunas.

Paleodepth (M. L. Cotton): Faunas in samples KG-14, KG-15, KG-17, KG-20, and KG-22 indicate paleodepths in the range upper to middle bathyal (= 150-1500 m). There is no information from the faunas in other samples.

Thermal exposure: Silica diagenesis is mainly a function of temperature in this area, and has been studied in a variety of locations, including a well near the Point Arguello field (Pisciotto, 1981a; Isaacs, 1982; Isaacs and others, 1983; Keller, 1984). Although individual beds can form diagenetic quartz at varying times, entire sequences of broad compositional range in which silica is entirely quartz are probably confined to burial temperatures exceeding 85° C (Keller and Isaacs, 1985; see also under **silica diagenesis** in *Geology Handbook*, Chapter E, this report).

Recent work on clay diagenesis has correlated characteristic ordering reactions in mixed layer illite-smectite with silica diagenesis in the subsurface of the onshore Santa Maria basin (Pollastro, 1990). The first ordering reaction is known from many studies in other areas to generally occur at about 100° C, and its occurrence relative to diagenetic quartz in the onshore Santa Maria basin is completely consistent with that temperature (Pollastro, 1990).

In the Lions Head section, all beds contain silica only as diagenetic quartz (Pisciotto, 1981b), but the first clay ordering reaction has not occurred. These relations together place the thermal history of the section in the window 85-100° C.

KG-16

Purpose of sample: this sample was intended to represent: (1) a dolomitic equivalent to typical lithologies in the upper calcareous-siliceous member (including the samples KG-5 and KG-6) at Naples; and (2) a typical lithology in the middle member at Lions Head to contrast with other lithologies in the sequence.

Questions: are values of maturity parameters similar to values in other rocks or are there lithologic influences? If there are lithologic influences, what associations do they show?

Lithology: dolomitic porcelaneous shale

ODP-equivalent sediment: muddy calcareous ooze with diatoms

Stow-Piper-Dean-equivalent sediment: smarl

Lithostratigraphic position: Monterey Formation (middle member of Woodring and Bramlette, 1950)

Inorganic composition:

by XRF (C. M. Isaacs; normalized to 100% w/o pyrite): 6% calcite, 46% dolomite, 2% apatite, 21% aluminosilicate minerals, 7% detrital quartz, 19% biogenic and diagenetic silica [diagenetic quartz].

By XRD (R. M. Pollastro; normalized to 100%): 0% calcite, 50% dolomite, 3% apatite, 13% aluminosilicate minerals (including 12% total clay, <1% plagioclase feldspar, 1% potassium feldspar), 32% quartz, 2% pyrite.

XRD analysis of $<2\mu$ clay fraction (R. M. Pollastro): 33% illite, 24% interstratified illite/smectite, 18% kaolinite, 0% chlorite, 26% aluminum hydroxy-interlayered illite/smectite.

Faunal and floral analysis:

Foraminifera and washed residue (M. L. Cotton): barren of foraminifera; fish remains, sponge spicules, and phosphatic material are all common. Age assignment: indeterminate.

Calcareous nannofossils (M. V. Filewicz): barren.

Tentative absolute age: estimated at 9.3-11.5 Ma (Chapter D, this report)

Silica phase: diagenetic quartz.

KG-19

Purpose of sample: this sample was intended to represent a bedded (probably late-formed) dolomite: (1) to explore the organic matter characteristics of a widespread lithology whose diagenetic formation is thought to be closely associated with the breakdown of organic matter; and (2) to contrast with other typical lithologies in the Lions Head sequence.

Questions: are values of maturity parameters similar to values in other rocks or are there lithologic influences? If there are lithologic influences, what associations do they show?

Lithology: dolostone

Lithostratigraphic position: Monterey Formation (middle member of Woodring and Bramlette, 1950)

Typicalness: a common lithology in this member and well within the range of compositions generally present.

Inorganic composition:

by XRF (C. M. Isaacs; normalized to 100% w/o pyrite): 4% calcite, 91% dolomite, 0.6% apatite, 2% aluminosilicate minerals, 1% detrital quartz, 2% biogenic and diagenetic silica [diagenetic quartz].

By XRD (R. M. Pollastro; normalized to 100%): 0% calcite, 96% dolomite, 0% apatite, <1% aluminosilicate minerals, 4% quartz, 0% pyrite.

XRD analysis of <2μ clay fraction (R. M. Pollastro): 19% illite, 19% interstratified illite/smectite, 62% kaolinite, 0% chlorite, 0% aluminum hydroxy-interlayered illite/smectite.

Faunal and floral analysis:

Foraminifera and washed residue (M. L. Cotton): barren.

Calcareous nannofossils (M. V. Filewicz): barren.

Tentative absolute age: estimated at 9.3-11.5 Ma (Chapter D, this report)

Silica phase: indeterminate due to low abundance but almost certainly diagenetic quartz.

KG-24

Purpose of sample: this sample was intended as a representative "shale" to contrast with (1) other representative lithologies in the uppermost part of the Lions Head sequence; (2) the sequence as a whole; and (3) the Naples sequence, particularly KG-6.

Questions: are values of maturity parameters similar to values in other rocks or are there lithologic influences? If there are lithologic influences, what associations do they show?

Lithology: siliceous shale

ODP-equivalent sediment: diatomaceous muddy mixed sediment

Stow-Piper-Dean-equivalent sediment: sarl

Lithostratigraphic position: Monterey Formation (middle member of Woodring and Bramlette, 1950)

Typicalness: a common lithology in this member and well within the range of compositions generally present; probably represents the "shale" of Dunham and Blake (1987).

Inorganic composition:

By XRF (C. M. Isaacs; normalized to 100% w/o pyrite): 1% calcite, 0% dolomite, 5% apatite, 44% aluminosilicate minerals, 15% detrital quartz, 36% biogenic and diagenetic silica [diagenetic quartz].

By XRD (R. M. Pollastro; normalized to 100%): 2% calcite, 3% dolomite, <1% apatite, 29% aluminosilicate minerals (including 23% total clay, 3% plagioclase feldspar, 3% potassium feldspar), 62% quartz, 3% pyrite.

XRD analysis of <2μ clay fraction (R. M. Pollastro): 15% illite, 47% interstratified illite/smectite, 7% kaolinite, 3% chlorite, 28% aluminum hydroxy-interlayered illite/smectite.

Faunal and floral analysis:

Foraminifera and washed residue (M. L. Cotton): barren.

Calcareous nannofossils (M. V. Filewicz): barren.

Tentative absolute age: estimated at 9.3-11.5 Ma (Chapter D, this report)

Silica phase: diagenetic quartz.

KG-17

Purpose of sample: this sample was intended to represent: (1) a calcareous shale with blebby apatite equivalent to typical lithologies in the carbonaceous marl member (especially KG-2) at Naples; and (2) a typical lithology in the middle part of the sequence at Lions Head to contrast with other lithologies in the sequence.

Questions: are values of maturity parameters similar to values in other rocks or are there lithologic influences? If there are lithologic influences, what associations do they show?

Lithology: phosphatic calcareous shale

ODP-equivalent sediment: calcareous diatomaceous ooze with mud and apatite

Stow-Piper-Dean-equivalent sediment: smarl

Lithostratigraphic position: Monterey Formation (lower member of Woodring and Bramlette, 1950)

Typicalness: a common lithology in this member and well within the range of compositions generally present.

Inorganic composition:

by XRF (C. M. Isaacs; normalized to 100% w/o pyrite): 33% calcite, 1% dolomite, 10% apatite, 17% aluminosilicate minerals, 6% detrital quartz, 34% biogenic and diagenetic silica [diagenetic quartz].

By XRD (R. M. Pollastro; normalized to 100%): 36% calcite, 5% apatite, 13% aluminosilicate minerals (including 10% total clay, 1% plagioclase feldspar, 2% potassium feldspar), 44% quartz, 2% pyrite, <1% gypsum.

XRD analysis of <2μ clay fraction (R. M. Pollastro): 8% illite, 20% interstratified illite/smectite, 44% kaolinite, 0% chlorite, 28% aluminum hydroxy-interlayered illite/smectite.

Faunal and floral analysis:

Foraminifera and washed residue (M. L. Cotton): Sample contains common free apatite and phosphatized foram fragments. Based on the fauna, a fairly low-oxygen setting, in the range 0.2-1.0 ml/L. Age assignment: Luisian age based on *Valvulineria californica appressa*, *Pullenia miocenica*, and *Anomalina salinasensis*.

Calcareous nannofossils (M. V. Filewicz): species are frequent to rare, poorly preserved, and include *Coccolithus pelagicus*, *Calcidiscus floridanus*, *Sphenolithus abies*, *Sphenolithus heteromorphus*, and *Calcidiscus macintyrei*. Age assignment: definitely Middle Miocene, CN4 zone; the presence of *Calcidiscus macintyrei* along with *Sphenolithus heteromorphus* suggests assignment to the CN4 zone.

Tentative absolute age: estimated at 14.0-15.7 Ma (Chapter D, this report)

Silica phase: diagenetic quartz.

KG-22

Purpose of sample: this sample was intended to represent a calcareous mudstone which is unusual in having common megafossil remains to contrast with (1) other representative samples in the sequence, and (2) samples in the Naples sequence.

Questions: Is there any difference in parameters related to oxygen level in this sample (in which the bottom water was clearly oxygenated) compared to better laminated samples? Are values of maturity parameters similar to values in other rocks or are there lithologic influences? If there are lithologic influences, what associations do they show?

Lithology: siliceous calcareous mudstone

ODP-equivalent sediment: muddy diatomaceous calcareous ooze

Stow-Piper-Dean-equivalent sediment: smarl

Lithostratigraphic position: Monterey Formation (lower member of Woodring and Bramlette, 1950)

Typicalness: a representative lithology in this member and well within the range of compositions generally present, but unusual in having megafossil remains.

Inorganic composition:

By XRF (C. M. Isaacs; normalized to 100% w/o pyrite): 33% calcite, 7% dolomite, 5% apatite, 21% aluminosilicate minerals, 7% detrital quartz, 28% biogenic and diagenetic silica [diagenetic quartz].

By XRD (R. M. Pollastro; normalized to 100%): 33% calcite, 7% dolomite, 3% apatite, 14% aluminosilicate minerals (including 12% total clay, 2% plagioclase feldspar, <1% potassium feldspar), 40% quartz, 3% pyrite, <1% gypsum.

XRD analysis of $<2\mu$ clay fraction (R. M. Pollastro): 13% illite, 10% interstratified illite/smectite, 39% kaolinite, 0% chlorite, 30% aluminum hydroxy-interlayered illite/smectite.

Faunal and floral analysis:

Foraminifera and washed residue (M. L. Cotton): Sample contains common free apatite and phosphatized foram fragments; also megafossil (shell) remains. Based on the fauna, a fairly low-oxygen setting, in the range 0.2-1.0 ml/L. Age assignment: Luisian age based on *Valvulineria californica appressa*, *Pullenia miocenica*, and *Anomalina salinasensis*.

Megafossils: abundant remains of an invertebrate megafossil *Delectopecten peckhamii* with dentition intact (J. G. Vedder, personal communication, 1991). The species has a broad paleodepth range, but the delicate dentition shows that the invertebrate lived *in situ* and was not transported any significant distance (E. J. Moore, personal communication, 1991). (See also comments on such fossils under **aerobic** in *Geology Handbook*, Chapter E, this report.)

Calcareous nannofossils (M. V. Filewicz): species are rare, poorly preserved, and include *Coccolithus pelagicus*, *Calcidiscus floridanus*, *Sphenolithus abies*, and *Discoaster sanmiguelensis*. Age assignment: Early to Middle Miocene, indeterminate zone.

Tentative absolute age: estimated at 14.0-15.7 Ma (Chapter D, this report)

Silica phase: diagenetic quartz.

KG-18

Purpose of sample: this sample was intended to represent an early-formed dolomite: (1) to explore the organic matter characteristics of a widespread lithology whose diagenetic formation is thought to be closely associated with carbon dioxide and methane produced during microbial breakdown of organic matter but which might have been extremely impermeable since shallow burial; and (2) to contrast with other typical lithologies in the Lions Head sequence, especially KG-14 (a sample from the bed within which the dolomite formed).

Questions: are values of maturity parameters similar to values in other rocks or are there lithologic influences? If there are lithologic influences, what associations do they show?

Lithology: clayey dolostone

Lithostratigraphic position: Monterey Formation (lower member of Woodring and Bramlette, 1950)

Typicalness: a common lithology in this member and well within the range of compositions generally present.

Inorganic composition:

by XRF (C. M. Isaacs; normalized to 100% w/o pyrite): 12% calcite, 56% dolomite, 0.2% apatite, 15% aluminosilicate minerals, 5% detrital quartz, 12% biogenic and diagenetic silica [diagenetic quartz].

By XRD (R. M. Pollastro; normalized to 100%): 0% calcite, 68% dolomite, <1% apatite, 14% aluminosilicate minerals (including 10% total clay, 3% plagioclase feldspar, 1% potassium feldspar), 18% quartz, 0% pyrite.

XRD analysis of <2μ clay fraction (R. M. Pollastro): 29% illite, 55% interstratified illite/smectite, 2% kaolinite, 3% chlorite, 11% aluminum hydroxy-interlayered illite/smectite.

Faunal and floral analysis:

Foraminifera and washed residue (M. L. Cotton): barren of foraminifera. Sample contains common pyrite. Age assignment: indeterminate.
Calcareous nannofossils (M. V. Filewicz): barren.
Tentative absolute age: estimated at 14.0-15.7 Ma (Chapter D, this report)
Silica phase: diagenetic quartz.

KG-14

Purpose of sample: this sample was intended to represent a typical lithology in the lowermost part of the Lions Head section to contrast in terms of depositional and diagenetic parameters with (1) other representative lithologies in the section, especially a dolostone concretion (KG-18) formed within the bed, and (2) the Naples samples. Since this part of the sequence is somewhat unlike any part of the Naples Beach sequence, the sample was not intended as a specific equivalent.

Questions: Are values of maturity parameters similar to values in other rocks or are there lithologic influences? If there are lithologic influences, what associations do they show?

Lithology: mudstone

ODP-equivalent sediment: mud with diatoms

Stow-Piper-Dean-equivalent sediment: sarl

Lithostratigraphic position: Monterey Formation (lower member of Woodring and Bramlette, 1950)

Typicalness: a homogeneous mudstone which is unusually thick, but well within the range of sample compositions generally present.

Inorganic composition:

By XRF (C. M. Isaacs; normalized to 100% w/o pyrite): 8% calcite, 6% dolomite, 0.2% apatite, 49% aluminosilicate minerals, 16% detrital quartz, 20% biogenic and diagenetic silica [diagenetic quartz].

By XRD (R. M. Pollastro; normalized to 100%): 8% calcite, 6% dolomite, 1% apatite, 37% aluminosilicate minerals (including 27% total clay, 7% plagioclase feldspar, 3% potassium feldspar), 44% quartz, 3% pyrite, 1% gypsum.

XRD analysis of $<2\mu$ clay fraction (R. M. Pollastro): 28% illite, 59% interstratified illite/smectite, 0% kaolinite, 3% chlorite, 10% aluminum hydroxy-interlayered illite/smectite.

Faunal and floral analysis:

Foraminifera and washed residue (M. L. Cotton): Based on the fauna (bolivinids and uvigerinids), a fairly low-oxygen setting, in the range 0.2-1.0 ml/L. The sample contains abundant pyrite. Age assignment: possible Relizian age based on rare *Siphogenerina branneri*.

Calcareous nannofossils (M. V. Filewicz): species are frequent to rare, poorly preserved, and include *Coccolithus pelagicus*, *Calcidiscus floridanus*, *Sphenolithus abies*, *Sphenolithus heteromorphus*, and *Calcidiscus macintyrei*. Age assignment:

definitely Middle Miocene, CN4 zone; the presence of *Calcidiscus macintyrei* along with *Sphenolithus heteromorphus* suggests assignment to the CN4 zone.
Tentative absolute age: estimated at 14.0-15.7 Ma (Chapter D, this report)
Silica phase: diagenetic quartz.

KG-15

Purpose of sample: this sample was intended to represent a more silica-rich bed to contrast with other adjacent mudstones (KG-14 and KG-20) in the lowermost part of the Lions Head section, and with other lithologies in the section as a whole. Since this part of the sequence is somewhat unlike any part of the Naples Beach sequence, the sample was not intended as a specific equivalent.

Questions: are values of maturity parameters similar to values in other rocks or are there lithologic influences? If there are lithologic influences, what associations do they show?

Lithology: porcelaneous shale

ODP-equivalent sediment: diatomaceous mud with calcite

Stow-Piper-Dean-equivalent sediment: smarl

Lithostratigraphic position: Monterey Formation (lower member of Woodring and Bramlette, 1950)

Typicalness: a common lithology in this member and well within the range of sample compositions generally present.

Inorganic composition:

By XRF (C. M. Isaacs; normalized to 100% w/o pyrite): 14% calcite, 7% dolomite, 0.7% apatite, 32% aluminosilicate minerals, 11% detrital quartz, 36% biogenic and diagenetic silica [diagenetic quartz].

By XRD (R. M. Pollastro; normalized to 100%): 12% calcite, 6% dolomite, $<1\%$ apatite, 27% aluminosilicate minerals (including 22% total clay, 5% plagioclase feldspar, 0% potassium feldspar), 54% quartz, 1% pyrite, $<1\%$ gypsum.

XRD analysis of $<2\mu$ clay fraction (R. M. Pollastro): 19% illite, 49% interstratified illite/smectite, 0% kaolinite, 15% chlorite, 17% aluminum hydroxy-interlayered illite/smectite.

Faunal and floral analysis:

Foraminifera and washed residue (M. L. Cotton): Based on the fauna, a fairly low-oxygen setting, in the range 0.2-1.0 ml/L. Abundant *Globigerina* spp. indicate an open-ocean location (meaning clear water, not immediately adjacent to abundant river influx). The sample contains rare fish remains, calcite, glauconite, and pyrite. Age assignment: Relizian age based on common *Siphogenerina branneri* and *Bulimina pseudoaffinis*.

Calcareous nannofossils (M. V. Filewicz): species are rare, poorly preserved, and include *Reticulofenestra pseudoumbilica*, *Coccolithus pelagicus*, *Sphenolithus heteromorphus*, *Calcidiscus floridanus*, *Discoaster variabilis*, and *Discoaster* cf. *druggi*. Age assignment: probable Middle Miocene, probable CN4 (possible CN3) zone.

Tentative absolute age: estimated at 15.2-17.4 Ma (Chapter D, this report)
Silica phase: diagenetic quartz.

KG-20

Purpose of sample: this sample was intended to represent a typical lithology in the lowermost part of the Lions Head section to contrast with other representative lithologies. Since this part of the sequence is somewhat unlike any part of the Naples Beach sequence, the sample was not intended as a specific equivalent.

Questions: are values of maturity parameters similar to values in other rocks or are there lithologic influences? If there are lithologic influences, what associations do they show?

Lithology: shale with prominent white layers (so-called phosphatic shale of Dunham and Blake, 1987)

ODP-equivalent sediment: mud with diatoms

Stow-Piper-Dean-equivalent sediment: sarl

Lithostratigraphic position: Monterey Formation (lower member of Woodring and Bramlette, 1950)

Inorganic composition:

by XRF (C. M. Isaacs; normalized to 100% w/o pyrite): 0% calcite, 6% dolomite, 0.6% apatite, 58% aluminosilicate minerals, 19% detrital quartz, 18% biogenic and diagenetic silica.

By XRD (R. M. Pollastro; normalized to 100%): 2% calcite, 0% dolomite, 1% apatite, 47% aluminosilicate minerals (including 35% total clay, 9% plagioclase feldspar, 3% potassium feldspar), 47% quartz, 3% pyrite, <1% gypsum.

XRD analysis of <2μ clay fraction (R. M. Pollastro): 24% illite, 56% interstratified illite/smectite, 0% kaolinite, 20% chlorite, 0% aluminum hydroxy-interlayered illite/smectite.

Faunal and floral analysis:

Foraminifera and washed residue (M. L. Cotton): Based on the fauna, a fairly low-oxygen setting, in the range 0.2-1.0 ml/L. A greater abundance of arenaceous foraminifera is observed in this sample than in other samples analyzed in the Lions Head section. The sample contains abundant white and gray fine-grained sand. Age assignment: Relizian age based on species as in KG-15 (common *Siphogenerina branneri* and *Bulimina pseudoaffinis)* and *Siphogenerina reedi* and *Bolivina perrini*.

Calcareous nannofossils (M. V. Filewicz): species are rare, poorly preserved, and include *Reticulofenestra pseudoumbilica*, *Coccolithus pelagicus*, *Sphenolithus heteromorphus*, *Calcidiscus floridanus*, *Discoaster variabilis*, and *Discoaster* cf. *druggi*. Age assignment: probable Middle Miocene, probable CN4 (possible CN3) zone.

Tentative absolute age: estimated at 15.2-17.4 Ma (Chapter D, this report)
Silica phase: diagenetic quartz.

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