

U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

**NATURAL HYDROCARBON GASES IN THE COAST RANGE OF
SOUTHERN OREGON**

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Open-File Report 95-93

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1995

ABSTRACT

Minor natural gas accumulations occur in shallow water wells and abandoned exploration wells in the convergent margin of the southern Oregon Coast Range and the northern Klamath Mountains. The hydrocarbon gas composition of well-gas samples were measured in samples from the pre-Tertiary melange (Sixes River terrane) of the Klamath Mountains, the Paleocene to middle Eocene upper and lower Umpqua basin/subduction-zone complex, and the middle and late Eocene Coos Bay forearc basin. Hydrocarbon gases from these three regions have a remarkably narrow range of molecular compositions (all >99.8% methane; that is, a very dry gas) but a very broad range of methane isotopic compositions ($\delta^{13}\text{C}$ from -28.1 to -64.9‰; δD from -123 to -245‰; relative to the PDB and SMOW standards, respectively). Methane from the lower and upper parts of the Umpqua Group generally (with one exception) has light $\delta^{13}\text{C}$ values (-64.8, -63.9, and -64.9‰), and a range of δD values (-245, -207, and -123‰). This methane may be mainly microbial in origin. In contrast, methane from wells in the Coos Bay basin and the Klamath Mountains is isotopically heavy, suggesting a thermal origin. Both carbon and hydrogen in methane from the Coos Bay basin are isotopically heavy ($\delta^{13}\text{C} = -28.1$ to -35.4 ‰, $\delta\text{D} = -123$ ‰); methane from the Klamath Mountains has intermediate isotopic values ($\delta^{13}\text{C} = -33.3$ and -50.6 ‰, $\delta\text{D} = -155$ and -134 ‰). The methane in these two areas may have migrated upward along faults from more deeply buried pre-Tertiary Klamath and subducted lower Umpqua basin source rocks.

Only partial success was achieved in sampling gas from outcrops and outcrop samples. Typically the amount of methane measured was <50 ppm. A coal outcrop in the upper Umpqua basin complex emitted hydrocarbon gases (<500 ppm) containing 99.7% methane with $\delta^{13}\text{C}$ and δD values of -39.9‰ and -142‰, respectively. Desorbed subsurface coal samples from the Coos Bay basin contain about 99.7% methane with a $\delta^{13}\text{C}$ value of about -34‰. Isobutane/*n*-butane ratios in well gas and outcrop samples are >1 in the upper Umpqua basin complex and Coos Bay basin and <1 in the lower Umpqua basin complex and the Klamath Mountain region, providing one possible geochemical tie between well and outcrop gases.

INTRODUCTION

Natural gases emitting from the earth's surface carry information on sources and processes that occur within the crust. In order to augment this kind of information in the northwestern United States, our study was undertaken along the convergent margin of the southern Oregon Coast Range and the northern Klamath Mountains in southwestern Oregon (Fig. 1). Previous work in the

northwestern U.S. has addressed the natural gas compositions in Yellowstone and Grand Teton National Parks in Wyoming (Kvenvolden and others, 1989a) and in the coastal Olympic Peninsula of Washington (Kvenvolden and others, 1989b). These previous studies have shown a rich variety of hydrocarbon gas distributions reflecting complex subsurface processes. In southwestern Oregon, we found hydrocarbon gases in water and abandoned petroleum-exploration wells and to a lesser extent at outcrops and in outcrop samples. Our report is preliminary, based on 21 well-gas samples (10 localities), 21 outcrop samples (6 localities), and 2 subsurface samples (1 locality) (Table 1).

GEOLOGIC SETTING

The southern Oregon Coast Range consists of three Tertiary basins (Fig. 1): the Paleocene to middle Eocene Umpqua basin, the middle Eocene southern Tyee basin, and the smaller middle Eocene to late Miocene Coos Bay basin (Ryu and others, 1992). These basins are adjacent to and unconformably overlie Mesozoic rocks of the Klamath Mountains (Blake and others, 1985; Niem and Niem, 1990).

The lower Umpqua basin contains >3,000 m of turbidite sandstone, slope mudstone, and fan delta conglomerate and pebbly sandstone [lower part of the Umpqua Group, Tenmile and Bushnell Rock Formations (Ryu and others, 1992) on Figure 2]. These formations overlie and locally interfinger with thick sequences of pillow lavas and basaltic breccias of the Paleocene to lower Eocene Siletz River Volcanics. The strata were deposited in a marginal basin setting (Umpqua basin) formed by convergence of oceanic crust, composed of Siletz River Volcanics, beneath Mesozoic crust of the Klamath Mountains (Heller and Ryberg, 1983; Fig. 3a). The northern Klamath Mountains consist largely of highly sheared melange and broken formation of deep-marine turbidite sandstone and mudstone, e.g., Jurassic and Cretaceous Sixes River terrane (Blake and others, 1985; Fig. 2). Scattered tectonic blocks of shallow- and deep-marine limestone, chert, greenstone, blueschist, and eclogite occur within the melange. Northwest-verging imbricate thrusts and strike-slip faults shortened this accretionary margin during a period of rapid oblique subduction in the late early Eocene to form the Umpqua basin subduction zone complex (Perttu and Benson, 1980; Ryberg, 1984; Fig. 2). Locally these thrust faults interleaved slices of lower Umpqua basin strata with the Mesozoic Sixes River terrane of the Klamath Mountains (Carayon, 1984; Roure and others, 1986; Niem and Niem, 1990).

Thickened buoyant oceanic basaltic crust and seamounts of the Siletz River Volcanics eventually clogged the early Eocene subduction zone (Fig. 3a), and a new subduction zone formed by the middle Eocene to the west in the vicinity of the present outer continental shelf and upper slope of western Oregon (Heller and

Ryberg, 1983; Fig. 3b). The intervening accreted oceanic crust of Siletz River Volcanics and strata of the Umpqua basin subduction zone then subsided, forming the upper Umpqua basin complex and the Tyee forearc basin. This north-south elongate basin developed across the NE-SW structural trend of the lower Umpqua basin subduction zone complex (Fig. 1). More than 5,000 m of coal-bearing deltaic, shelf, and turbidite sandstone and slope mudstone [White Tail Ridge and Camas Valley Formations (Ryu and others, 1992), and later the Tyee and Elkton Formations on Figure 3b] rapidly filled the newly formed forearc basin (Chan and Dott, 1983; Heller and Ryberg, 1983; Heller and Dickinson, 1985; Niem and Neim, 1990; Niem and others, 1992a).

In the middle and late Eocene, the Coos Bay forearc basin subsided along the western margin of the Tyee basin (Fig. 1). This smaller, elongate N-S basin was filled with more than 1,700 m of coal-bearing deltaic sandstone and prodelta mudstone of the Coaledo Formation (Fig. 2 and 3b; Dott, 1966; Heller and Ryberg, 1983; Niem and others, 1992a, 1992b). The basin continued to accumulate shelf and slope sediments, derived mainly from the Western Cascades arc (Fig. 1) during the late Eocene to Miocene (Armentrout, 1980). Basin filling ceased in the late Miocene when oblique subduction of the Juan de Fuca oceanic plate beneath the North American continental plate resulted in uplift of the Oregon Coast Range and adjacent Klamath Mountains (Niem and others, 1992a, 1992b).

METHODS

Different methods were used to sample gases from wells, outcrops, and outcrop samples, depending on the circumstances at the sampling sites. Where gas flow was significant (Localities 3 and 12A), gas samples were collected by water displacement into glass bottles which were sealed so that there was minimum opportunity for extraneous air contamination (Kvenvolden and Pettinga, 1989). The headspace in wells without obvious flowing gas was usually sampled with a 50-cc gas-tight syringe or with a gas sampling system consisting of a laminated, impermeable gas-sampling bag with valve. The bag is inserted into a sealed glass jar which is evacuated with a hand pump, effectively placing the sample bag under vacuum. Gas samples are drawn into the bag through fine tubing connected at the valve. Well gas was sampled in two abandoned petroleum exploration wells in Coos Bay basin, in water wells in the lower and upper Umpqua basin complexes, and in the Klamath Mountains.

Outcrop gas and gas from outcrop samples were each obtained by different methods. Gas at fractures in mudstone and at cleats in coal were sampled by either the syringe or gas sampling systems as described previously. Outcrop samples of mudstone, limestone, and coal were crushed and placed in sealed cans

equipped with septa. The headspace of each can was purged with helium, and the samples were allowed to outgas inside the can. The headspace of the cans were sampled at intervals ranging from 10 min. to 30 days. This headspace method was used to attempt to measure relative proportions of hydrocarbon gases in the released gas mixtures.

Compositions of gases from wells and rock outcrops were initially measured in the field with a portable gas chromatograph, equipped with two columns, Carboplot (4 m) and Poroplot U (6 m) and thermal conductivity detector. Methane (C₁) and ethane (C₂) were measured in the field when concentrations were sufficient. Gas samples were measured later in the laboratory with an analytical gas chromatograph equipped with two columns: *n*-octane on 100/120 mesh Porosil C (2 m) and 50/80 mesh 50% Porapak N and 50% Porapak Q (2 m). Both thermal conductivity and flame ionization detectors were used. A valving system allows the separation of C₁ and the higher molecular weight hydrocarbons (ethane (C₂), propane (C₃), *n*-butane (*n*-C₄), isobutane (iC₄), and C₅₊). The higher molecular weight hydrocarbons were often present in relatively very small amounts compared to C₁. The ratio of C₁/(C₂+C₃) was calculated to provide a guide to the relative dryness or wetness of the natural gas.

Seven samples were analyzed for carbon and deuterium isotopic composition by isotope ratio mass spectrometry (Global Geochemistry Corporation, Canoga Park, CA). Two carbon isotopic values for two subsurface samples were provided by Carbon Energy International. The results are reported in δ notation relative to the Peedee Belemnite (PDB) standard for carbon and Standard Mean Ocean Water (SMOW) for hydrogen. $\delta^{13}\text{C}\text{‰}$ and $\delta\text{D}\text{‰} = (R_{\text{sample}}/R_{\text{standard}} - 1) \times 10^3$, where $R = {}^{13}\text{C}/{}^{12}\text{C}$ or D/H .

RESULTS

Our results are summarized in Table 2 in order of decreasing age of the geologic units (Fig. 2) in which the hydrocarbon gases were found.

Klamath Mountains (Sixes River Terrane)

Four localities were examined in the Klamath Mountain pre-Tertiary melange (Fig. 1, Localities 10, 11, 16, 17). Well gas from two wells in the extensively deformed Sixes River terrane was sampled by syringe and gas bag with two syringe samples stored in sealed bottles. Both wells were open to the atmosphere and the hydrocarbon gases were greatly diluted with air. The maximum C₁ concentration measured 13.5%. Higher molecular weight

hydrocarbons were present with $C_1/(C_2+C_3)$ ratios ranging from ~2,700 to 14,000 (>99.9% C_1).

Methane isotopic compositions were measured in two samples: $\delta^{13}C = -50.6$ and -33.3‰ , $\delta D = -135$ and -155‰ , respectively. Two samples of sheared mudstone from the Sixes River Terrane melange were crushed in cans, and the resulting hydrocarbon gases were measured both in the field and in the laboratory. C_1 through C_{5+} hydrocarbons were present with maximum C_1 concentrations of about 11 ppm. The same $iC_4/n-C_4$ ratios of 0.59 were measured for each sample. In addition to these two mudstone samples, four samples of petroliferous limestone were broken up and crushed in sealed cans for various time periods ranging from 10 min. to 4 d. Hydrocarbon gases through C_{5+} were released during this experiment. C_1 concentrations averaged 34 ppm, $C_1/(C_2+C_3)$ ratios were near 1, and $iC_4/n-C_4$ ratios averaged 0.81.

Lower Part of the Umpqua Basin Subduction Zone Complex

One abandoned water well (Locality 5) in the early Eocene lower part of the Umpqua basin complex yielded very low concentrations of C_1 , 30 ppm as measured in the field and 20 ppm as measured in the laboratory. Other hydrocarbon gases were not detected. A second water well in the Tenmile Formation (Locality 18) yielded about 500 ppm C_1 , having $\delta^{13}C = -64.9\text{‰}$ and $\delta D = -123\text{‰}$, and only a trace of iC_4 . An attempt was made to sample outcrop gas at the exposed Bonanza thrust fault (Locality 1). About 2 ppm C_1 were measured in seven samples both in the field and laboratory. The results cannot be distinguished from atmospheric background. However, iC_4 and $n-C_4$ may be from outcrop gas. The ratios of these gases average about 0.35. The locations of these three localities are shown in Figure 1.

Upper Part of the Umpqua Basin Subduction Zone Complex

Six localities were sampled in the early and middle Eocene upper part of the Umpqua basin complex (Fig. 1, Localities 3,4,7,9,14,15). Four of these localities are water wells and two are coal outcrops, all in the White Tail Ridge Formation. The water well on Nob Hill Road released hydrocarbon gases under pressure. A C_1 concentration of 78% was measured in the field and 76% in the laboratory. Its isotopic compositions were determined to be $\delta^{13}C = -64.8\text{‰}$ and $\delta D = -245\text{‰}$. Other hydrocarbon gases to C_{5+} were present, with $C_1/(C_2+C_3)$ and $iC_4/n-C_4$ ratios of 11,000 and 56, respectively. C_1 concentration in the headspace of a well on Elgarose Road measured 52% in one sample, with isotopic values of $\delta^{13}C = -63.9\text{‰}$ and $\delta D = -207\text{‰}$. A second sample collected in a gas bag measured 13% C_1 in the field and 11 % in the laboratory. Other hydrocarbon gases to C_{5+} were present in both samples, and $C_1/(C_2+C_3)$ ratios were 630 and 890 (99.8% C_1). Ratios of $iC_4/n-C_4$ ranged from 29 to 190. The

hydrocarbons in the headspace of two additional wells had very low amount of C₁, less than 30 ppm as measured in the laboratory. Other hydrocarbon gases were not detected.

Coal gas was measured directly at the outcrop and in crushed samples from the White Tail Ridge Formation at two localities. Gas samples obtained from fractures in the coal contained about 600 ppm C₁, measured in the field, and 230 to 480 ppm, measured in the laboratory. This C₁ had isotopic compositions of $\delta^{13}\text{C} = -39.9\text{‰}$ and $\delta\text{D} = -142\text{‰}$. Higher molecular weight hydrocarbons were also present in the coal fractures; C₁/(C₂+C₃) ratios of 290 and 1,000 and iC₄/n-C₄ ratios of about 3 were measured. Crushed samples of coal from two localities yielded very low amounts of C₁, ranging from about 6 to 13 ppm along with other hydrocarbon gases. C₁/(C₂+C₃) ratios ranged between 6 and 28, and iC₄/n-C₄ ratios ranged between 2 and 56.

Coos Bay Forearc Basin

Although no samples were collected in the Tyee forearc basin, three localities were examined in the middle and late Eocene Coos Bay forearc basin (Fig. 1, Localities 12A,12B,20,21). Gas samples were obtained from two abandoned exploration wells in the Coaledo Formation, from a coal outcrop in the same rock unit, and from two subsurface coal samples from which gas was desorbed. The well designated 12A (Table 1) produced gas and water under pressure. This gas contained 75% C₁ (field measurement) and 59% (laboratory measurement) with a $\delta^{13}\text{C}$ value of -28.1‰ and $\delta\text{D} = -123\text{‰}$. Other hydrocarbon gases were also present; C₁/(C₂+C₃) and iC₄/n-C₄ ratios measured 2,000 (99.9% C₁) and 2.4, respectively. Well 12 B was not pressurized, and a headspace sample was recovered that contained about 11% C₁ and small amounts of C₂ and C₃ [C₁/(C₂+C₃) = 2,500 (99.9% C₁)]. A crushed coal sample yielded minimal hydrocarbons (C₁ = 0.4 ppm). Lastly, gases, desorbed from two samples of coal, recovered at subsurface depths of 365 and 385 m in a single well, contained about 19 and 54% C₁ with $\delta^{13}\text{C}$ values of -35.4 and -33.8‰ , respectively. C₂ was determined to be 300 and 200 ppm in the gas samples, and C₁/C₂ ratios measured 630 and 270 (>99.6% C₁), respectively.

DISCUSSION

Our preliminary survey of hydrocarbon gases in the Coast Range of southern Oregon has shown that in each of the geologic regions sampled abandoned water and exploration wells provide a convenient access for gas samples of varying quality. Where shut-in wells were vented so that samples were delivered above ambient pressure, gases were recovered containing more than 70% C₁ as in the upper part of the Umpqua basin complex and Coos Bay

forearc basin. These samples provided the best assessment of the total hydrocarbon gas composition and sufficient sample for the measurement of isotopic compositions of C₁. The headspace of wells which were not overpressured provided samples that were very diluted with air such that C₁ concentrations range from a maximum of about 13% to minimum values of about 20 ppm. Nevertheless, many of these samples yielded information on total hydrocarbon gas compositions, but only samples with more than 0.05% C₁ were useful for isotopic determinations. It is for these samples from which the most satisfactory interpretations can be made.

Natural gas having C₁ concentrations exceeding 0.05% is present in the Sixes River terrane of the Klamath Mountains, the Umpqua basin subduction zone complex, and the Coos Bay basin. C₁/(C₂+C₃) ratios for these samples ranged from 630 to 14,000. These values indicate that 99.8 to >99.9% of the hydrocarbon gas present is C₁, that is, a very dry gas with respect to the hydrocarbons. Thus, the dry gases from these regions have a remarkably narrow molecular hydrocarbon composition, but a broad range of C₁ isotopic compositions:

	<u>δ¹³C(‰)</u>	<u>δD(‰)</u>
Klamath Mountains	-50.6	-134
	-33.3	-155
Umpqua complex (lower part)	-64.9	-123
Umpqua complex (upper part)	-64.8	-245
	-63.9	-205
Coos Bay basin	-28.1	-123

These methane isotopic values are plotted on Figure 4. This figure suggests that C₁ from the Umpqua basin complex is microbial in origin, although the δD value of C₁ from the lower part of the Umpqua basin complex (-123‰) is unusually heavy for a microbial gas. In contrast, C₁ from wells in melange of the Klamath Mountains and Coos Bay forearc basin appear to be of thermal origin on the basis of their isotopic values. Thermogenic gas, however, can result from both catagenic and metagenic processes (Tissot and Welte, 1984). Catagenic gas normally has C₁/(C₂+C₃) ratios less than about 100 (Bernard and others, 1976), whereas in metagenic gas this ratio is usually large, exceeding about 1,000. Figure 5 shows the general ranges of carbon isotopic values for microbial, catagenic, and metagenic gas relative to C₁/(C₂+C₃) ratios. Our samples, plotted on Figure 5, from the Klamath Mountains and Coos Bay forearc basin appear, for the most part, to be a mixture of catagenic approaching metagenic gases. In order to provide an appropriate thermal regime for the thermogenic C₁ in these two widely separated areas (Fig. 1), we postulate that the source of natural gas is in the deeply buried pre-Tertiary terrane of the Klamath Mountains and the

deeply buried subducted Umpqua basin complex. The thermal C₁ is believed to have migrated along faults from these deeply buried sources (Fig. 3). Another process leading to dry hydrocarbon gas mixtures with heavy isotopic compositions is migrational stripping of non-C₁ hydrocarbons in catagenic gas during migration (Schoell, 1983). This process may also be a factor in explaining our results.

Dry gas mixtures similar to those found in our samples from the Klamath Mountains and Coos Bay forearc basin have been reported in analyses of gas from the Mist gas field in the northern Oregon Coast Range (Armentrout and Suek, 1985) and in gas seeps of the western Olympic Peninsula of Washington (Kvenvolden and others, 1989b). In both of these cases the dry gas was considered to be thermal in origin and to have migrated from deep-buried sources. Thus, dry, thermal C₁-dominated hydrocarbon gas mixtures seem to be common along the west coast of Oregon and Washington.

Coal was also considered as a candidate source for gas in the upper part of the Umpqua basin complex and the Coos Bay forearc basin. Gas from coals, in general may have a broad range of molecular and C₁ isotopic compositions (Schoell, 1983; Rice 1994), including compositions consistent with metagenic, deep sourced gas (Fuex, 1977). Gas samples were obtained in our study from a coal in each of these two areas. Gas from a coal outcrop of the White Tail Ridge Formation in the upper part of the Umpqua basin complex is dry [C₁/(C₂+C₃) = 290, and C₁ has isotopic values of $\delta^{13}\text{C} = -39.9\text{‰}$ and $\delta\text{D} = -142\text{‰}$](Table 2). These isotopic values contrast greatly with those obtained from well gas in the same area ($\delta^{13}\text{C} = -64.8, -63.9\text{‰}$ and $\delta\text{D} = -245, -207\text{‰}$). Although the evidence is minimal (one sample), we conclude that because of the contrasting isotopic compositions, the coal gas is not likely a source of the sampled well gas.

Gas was desorbed from two subsurface coal samples from a well in the Coos Bay forearc basin. Dry gas [(C₁/(C₂+C₃) ratios of 627 and 269) was released, having $\delta^{13}\text{C}$ values of -35.4 and -33.8‰ (Table 2). No δD values were obtained. This carbon isotopic composition is somewhat lighter than that found in well gas of the same area ($\delta^{13}\text{C} = -28.1\text{‰}$). Also the $\delta^{13}\text{C}$ values of the coal gas are heavier than expected for the maturity of the coal as indicated by vitrinite reflectance values less than 0.4% (information from Carbon Energy International). Thus the desorbed coal gas may have migrated into the coal from elsewhere. We conclude that at least the coal we sampled is not likely the source of the isotopically heavy well-gas.

Our attempts to acquire information from outcrops and outcrop samples were not as successful as our analyses of well gas. C₁ in gas obtained from joints

and cracks in the lower part of the Umpqua Group where the Bonanza thrust fault breaks the surface appears to be atmospheric background, but the higher molecular weight hydrocarbons, iC_4 and $n-C_4$, may be from the rocks. Ratios of these compounds average 0.35. Low $C_1/(C_2+C_3)$ ratios of these samples are mostly suspect because of possible preferential loss of C_1 , especially in samples containing low concentrations of hydrocarbon gases. In samples from melange of the Klamath Mountains, $iC_4/n-C_4$ ratios for crushed mudstone (0.59), crushed limestone (average 0.80), and well gas (0.61) are similar suggesting a possible correlation between hydrocarbons in the rocks and in the wells. Ratios of $iC_4/n-C_4$ greater than 1 are found in coal and well gas samples from the upper part of the Umpqua basin complex (Table 1); however, these ratios are usually larger in the well gas (maximum value of 190) than in the coal (maximum value of 56). This result appears to support the conclusion based on isotopic considerations that coal is probably not the source of well gas sampled in this basin complex.

SUMMARY

This preliminary study demonstrates that gas from wells can provide useful samples for hydrocarbon gas analyses in different geologic regions in the Coast Range of southern Oregon. The generalizations made as a result of this study need to be tested by more extensive and better sampling in the future. A significant observation is that the hydrocarbon gases found in melange of the Klamath Mountains, in the upper and lower parts of the Umpqua basin complex, and in the Coos Bay forearc basin, spanning a period of geologic time from the Cretaceous to the Miocene, are dry, dominated by C_1 ; the hydrocarbon gas mixtures contain greater than 99.8% C_1 . Thus, the hydrocarbon molecular compositions of these gas mixtures are remarkably similar considering that they come from such different geologic settings of different geologic ages.

The carbon and hydrogen isotopic compositions of C_1 in these gases signal different sources, however. The lightest carbon isotopic values ($\delta^{13}C = -64\text{‰}$) are found in well gas from the Umpqua basin complex, whereas the heavier values are found in the younger Coos Bay forearc basin ($\delta^{13}C = -28\text{‰}$) and in the much older pre-Tertiary melange of the Klamath Mountains ($\delta^{13}C = -51$ and -33‰). Heavier hydrogen isotopic values usually follow the heavier carbon isotopic values. A microbial origin is attributed to the dry C_1 from the Umpqua basin complex. The isotopically heavy C_1 from the melange of the Klamath Mountains and the Coos Bay basin appears to be a dry thermogenic gas which migrated upward along faults from more deeply buried pre-Tertiary Klamath Mountain terrane source rocks and from subducted source rocks in the lower part of the Umpqua basin complex.

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Table 1. Location of natural gas samples from the pre-Tertiary melange of the Klamath Mountains, from the Eocene upper part of the Umpqua basin subduction zone complex, and from the Eocene to Miocene Coos Bay forearc basin in southwestern Oregon.

Sample ID	Locality Number	Basin	Sample Description	Collection Method	Lat. N	Long. W
KL93 1604	16	SRT	Well gas, Near Clarks Branch Creek, Sixes River terrane	gas bag	43° 05.875	123° 17.136
N93 202	16	SRT	Well gas, Near Clarks Branch Creek, Sixes River terrane	syringe to bottle	43° 05.875	123° 17.136
KL 931701	17	SRT	Well gas, Near Clarks Branch Creek, Sixes River terrane	syringe	43° 05.120	123° 20.251
N93 201	17	SRT	Well gas, Near Clarks Branch Creek, Sixes River terrane	syringe to bottle	43° 05.120	123° 20.251
KL93 1003	10	SRT	Outcrop gas, Sixes River terrane	crushed sample in can	43° 06.363	123° 17.225
KL93 1004	10	SRT	Outcrop gas, Sixes River terrane	crushed sample in can	43° 06.363	123° 17.225
KL93 1105	11	SRT	Petroliferous limestone, Sixes River terrane, broken up and degassed for 10 minutes	crushed sample in can	43° 06.822	123° 18.896
KL93 1105	11	SRT	Petroliferous limestone, Sixes River terrane, broken up and degassed for 1.5 hours	crushed sample in can	43° 06.822	123° 18.896
KL93 1105	11	SRT	Petroliferous limestone, Sixes River terrane, broken up and degassed for 3 hours	crushed sample in can	43° 06.822	123° 18.896
KL93 1105	11	SRT	Petroliferous limestone, Sixes River terrane, broken up and degassed for 4 days	crushed sample in can	43° 06.822	123° 18.896
KL93 504	5	LUB	Well gas, poor sample, 2' dia. well, Coles Valley, lower part of Umpqua Group ¹	syringe	43° 21.943	123° 29.541
KL93 503	5	LUB	Well gas, poor sample, 2' dia. well, Coles Valley, lower part of Umpqua Group ¹	syringe	43° 21.943	123° 29.541
N93 208	5	LUB	Well gas, poor sample, 2' dia. well, Coles Valley, lower part of Umpqua Group ¹	syringe to bottle	43° 21.943	123° 29.541
N93 204	18	LUB	Well gas, 2289 W. Ireland Road, Tenmile Formation ¹	syringe to bottle	43° 04.350	123° 37.083
N-93-1	1	LUB	Outcrop gas, joints and cracks in mudstone of the lower part of Umpqua Group ¹	gas bag	43° 19.759	123° 26.385
N-93-2	1	LUB	Outcrop gas, joints and cracks in mudstone of the lower part of Umpqua Group ¹	gas bag	43° 19.759	123° 26.385
N-93-3	1	LUB	Outcrop gas, joints and cracks in mudstone of the lower part of Umpqua Group ¹	gas bag	43° 19.759	123° 26.385
N-93-4	1	LUB	Outcrop gas, joints and cracks in mudstone of the lower part of Umpqua Group ¹	gas bag	43° 19.759	123° 26.385
KL93 101	1	LUB	Outcrop gas, joints and cracks in mudstone of the lower part of Umpqua Group ¹	syringe	43° 19.759	123° 26.385
KL93 102	1	LUB	Outcrop gas, joints and cracks in mudstone of the lower part of Umpqua Group ¹	syringe	43° 19.759	123° 26.385
KL93 103	1	LUB	Outcrop gas, joints and cracks in mudstone of the lower part of Umpqua Group ¹	syringe	43° 19.759	123° 26.385
KL93 304	3	UUB	Well gas, Nob Hill Rd., White Tail Ridge Fm. ¹	water displacement	43° 15.433	123° 28.741
KL93 307	3	UUB	Well gas, Nob Hill Rd., White Tail Ridge Fm. ¹	gas bag	43° 15.433	123° 28.741
N93 205	4	UUB	Well gas, Elgarose Rd., White Tail Ridge Fm. ¹	syringe to bottle	43° 15.934	123° 30.426
KL93 401	4	UUB	Well gas, Elgarose Rd., White Tail Ridge Fm. ¹	gas bag	43° 15.934	123° 30.426
KL93 701	7	UUB	Well gas, Elgarose Loop, White Tail Ridge Fm. ¹	gas bag	43° 15.824	123° 29.103
KL93 903	9	UUB	Well gas, near Hwy. 42, Camas Valley, White Tail Ridge Fm. ¹ , well by home	syringe	43° 02.965	123° 39.678
KL93 904	9	UUB	Well gas, near Hwy. 42, Camas Valley, White Tail Ridge Fm. ¹ , 400' W of home	syringe	43° 02.861	123° 39.661
KL93 905	9	UUB	Well gas, near Hwy. 42, Camas Valley, White Tail Ridge Fm. ¹ , 400' W of home	syringe	43° 02.861	123° 39.661
N93 203	9	UUB	Well gas, near Hwy. 42, Camas Valley, White Tail Ridge Fm. ¹ , 400' W of home	syringe	43° 02.861	123° 39.661
KL93 1401	14	UUB	Coal, Whitetail Ridge Fm. ¹ Hwy. 42, broken up and degassed for 10 minutes	crushed sample in can	43° 00.497	123° 53.989
KL93 1401	14	UUB	Coal, Whitetail Ridge Fm. ¹ Hwy. 42, broken up and degassed for 1 day	crushed sample in can	43° 00.497	123° 53.989
KL93 1403	14	UUB	Coal outcrop gas, Whitetail Ridge Fm. ¹ Hwy. 42	syringe	43° 00.497	123° 53.989
KL93 1502	15	UUB	Coal outcrop gas, Coquille Mbr., Whitetail Ridge Fm. ¹ Hwy. 42	syringe	43° 00.155	123° 42.696
KL93 1503	15	UUB	Coal outcrop gas, Coquille Mbr., Whitetail Ridge Fm. ¹ Hwy. 42	syringe	43° 00.155	123° 42.696
KL93 1501	15	UUB	Coal, Coquille Mbr., Whitetail Ridge Fm. ¹ Hwy. 42 broken up and degassed for 2 hours	crushed sample in can	43° 00.155	123° 42.696
N93 206	15	UUB	Coal outcrop gas, Coquille Mbr., Whitetail Ridge Fm. ¹ Hwy. 42	syringe to bottle	43° 00.155	123° 42.696
KL93 1205	12A	CB	Well gas, near Coquille, OR, Eocene Coaledo Fm.	syringe	43° 09.395	124° 13.576
KL93 1207	12A	CB	Well gas, near Coquille, OR, Eocene Coaledo Fm.	water displacement	43° 09.395	124° 13.576
KL93 1212	12B	CB	Well gas, near Coquille, OR, Eocene Coaledo Fm.	syringe	43° 09.275	124° 13.657
KL93 1215	12B	CB	Well gas, near Coquille, OR, Eocene Coaledo Fm.	gas bag	43° 09.275	124° 13.657
N94-2A	20	CB	Coal, Beaver Hill, Eocene Coaledo Fm. on Hwy 101	crushed sample in can	43° 11.750	124° 18.865
N94-WNS3	21	CB	WNS-Menasha 32-1 well, 365 m	desorbed coal gas	43° 16.009	124° 16.031
N94-WNS3	21	CB	WNS-Menasha 32-1 well, 385 m	desorbed coal gas	43° 16.009	124° 16.031

SRT, Sixes River Terrane; LUB, lower Umpqua basin; UUB, upper Umpqua basin; CB, Coos Bay basin

¹ Ryu and others, (1992)

Table 2. Hydrocarbon compositions of natural gas samples from the pre-Tertiary melange of the Klamath Mountains, from the Eocene upper part of the Umpqua basin subduction zone complex, and from the Eocene to Miocene Coos Bay forearc basin in southwestern Oregon.

Sample ID	Loc. No.	Field GC		Hydrocarbon Gas Concentration (ppm-v)										Ratios		Isotopes	
		C1	C2	C1	C2	C2:1	C3	C3:1	iC4	nC4	C5+	C1/C2+C3	iC4/nC4	$\delta^{13}C_{C1}$	δD_{C1}		
KL93 1604	16	na	na	4400	0.6	nd	1.0	nd	nd	nd	nd	nd	2710	---	na	na	
N93 202	16	na	na	2300	1.5	nd	nd	nd	0.1	trace	nd	1530	---	-50.57	-134		
KL 931701	17	na	na	135000	7.4	0.5	2.6	nd	0.3	0.6	nd	13560	0.61	na	na		
N93 201	17	na	na	9900	0.5	nd	0.4	0.6	trace	trace	nd	11050	---	-33.33	-155		
KL93 1003	10	1.8	nd	2.2	trace	nd	nd	nd	0.1	0.1	yes	---	0.59	na	na		
KL93 1004	10	10.8	nd	8.7	1.4	nd	8.4	nd	0.1	0.1	yes	1	0.59	na	na		
KL93 1105	11	na	na	30.1	0.8	nd	14.7	nd	9.3	13.0	yes	2	0.72	na	na		
KL93 1105	11	na	na	29.8	2.6	nd	65.0	nd	38.3	48.7	yes	<1	0.79	na	na		
KL93 1105	11	na	na	40.8	3.6	nd	71.4	nd	56.4	68.7	yes	1	0.82	na	na		
KL93 1105	11	na	na	36.3	4.9	nd	94.4	nd	94.4	110	yes	<1	0.86	na	na		
KL93 504	5	30.2	na	na	na	na	na	na	na	na	na	---	---	na	na		
KL93 503	5	27.4	na	na	na	na	na	na	na	na	na	---	---	na	na		
N93 208	5	na	na	19.7	nd	nd	nd	nd	nd	nd	nd	---	---	na	na		
N93 204	18	na	na	490	nd	nd	nd	nd	trace	nd	nd	---	---	-64.93	-123		
N-93-1	1	na	na	1.8	nd	nd	nd	nd	0.1	0.2	yes	---	0.25	na	na		
N-93-2	1	na	na	1.8	nd	nd	trace	nd	0.1	0.2	yes	---	0.35	na	na		
N-93-3	1	na	na	1.8	nd	nd	nd	nd	0.1	0.2	yes	---	0.46	na	na		
N-93-4	1	na	na	1.8	nd	nd	nd	nd	0.1	0.2	yes	---	0.32	na	na		
KL93 101	1	2.2	nd	na	na	na	na	na	na	na	na	---	---	na	na		
KL93 102	1	2.4	nd	na	na	na	na	na	na	na	na	---	---	na	na		
KL93 103	1	2.4	nd	na	na	na	na	na	na	na	na	---	---	na	na		
KL93 304	3	na	na	na	na	na	na	na	na	na	na	---	---	-64.80	-245		
KL93 307	3	781000	71.2	761000	55.2	nd	12.4	nd	0.6	0.0	yes	11250	56.00	na	na		
N93 205	4	na	na	522000	750	0.6	72.4	trace	35.8	1.2	yes	640	29.40	-63.87	-207		
KL93 401	4	127000	220	111000	120	nd	6.2	nd	3.8	0.0	yes	880	190.00	na	na		
KL93 701	7	5.7	nd	21.9	nd	nd	0.2	nd	0.6	0.0	yes	120	64.60	na	na		
KL93 903	9	87.0	nd	na	na	na	na	na	na	na	na	---	---	na	na		
KL93 904	9	7.4	nd	na	na	na	na	na	na	na	na	---	---	na	na		
KL93 905	9	34.5	nd	na	na	na	na	na	na	na	na	---	---	na	na		
N93 203	9	na	na	29.1	nd	nd	nd	nd	nd	nd	nd	---	---	na	na		
KL93 1401	14	na	na	8.7	0.5	0.2	0.4	0.2	0.1	0.0	yes	9	6.50	na	na		
KL93 1401	14	na	na	5.5	0.7	nd	0.2	trace	0.6	0.0	yes	6	56.10	na	na		
KL93 1403	14	na	na	300	0.3	nd	trace	trace	0.2	0.1	yes	1130	2.53	na	na		
KL93 1502	15	na	na	480	0.4	nd	trace	nd	0.0	0.0	yes	1110	3.70	na	na		
KL93 1503	15	610	nd	na	na	na	na	na	na	na	na	---	---	na	na		
KL93 1501	15	na	na	13.0	0.2	nd	0.3	nd	0.5	0.3	yes	28	2.00	na	na		
N93 206	15	na	na	230	0.6	nd	0.2	nd	0.1	nd	nd	290	---	-39.88	-142		
KL93 1205	12A	746000	350	na	na	na	na	na	na	na	na	---	---	na	na		
KL93 1207	12A	na	na	590000	280	nd	20.0	nd	0.3	0.1	yes	1970	2.44	-28.10	-123		
KL93 1212	12B	11400	nd	na	na	na	na	na	na	na	na	---	---	na	na		
KL93 1215	12B	na	na	11900	4.5	nd	0.2	nd	nd	nd	nd	2520	---	na	na		
N94-2A	20	na	na	0.4	0.1	nd	0.1	0.5	0.1	0.1	yes	2	1.36	na	na		
N94-WNS3	21	na	na	188000	300	nd	nd	nd	nd	nd	nd	630	---	-35.42	na		
N94-WNS3	21	na	na	538000	2000	nd	nd	nd	nd	nd	nd	270	---	-33.78	na		

na, not analyzed; nd, not detected; yes, present but unresolved by the gas chromatograph; trace, detected but not quantifiable

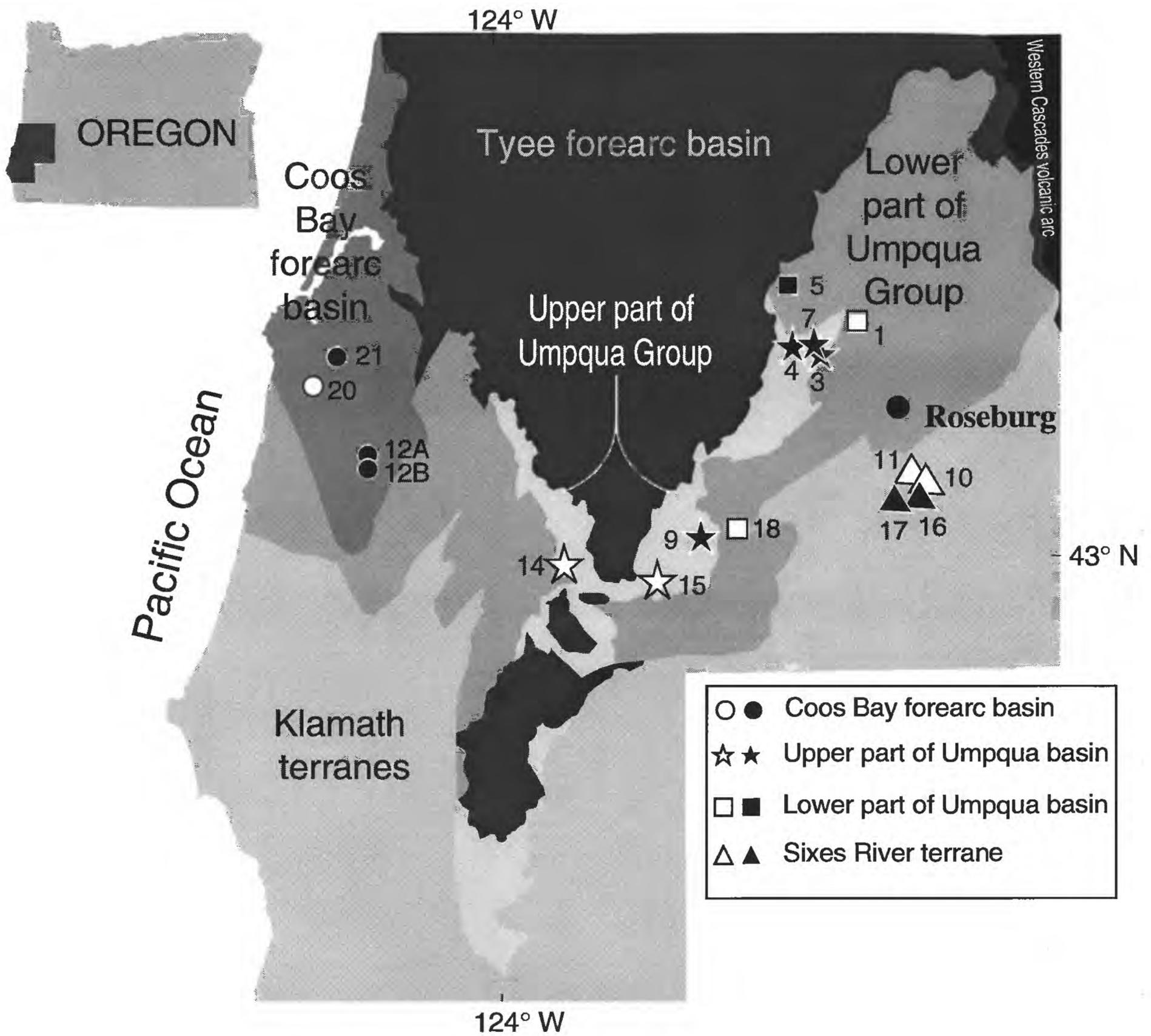


Fig. 1. Generalized geologic map of the study area showing gas sampling sites. Open symbols indicate samples from outcrop and from seeps in joints and faults in roadcuts and quarries. Solid symbols indicate samples from water wells and petroleum exploration wells. Numbers correspond to locality numbers in Tables 1 and 2.

Age (Ma)	System	Series	Lithostratigraphic Unit	Setting		
49	Tertiary	Eocene	middle	Coaledo Fm.	Coos Bay forearc basin	
			lower	Elkton Fm.	Tyeo forearc basin	
				Tyeo Fm. ¹		
				Upper part of Umpqua Group ¹	Camas Valley Fm. ¹	Umpqua basin subduction zone complex
				White Tail Ridge Fm. ¹		
		Lower part of Umpqua Group ¹		Tenmile Fm. ¹		
			Bushnell Rock Fm. ¹			
		54	Paleocene	upper	Siletz River Volcanics	
				lower		
		60.2	Cretaceous	Upper	Sixes River terrane	
66.5	Senonian					
96	Lower	Neocomian				
131	Jurassic	Upper	Sixes River terrane			
152			Malm			

Fig. 2. Stratigraphic column of rock units of Umpqua, Tyeo and Coos Bay basins and adjacent Klamath Mountains (Sixes River terrane). Symbols mark units sampled in this study.

¹Ryu and others, (1992)

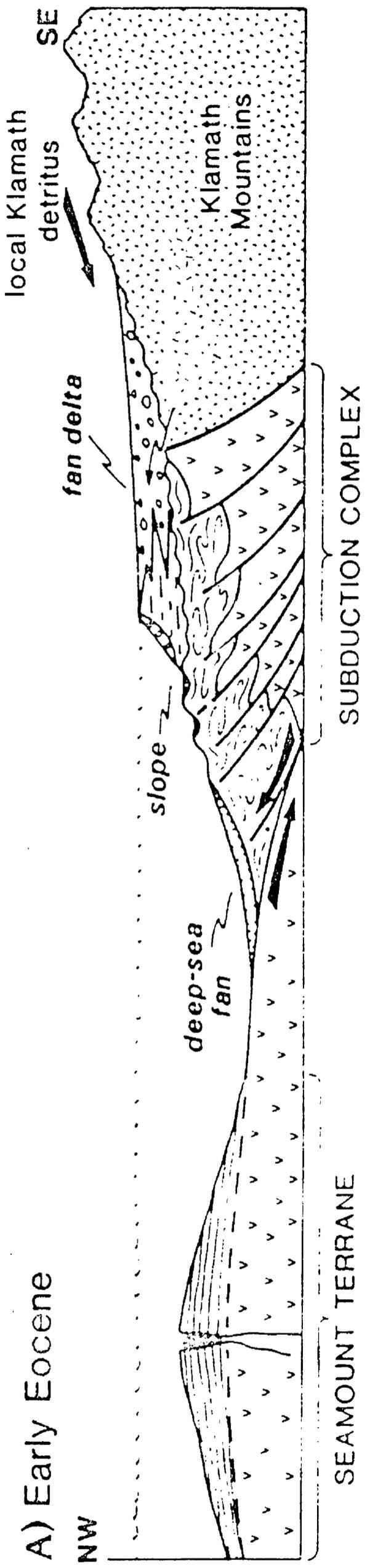
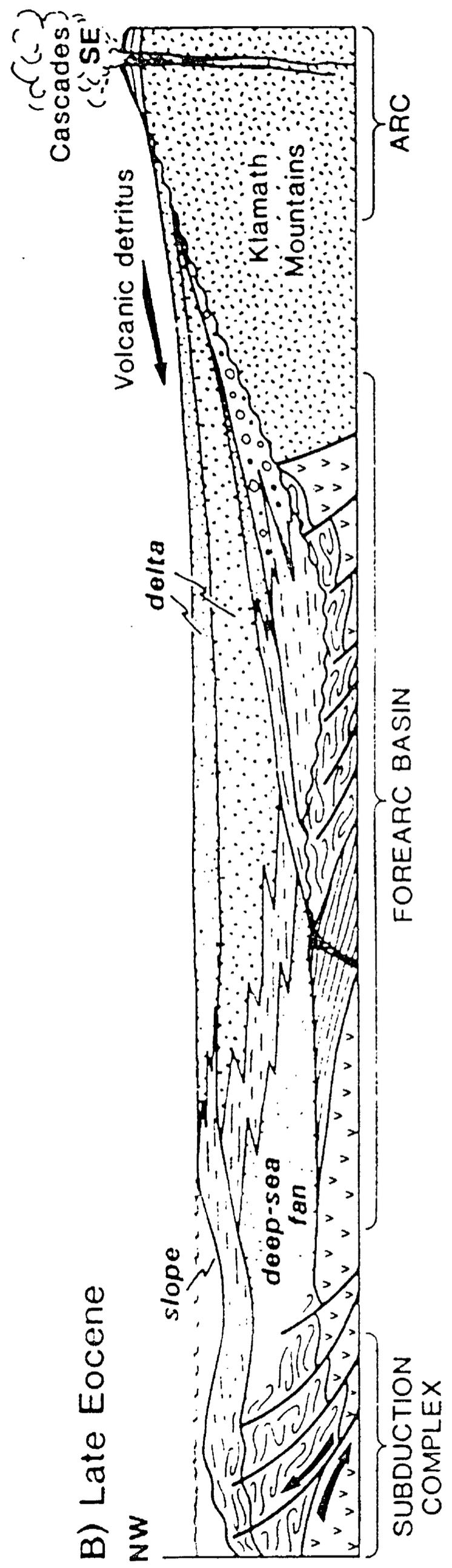


Fig. 3. (a) Subduction zone setting of the Umpqua basin in the early Eocene. Thrust faults juxtapose thermally immature Paleocene-Eocene lower Umpqua Group strata with thermally mature pre-Tertiary Sixes River Terrane (melange) of the northern Klamath Mountains.



(b) Formation of the overlying upper Umpqua basin and the Tye and Coos Bay forearc basins in the early, middle, and late Eocene and early Miocene, including deposition of thermally immature deltaic coal-bearing strata. Modified from Heller and Ryberg (1983).

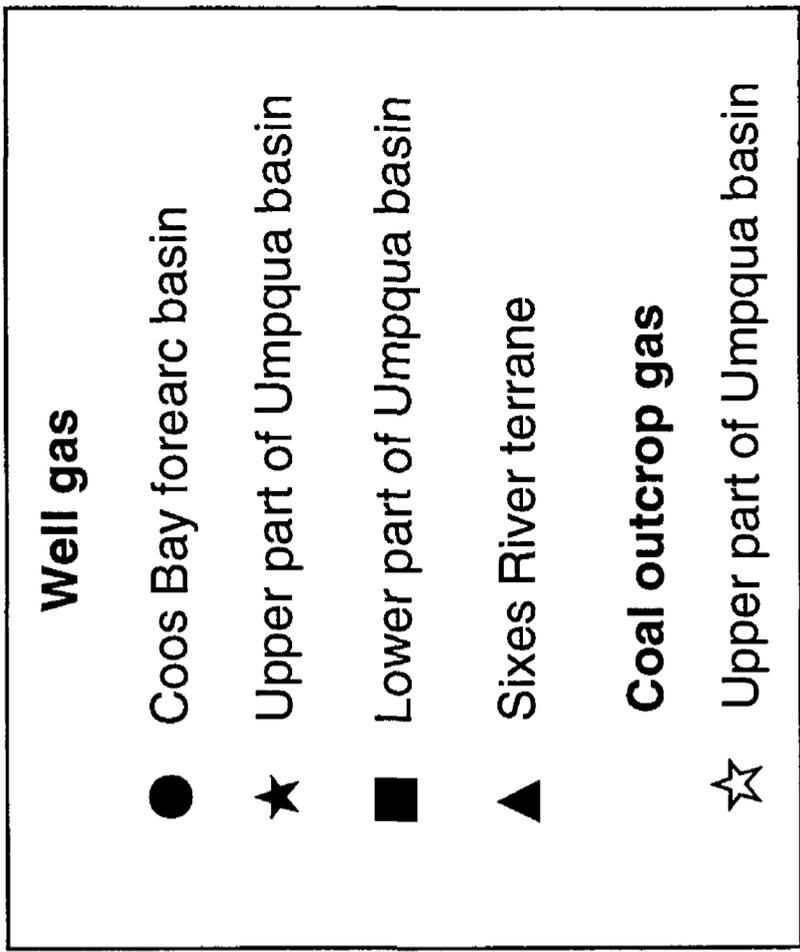
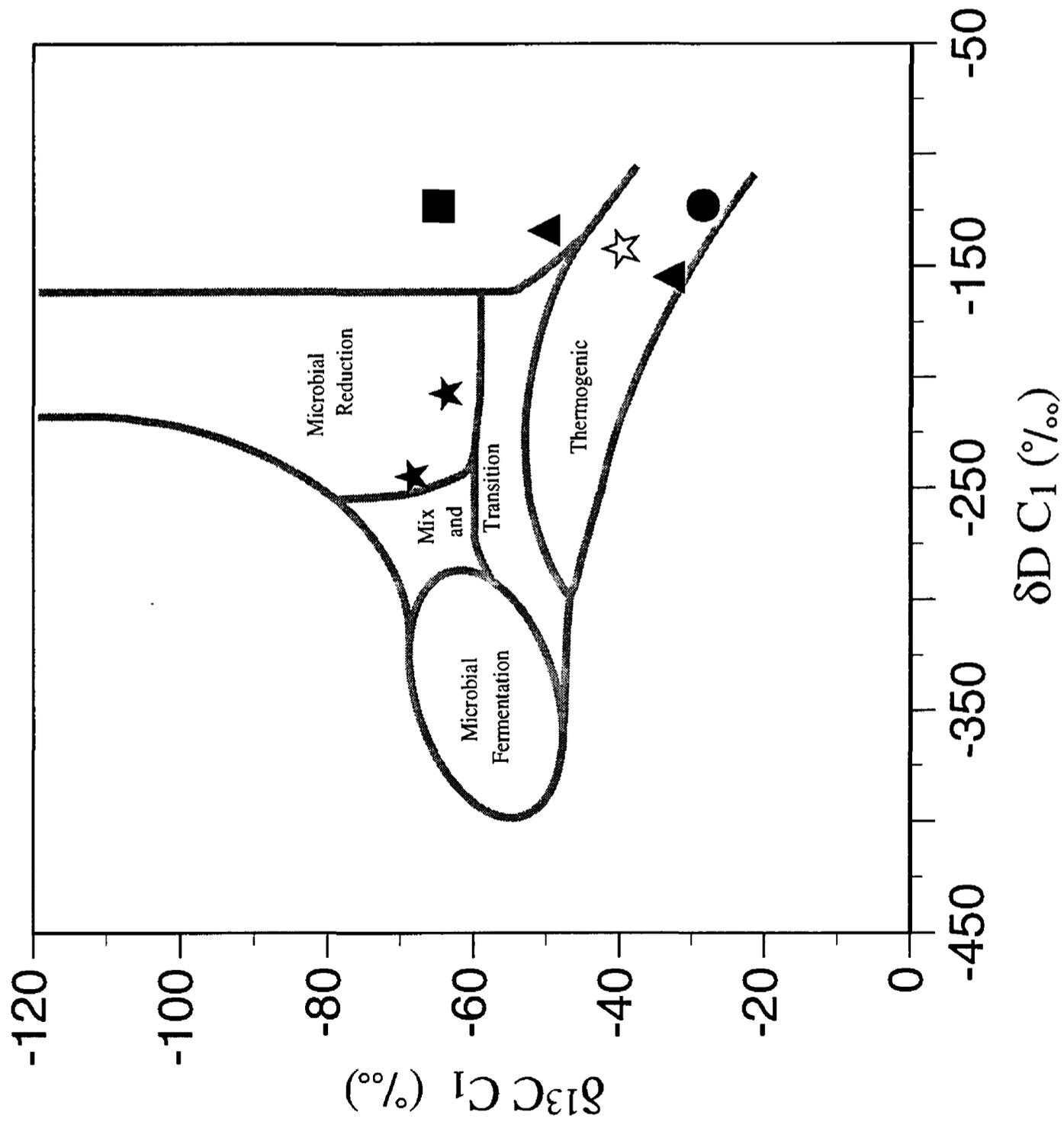


Fig. 4. $\delta^{13}\text{C}$ vs δD of C_1 with compositional fields for microbial and thermal natural gases (modified from Whiticar, 1990). Samples from this study are plotted indicating the presence of both microbial and thermal C_1 .

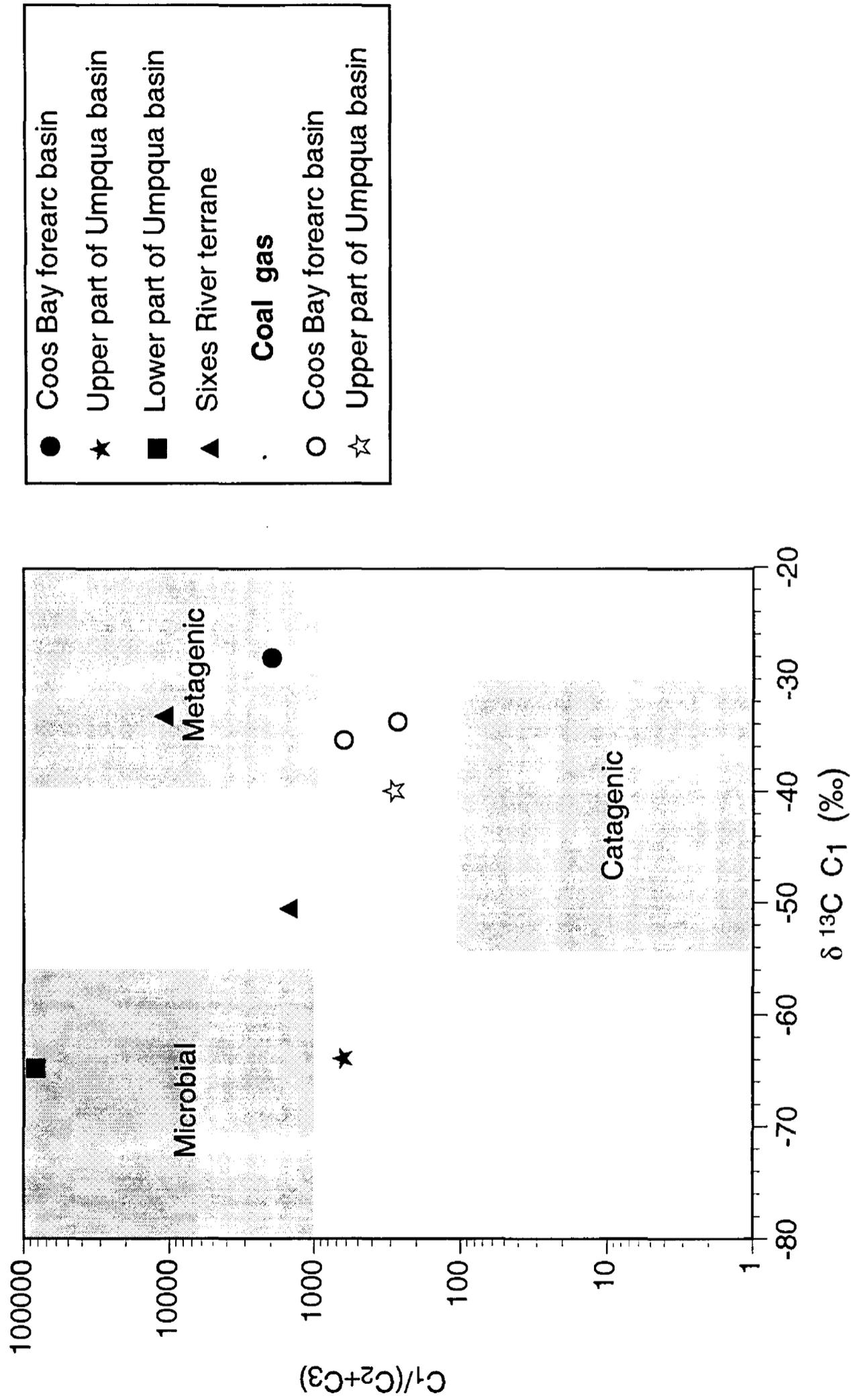


Fig. 5. $C_1/(C_2+C_3)$ vs $\delta^{13}C_{C_1}$ with compositional fields for microbial and thermal natural gases. The thermogenic gas field is further divided into catagenic and metagenic fields (modified from Armentrout and Suek, 1985). Samples from this study are plotted and show the presence of dry natural gas with C_1 from both microbial and thermal sources.