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Abstract

The drilling of four deep wells by Shell Oil Company in the Columbia Basin has provided the first direct information about the nature and hydrocarbon potential of the rocks underlying the Columbia River basalt. Rocks encountered by sub-basalt drilling include Tertiary volcaniclastics and fluvial sedimentary rocks plus minor marine and igneous rocks. The sedimentary units can be correlated with rocks occurring along the basalt margin.

The well data confirms the southward extent of the Naneum-Hog Ranch cross-structure. This structure appears to control the kind and distribution of sedimentary rocks underlying the Columbia River basalt. Results of exploration to date indicate little or no oil and only non-commercial deposits of gas. The source of the hydrocarbons is thought to be derived from coal beds of Tertiary age.

Since oil and gas exploration in the Columbia Basin is continuing, this report will be updated when new well data becomes available. Data from the Shell Oil Company well 1-9 BN Saddle Mountains well are expected to be released in March 1986.

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EXECUTIVE SUMMARY

In 1980, the Shell Oil Company began drilling a series of deep wells in the northwestern Columbia Basin to test for hydrocarbons beneath the Columbia River basalt. Four wells, the 1-33 Yakima Minerals, the 2-33 Yakima Minerals, the 1-29 Bissa, and the 1-9 BN Saddle Mountains, have been completed. Although all four completed wells were deemed noncommercial, gas was encountered in each well, and the exploration effort set off an exploration boom in the Columbia Basin. This report presents a reevaluation of the hydrocarbon potential and pre-basalt stratigraphy of the Columbia Basin based on new information supplied from these wells.

STRATIGRAPHY

The 1-33 Yakima Minerals well passed through Columbia River basalt, Wildcat Creek sediments, Ohanapecosh volcaniclastics, Roslyn fluvial sediments, Teanaway pyroclastics, and Swauk (Manashtash) fluvial sediments. The well bottomed in Swauk sediments at 16,199 ft after passing through a sheared serpentinite zone thought to represent faulted Swauk.

The 2-33 Yakima Minerals well passed through Columbia River basalt and bottomed in Wildcat Creek sediments at 5,604 ft. The 1-29 Bissa well passed through Columbia River basalt, Roslyn fluvial sediments, Cretaceous marine shale and limestone (probable), and bottomed in granite at 14,965 ft. No stratigraphic information from well logs is available for the 1-9 BN Saddle Mountains well.

The wells encountered coals and carbonaceous shales in early Tertiary Roslyn and Swauk Formations that are considered to be the source rocks for the gas found under the basalt. There are no known source rocks for oil or condensate, although the presence of marine rocks in the 1-29 Bissa well increases the possibility of oil if these rocks thicken to the southeast under the Columbia Basin.

The Roslyn Formation contains the best reservoir rocks (fluvial sands); however permeable zones also exist in the Swauk, Ohanapecosh, and Wildcat Creek sediments. The Columbia River basalt is not a reservoir rock but acts as a cap rock to confine upward migration of gas. Other impermeable rocks downsection that may trap gas include Teanaway and Ohanapecosh tuffs as well as shales within the Swauk Formation.

STRUCTURE

The 1-29 Bissa well confirmed the presence of a pre-basalt structure, the Naneum Ridge-Hog Ranch high, which is present as a surface cross fold extending south as far as Rattlesnake Ridge. This high has restricted the eastward movement of Cascade-type volcaniclastics present in the 1-33 Yakima Minerals well but is missing at the 1-29 Bissa well (located on the crest of the high). The presence of this high increases the chance of stratigraphic traps along both sides of the uplift.

Except for the Naneum Ridge-Hog Ranch high, the well data give no clear evidence of the orientation of pre-Tertiary rocks. Surface anticlines remain the best drilling prospects for gas, although the poor shows in the 1-29 Bissa well make folds in the extreme northwest part of the Columbia Basin less attractive.

TESTING PROCEDURES AND RESULTS

Mud logging techniques used in the 1-33 Yakima Minerals well detected numerous gas shows in the sedimentary sequence beneath the basalt. The strongest kicks were in Wildcat Creek sediments just beneath the Columbia River basalt and in numerous zones throughout the Roslyn Formation. The Columbia River basalt showed small gas kicks in two interbeds. Following the drilling, eight zones were tested for gas production. The two best zones (in the Roslyn Formation) each yielded gas at rates up to 500 thousand cubic feet per day (Mcfpd), but rapid pressure reduction and high water yields made the zones noncommercial. Initial total yield from all eight zones was nearly 1.3 MMcfpd.

The 2-33 Yakima Minerals well was drilled to test zones immediately below the basalt. This well produced more gas shows than the 1-33 Yakima Minerals well from interbeds of the Columbia River basalt because lighter weight mud was used. Interbeds yielded only small amounts of gas and many were gas free. The 2-33 Yakima Minerals mud log indicated good gas shows in the Wildcat Creek sediments, but subsequent tests recovered very little gas.

Flow tests in the 1-29 Bissa well yielded only small amounts of gas. No oil or condensate was recovered in any of the wells.

HYDROCARBON POTENTIAL OF THE PASCO BASIN

More information about the pre-basalt rocks under the Pasco Basin will be available after release of well log data for the 1-9 BN Saddle Mountains well. Pre-basalt sediments under the basin are thought to derive either from a southeastern extension of the Chiwaukum graben or from sediments carried down the Palouse slope before the eruption of the Columbia River basalt. The Naneum Ridge-Hog Ranch high may have prevented Cascade Province volcaniclastics from reaching the Pasco Basin. The possibility of marine rocks under the Pasco Basin is enhanced by their discovery in the 1-29 Bissa well.

The Pasco Basin structural low is no more attractive as an exploration target than it was before deep drilling in 1980. The western edge of the basin along the Naneum Ridge-Hog Ranch high might contain favorable stratigraphic traps, but more subsurface data are needed to prove the existence of such prospects. The best potential in the Columbia Basin is still considered to be surface anticlines with west or northwest structural closure.

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INTRODUCTION

The search for hydrocarbons in the Columbia Basin* during the past 80 yr has involved numerous companies and random prospecting over a wide geographical area. In the late 1970s, the Shell Oil Company (Shell) began an escalated search for oil and gas in the basin. In 1980, after acquiring a dominant acreage position in the northwestern part of the Columbia Basin, Shell began drilling a series of deep wells designed to penetrate the Columbia River basalt and to test for hydrocarbons in pre-basalt sediments. This ongoing drilling program has resulted in significant gas shows and triggered the largest exploration and lease "play" in state history. Major and independent oil companies leased most of the Columbia Basin, paying, in some cases, lease bonuses exceeding $400 an acre.

The original gas shows proved uneconomical, but Shell is continuing to test pre-basalt rocks. By April 1985, Shell and various partners completed drilling on the 1-33 Yakima Minerals, 2-33 Yakima Minerals, 1-29 Bissa, and 1-9 BN Saddle Mountains wells. Shell has two other drilling permits, one for the Frenchman Hills and a second for northern Oregon, but has not announced any plans for development of these sites.

*Basin will be used in this report rather than plateau to indicate that the rocks form a true structural and topographic basin.

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OBJECTIVE

Mud and wire-line logs are available for the 1-33 and 2-33 Yakima Minerals wells and the 1-29 Bissa well (the 1-9 BN Saddle Mountains and 1-A Moses Lake wells are still tight holes). Using the information from these wells, this report will perform the following functions:

1. Evaluate and interpret the borehole stratigraphy and relate it to the regional geology

2. Provide updated information concerning the hydrocarbon potential in the northwestern and central Columbia Basin (previous documentation (Rockwell and Leaming 1981) does not include data from the Shell wells).

This report will not discuss rocks and hydrocarbon potential in the extreme south and eastern Columbia Basin.

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WELL SITE LOCATIONS

The RSH-1 Rattlesnake Hills well, the first deep exploratory well in the Columbia Basin, was drilled in 1958. This well penetrated, but did not pass through, the Columbia River basalt.

Since 1979, five deep wells have been drilled exclusively for petroleum evaluation in the northwestern Columbia Basin (table 1). Each well, except the 1-A Moses Lake well, is located on the crest of an anticlinal ridge having west structural and topographical closure (fig. 1 and plate 1).

RATIONALE FOR WELL SITE SELECTION

Oil and gas well sites are chosen for many reasons--favorable geology, available lease lands, environmental conditions, political considerations, and access potential--most of which are outside the scope of this report. One can, however, make a reasonable interpretation of the favorable geological conditions that led to the drilling of several wells in the Columbia Basin. The following four conditions are necessary for any significant accumulations of hydrocarbons to occur:

1. Adequate source beds to generate hydrocarbons
2. Nearby porous and permeable beds to act as a reservoir
3. A cap rock to prevent the escape of newly formed oil and gas
4. A trapping mechanism.

All of these conditions may exist under the Columbia River basalt.

Source Beds

Two rock types that can act as source beds may be present under the Columbia Basin. The most likely source beds are coals and carbonaceous shales contained in early Tertiary fluvial rocks: the Roslyn, Chumstick, and Swauk Formations. The Roslyn Formation contains numerous thick coal beds and the Swauk and Chumstick Formations contain minor coals and several black shales. These rocks crop out along the basalt margin and appear to extend southward under the basalt (plate 1). Analysis of the well logs indicates that these rocks are present in the 1-29 Bissa and the 1-33 Yakima Minerals wells (see the following discussion).

Table 1. Deep Well Sites in the Northwestern Columbia Basin.

Characteristics	1-33 Yakima Minerals well	2-33 Yakima Minerals well	1-29 Bissa well	1-A Moses Lake well	1-9 BN Saddle Mountains well
Location	33-15N-19E Kittitas County	33-15N-19E Kittitas County	29-18N-21E Kittitas County	13-20N-26E Grant County	9-15N-25E Grant County
Operator	Shell	Shell	Shell	Snowbird Resources	Shell
Total depth (ft)	16,199	5,604	14,965	6,979	17,518
Date completed	6/30/81	2/20/82	7/9/82	12/22/81 (?)	10/13/85
Anticlinal structure	Selah Butte	Selah Butte	Whiskey Dick Ridge	Beezley Hills (?)	Saddle Mountains
Structural closure (ft)	700	700	450	Unknown	600
Topographic closure (ft)	800	800	450	None	300

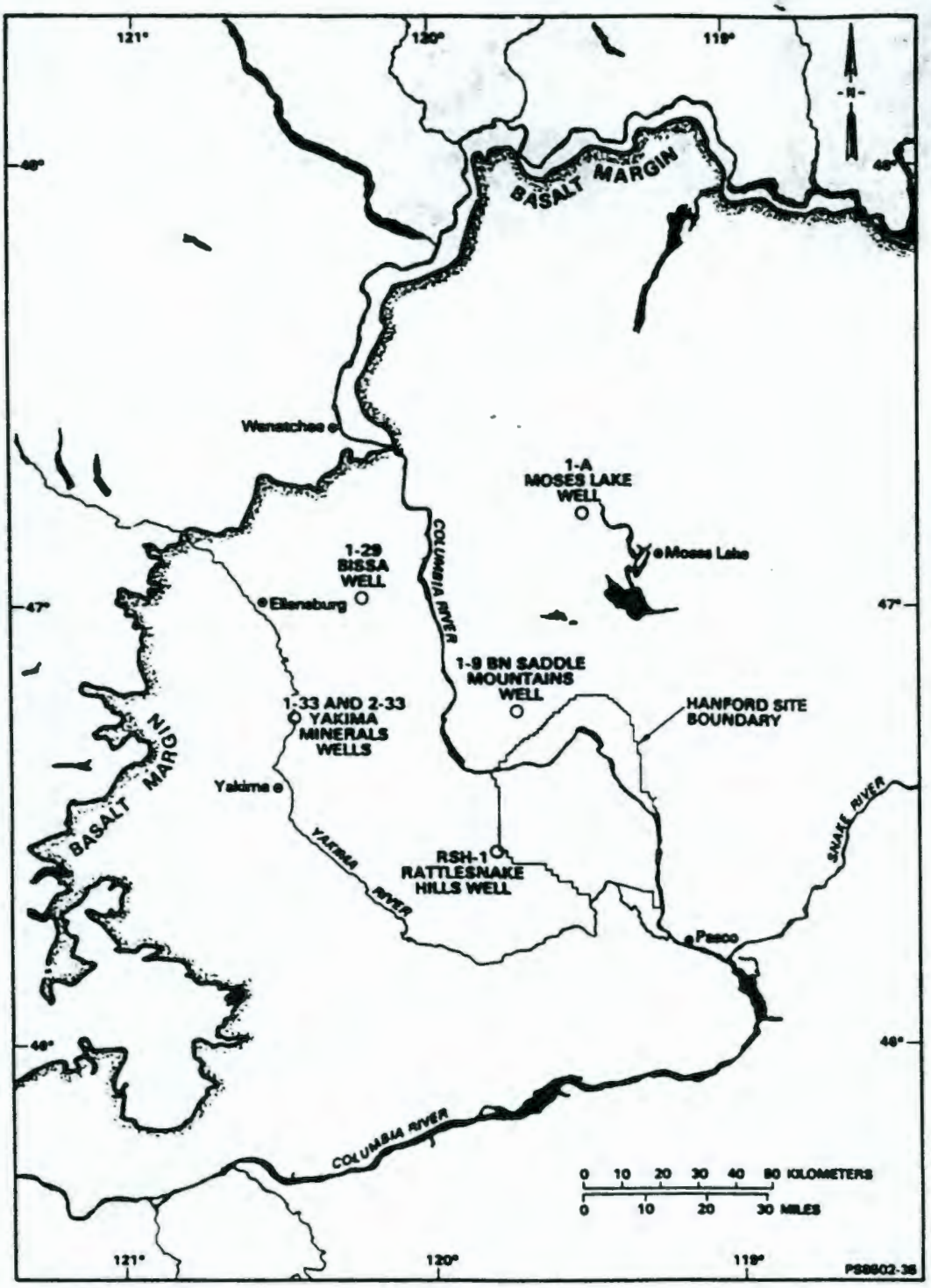

Figure 1. Location Map Showing Well Sites and Columbia River Basalt Margin, Northwest Columbia Basin.

A second potential group of source beds are Cretaceous marine rocks found north of the Columbia Basin in the Methow graben and in central Oregon. The Virginia Ridge, Harts Pass, and Panther Creek Formations all contain black shales capable of generating hydrocarbons providing they are present under the Columbia River basalt (fig. 2 and table 2). Logs from the 1-29 Bissa well indicate that marine shales and limestones were encountered near the bottom of the well.

Hydrocarbons may have been liberated from source rocks under the basalt without being destroyed by thermal effects from the eruption of the Columbia River basalt and volcanics from the Cascade Range. In addition, the volcanics may have aided coal gasification by providing added heat and pressure. Coal and carbonaceous shale in lower Tertiary rocks are the most likely sources of hydrocarbons. Cretaceous rocks seem less likely to have generated gas.

Reservoir Rocks

Clean, quartz-rich sandstones capable of holding hydrocarbons are present in Tertiary rocks along the basalt margin north and west of the well sites (fig. 2). Among the most favorable reservoir rocks are the Wenatchee, upper Roslyn, and middle Chumstick Formations, but clean sands are also present in Swauk and Wildcat Creek sediments. These fluvial sandstones (and sand derived from volcanic rocks) have a poorly sorted nature and contain zeolites, clay, and tuffaceous silt that reduce the permeability of the rock. In addition, the lensey nature of the sediments tends to reduce the volume of the reservoir and restrict lateral migration of fluids.

One favorable aspect is that fluvial sediments often contain buried sand bars and old stream channels that are excellent reservoirs. Since migrating gas requires less permeability and porosity than oil, some tuffaceous and silty sandstones in the Tertiary sequence may be potential gas reservoirs. Shell tested a variety of rock types and recovered gas in most of these units (see well data below).

Certain Cretaceous marine rocks, if they exist beneath the Columbia River basalt, may be reservoir rocks. In the Methow graben to the north, the Goat Creek and Winthrop sandstones are potential reservoirs; however, most Cretaceous rocks in the graben tend to be tightly cemented and compacted with abundant clay matrix and are sometimes thermally altered. A sequence of probable Cretaceous rocks encountered in the 1-29 Bissa well contained only one thin sandstone.

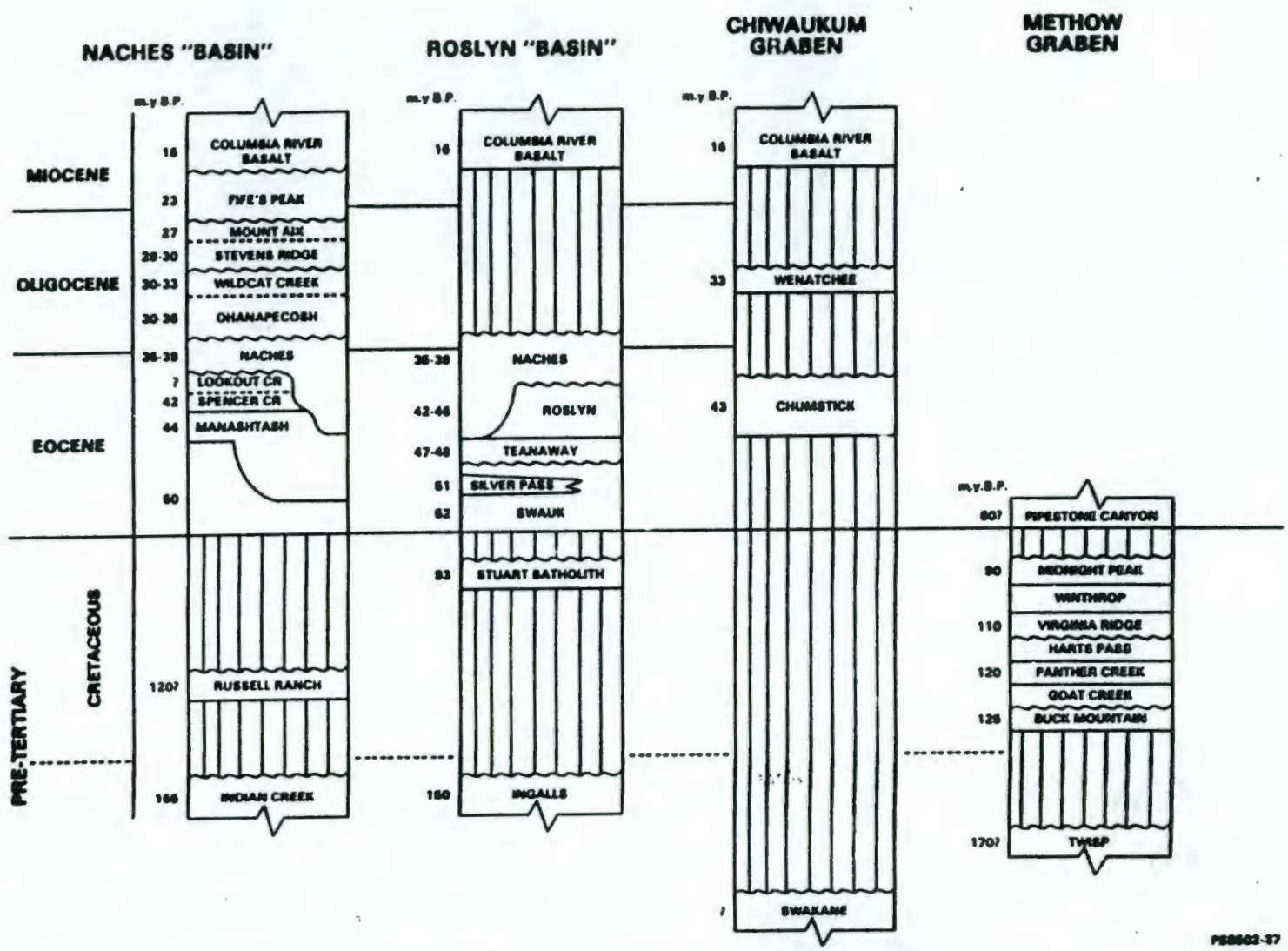

Figure 2. Stratigraphic Correlation of Rock Units Found Along the Basalt Margin and in the Methow Graben. (Information is modified from data by Tabor et al. (1982, 1984), Gresens (1983), Schreiber (1981), Walker (1980), and Barksdale (1975)).

Table 2. Stratigraphic Description of Rock Units. (Information is modified from data by Tabor et al. (1982, 1984), Gresens (1983), Frizzel (1979), Schreiber (1981), and Hammond et al. (1977)).

NACHES "BASIN"

	NAME	AGE (m.y.B.P.)	MAXIMUM THICKNESS (ft)	DESCRIPTION
"TEKOSKUS VOLCANICS"	FIFES PEAK FORMATION	23	2,500	ANDESITE FLOWS, BRECCIAS, AND TUFF
	MOUNT AIX VOLCANICS	27	1,500+	INTERBEDDED ANDESITES, RHYOLITES, DACITES, AND TUFFS PROBABLY AGE EQUIVALENT TO STEVENS RIDGE FORMATION
	STEVENS RIDGE FORMATION	28-30	4,000	LITHIC ASH FLOW TUFFS, LAHARS, AND VOLCANICLASTICS, A FEW ANDESITE FLOWS
	WILDCAT CREEK SEDIMENTS	30-33	500+	GREEN VIOLET VOLCANICLASTICS AND ANDESITE SANDSTONES PROBABLY AGE EQUIVALENT TO UPPER OHANAPECOSH FORMATION
	OHANA PECOSH FORMATION	30-36	18,000	ANDESITE FLOWS, TUFFS, BRECCIAS, AND VOLCANICLASTICS. MAY INCLUDE WILDCAT CREEK SEDIMENTS
PUGET GROUP	NACHES FORMATION	36-39 AND 44	8,000+	RHYOLITE, ANDESITE, AND BASALT FLOWS INTERBEDDED WITH SANDSTONE AND TUFF
	LOOKOUT CREEK SANDSTONE	?	600	LITHIC AND QUARTZ RICH SANDSTONE AND MINOR SHALE MAY BE AGE EQUIVALENT WITH SPENCER CREEK SEDIMENTS
	SPENCER CREEK SEDIMENTS	42	660+	INTERBEDDED GRAYWACKE, SANDSTONE, TUFF, AND SHALE
	MANASH TASH FORMATION	44 AND 50	3,000/	FLUVIAL QUARTZ RICH SANDSTONE, SHALE, CONGLOMERATE, AND MINOR COALS. PROBABLY AGE EQUIVALENT TO UPPER SCHAIR FORMATION
	RUSSELL RANCH FORMATION	120/	5,000/	INTERBEDDED ARGILLITE, GREENSTONE, AND GRAYWACKE. SOME CONGLOMERATE
	SCHAN CREEK GNEISS	156	UNKNOWN	GNEISS ORTHOGNEISS, AND AMPHIBOLITE

ROSLYN "BASIN"

NAME	AGE (m.y.B.P.)	MAXIMUM THICKNESS (ft)	DESCRIPTION
NACHES FORMATION	36-39 AND 44	8,000+	RHYOLITE, ANDESITE, AND BASALT FLOWS INTERBEDDED WITH SANDSTONE AND TUFF.
ROSLYN FORMATION	42-46	8,000	FLUVIAL ARKOSIC AND TUFFACEOUS SANDSTONE, SILTSTONE, AND SHALE WITH NUMEROUS COAL BEDS.
TEANAWAY "BASALT" FORMATION	47-48	8,000+	BASALT FLOWS AND DIKES WITH ABUNDANT WELDED TUFFS AND VOLCANICLASTICS
SILVER PASS / SWAUK FORMATION	51-52	10,000+	FLUVIAL ARKOSIC SANDSTONE WITH INTERBEDDED BLACK SHALE AND CONGLOMERATE. SILVER PASS = GREEN ANDESITIC LAVAS AND TUFF
STUART BATHOLITH	93	-	GRANODIORITE AND QUARTZ DIORITE
INGALLS COMPLEX	150	UNKNOWN	CALC SILICATES, AMPHIBOLITES, SERPENTINITE, AND SCHIST

CHIWAUKUM GRABEN

NAME	AGE (m.y.B.P.)	MAXIMUM THICKNESS (ft)	DESCRIPTION
WENATCHEE FORMATION	33	[illegible]	QUARTZ RICH FLUVIAL SANDSTONE AND SHALE
CHUMSTICK FORMATION	43	19,000/	FLUVIAL ARCACTOVS SANDSTONE WITH INTERBEDDED CONGLOMERATE AND SHALE
SWAKANE GNEISS	?	-	BIOTITE GNEISS

METHOW GRABEN

NAME	AGE (m.y.B.P.)	MAXIMUM THICKNESS (ft)	DESCRIPTION
PIPESTONE CANYON FORMATION	60	2,300	NONMARINE CONGLOMERATE WITH MINOR ARKOSE AND SHALE.
MIDNIGHT PEAK FORMATION	80	10,400	NONMARINE ANDESITIC SANDSTONE, T[illegible], BRECCIAS, AND MINOR FLOWS.
WINTHROP SANDSTONE	100/	13,500	NONMARINE MASSIVE ARKOSE SANDSTONE AND SHALE.
VIRGINIA RIDGE FORMATION	110	11,000	MARINE BLACK SHALE AND SILTSTONE WITH INTERBEDDED CHERTY SANDSTONE AND CONGLOMERATE.
HARTS PASS FORMATION	115	7,000	MARINE MASSIVE ARKOSIC SANDSTONE WITH MINOR BLACK SHALE INCREASING TOWARD BASE.
PANTHER CREEK FORMATION	120	5,300	MARINE BLACK SHALE WITH MINOR CONGLOMERATE AND ARKOSE
GOAT CREEK FORMATION	120/	5,100	MARINE (?) ARKOSIC SANDSTONE AND ARGILLITIC SHALE.
BUCK MOUNTAIN FORMATION	130	14,500	ANDESITE BRECCIAS AND VOLCANICLASTIC ROCKS PLUS MINOR ANDESITE FLOWS INTERBEDDED WITH MARINE SANDSTONE AND BLACK SHALE
TWISP FORMATION	170/	4,000+	ARGILLITE AND BLACK SHALE.

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Cap Rocks

The Columbia River basalt is considered to be a seal to upward migration of gases and liquids from rock below the basalt. Hydrologic studies at the Hanford Site indicate that some lava flows are extremely impermeable even under high pressure. Further evidence is the relatively high pressures and strong gas kicks recorded at the base of the basalt in the 1-33 and 2-33 Yakima Minerals wells. Interbeds only a few hundred feet uphole contained almost no gas. Nonetheless, some leakage must occur over long periods of time. One possible source of the gas in shallow water wells throughout the northwest Columbia Basin may be upward migration through the basalt. If so, escape of gas through the basalt must occur at an extremely slow rate.

Other rock seals must exist below the Columbia River basalt because Shell obtained and tested gas from several lower zones in the 1-33 Yakima Minerals well. Possible rock seals include sills and flows of the Teanaway basalt, welded tuffs in the Ohanapecosh Formation, and shales in the Swauk and Roslyn Formations (see fig. 2 and table 2).

Traps

Structural, rather than stratigraphic, traps have always received first priority during initial exploration of undrilled basins. This is especially true in the Columbia Basin where seismic techniques will not penetrate the basalt and magnetotelluric data give only general approximations for the thickness of the sediments under the basalt. Although the structure of the underlying sediments may differ from that of the basalt, surface anticlines are the obvious first choice in any exploration effort.

Shell drilled its first four wells on relatively simple anticlines away from thrust faults or other complex structures. The sites are folds with western closure and align with Tertiary basins that project southeastward under the Yakima Fold Belt. Plate 1 shows the positions of these folds with respect to margin geology. These sites were probably chosen to ensure a thick sedimentary sequence under the anticlines and to limit the influx of volcaniclastics from the Cascades to the west. In addition, these sites appear to avoid possible complex faulting along basin (graben) margins.

A second consideration may have been an attempt to sample the geology on both sides and on top of a major, pre-basalt high--the Naneum Ridge-Hog Ranch high uplift (see plate 1). This structure begins northwest of the basalt margin and includes the Leavenworth fault system in the Swauk Pass-Wenatchee area. Here, pre-Tertiary basement rocks and Tertiary sediments are fault-elevated in a southeast trending ridge system. The fault and ridge system passes under the Columbia River basalt forming the Naneum Ridge anticline. This fold turns south and, at the surface, becomes a cross fold running through Whiskey Dick, Manashtash, Umtanum, and Yakima Ridges where it apparently ends just beyond Rattlesnake Ridge (plate 1).

The Shell 1-33 and 2-33 Yakima Minerals wells tested the pre-Columbia River basalt rocks west of, the 1-29 Bissa rocks on top of, and the 1-9 BN Saddle Mountain well rocks east of the postulated pre-basalt structure. The 1-33 and 1-9 wells present additional advantage of testing for possible stratigraphic pinchouts against the high, while the 1-29 tested for long-distance migration of hydrocarbons upward onto the crest of the cross-structure (fig. 3).

STRATIGRAPHIC RELATIONSHIPS

REGIONAL STRATIGRAPHY

Pre-basalt rocks that crop out along the Columbia River basalt margin are known in moderate detail. Tabor et al. (1982, 1984), Gresens (1983), Walker (1980), and Barksdale (1975) describe these rocks and include discussions from all previous investigations. Detailed discussion of these rocks is beyond the scope of this report, but the sedimentary rocks adjoining the basalt margin can be fitted into three distinctive tectonic and depositional depressions: the Naches River "basin" containing primarily volcaniclastics derived from Cascade Range andesitic rocks, the Roslyn "basin" (Teanaway River block of Tabor et al., 1984) containing primarily deltaic fluvial sediments, and the Chiwauckum graben filled with locally derived fluvial sandstones and shales. The "basins" are separated by fault-bounded highs that contain thinner sections of Tertiary sediments and exposed pre-Tertiary rocks (Tabor et al. 1982, 1984). A fourth area, the Methow graben, while further removed from the basalt margin, contains the closest known surface exposures of Cretaceous marine rocks. A correlation chart for the above areas and a brief stratigraphic description of each rock unit are given in figure 2 and table 2, respectively.

It is important to recognize that Tertiary fluvial sediments associated with the basin margin are very difficult to distinguish in field and hand specimens. Correlation and separation of these rocks is usually made on gross features over large areas, by dating of tuffs, and by stratigraphic position. Detailed sedimentalogical analysis and thin-section work is sometimes helpful. Therefore, correlation between well localities, as discussed below, involves a certain amount of speculation.

WELL SITE STRATIGRAPHY

Mud logs and various wire-line logs are available for the 1-33 and 2-33 Yakima Minerals and the 1-29 Bissa wells, but little or no information has been released for the 1-A Moses Lake and 1-9 BN Saddle Mountains wells. Table 3 contains the formation picks for these wells and figure 4 gives more detailed stratigraphic descriptions for wells that penetrate the basalt (comments for each well are given below).

Correlation of individual sedimentary units between the 1-33 Yakima Minerals and 1-29 Bissa wells, using wire-line logs, is extremely difficult. This was expected because fluvial and deltaic sediments change lithologies laterally over very short distances. Final correlation was made using a combination of wire-line and mud logs and by matching coal-bearing sediments between wells (fig. 5). Radiometric dates on tuffs encountered in the wells would aid in correlation, but these have not been released by Shell.

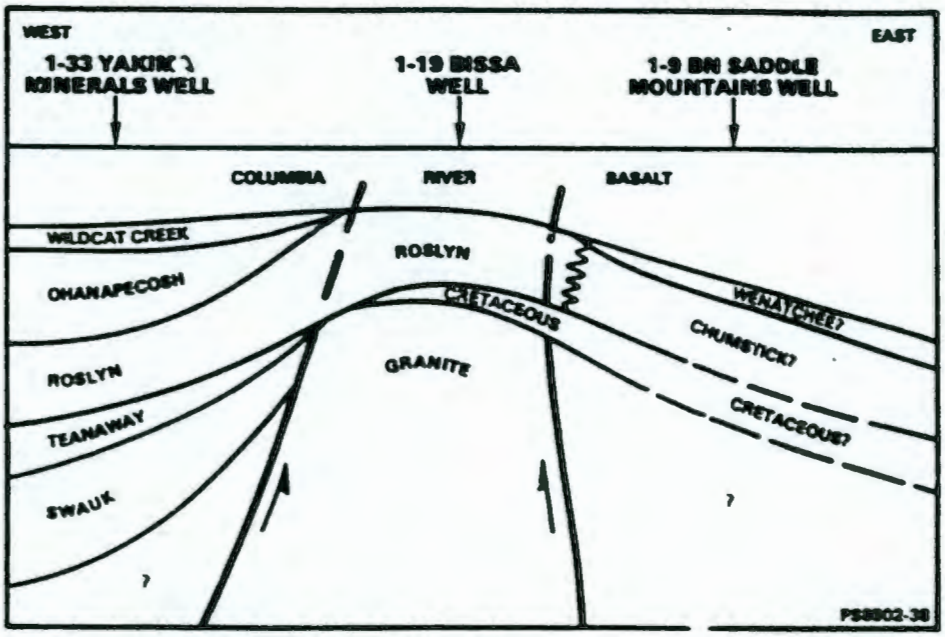

Figure 3. Sketch Across the Naneum High Before the Uplift of the Columbia River Basalt.

Table 3. Rock Units Cut by Deep Wells in the North Western Columbia Basin.

Depth (ft)	Rock unit	Depth (ft)	Rock unit
1-33 Yakima Minerals Well		**1-29 Bissa Well**	
0	CRB	0	CRB
4,930	Wildcat Creek	4,570	Roslyn
6,610	Ohanapecosh	13,610	Cretaceous
9,776	Roslyn	14,900	Granite
13,278	Teanaway	14,960	
13,980	Swauk	**1-A Moses Lake Well**	
15,728	Shear Zone (?)	0	CRB
16,080	Swauk	6,979	
16,190			
2-33 Yakima Minerals Well		**1-9 BN Saddle Mountain Well**	
0	CRB	0	CRB
4,940	Wildcat Creek	11,485 (?)	Sediments
5,604		15,000 (?)	

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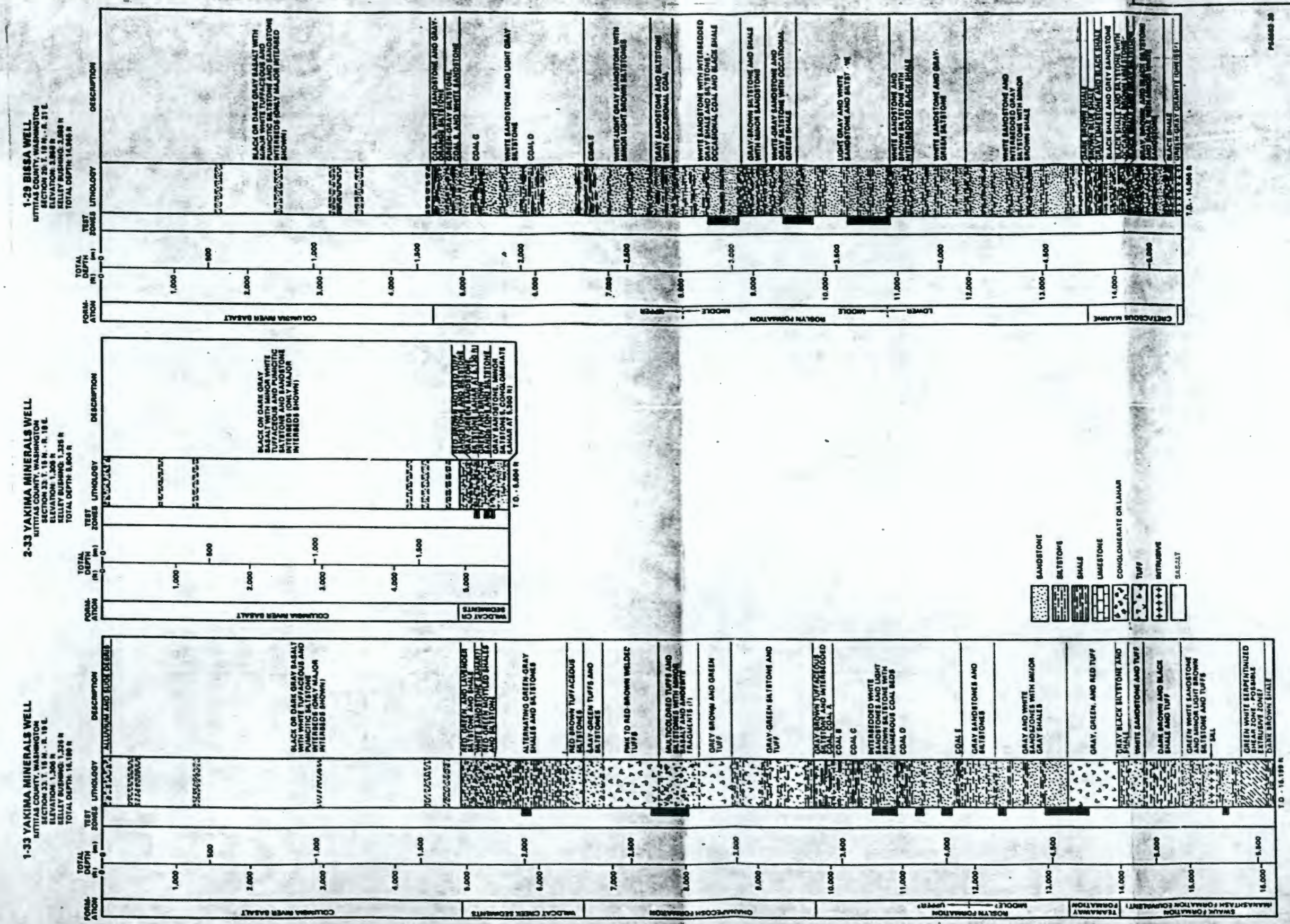

Figure 4. Borehole Stratigraphy and Lithologic Description for the 1-33 and 2-33 Yakima Minerals and 1-29 Bissa Wells.

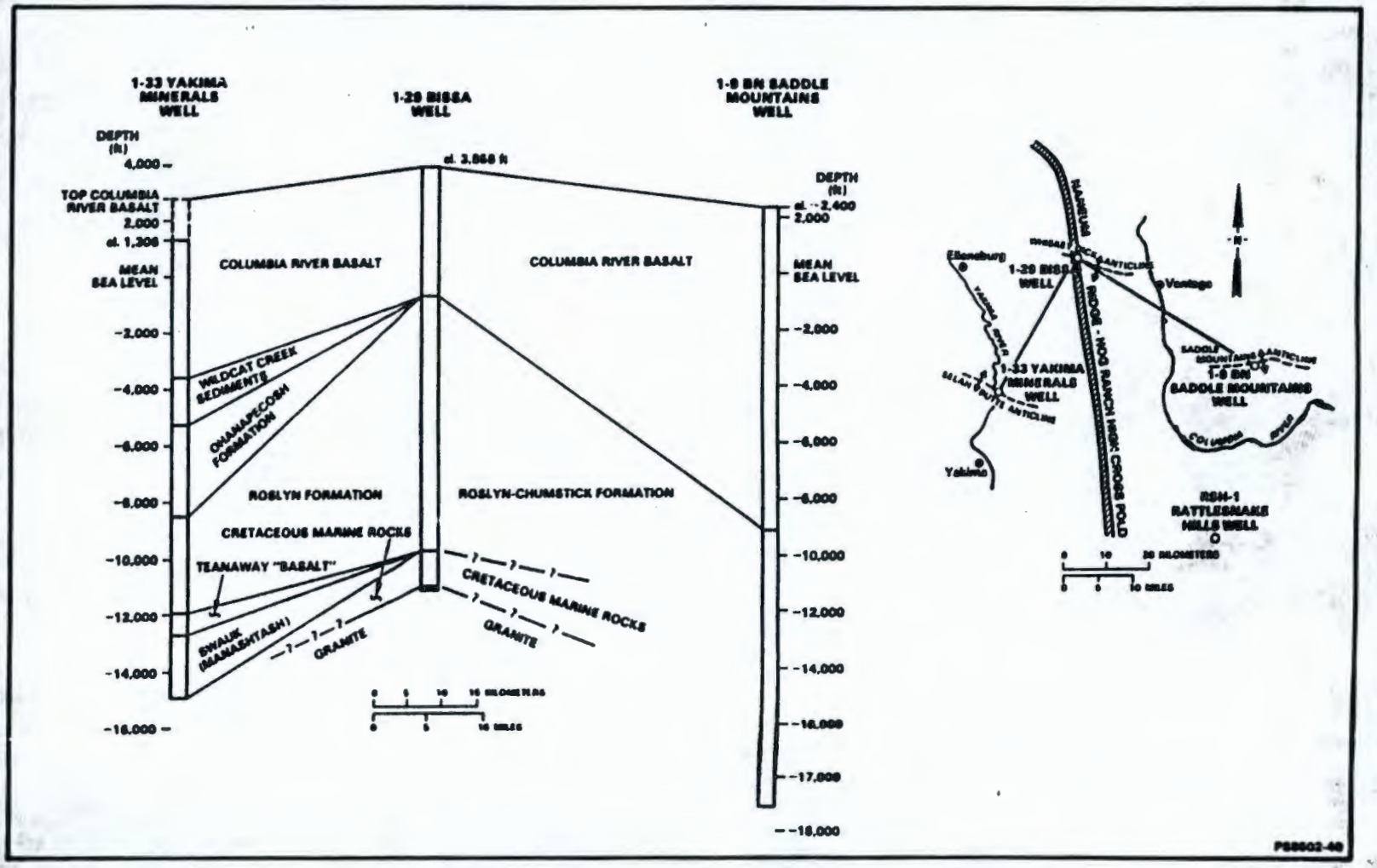

Figure 5. Diagrammatic Cross-Section Through the 1-33, 1-29, and 1-9 Wells.

1-33 Yakima Minerals Well

Shell bypassed approximately 1,500 ft of basalt by drilling in the Yakima River Canyon; the overall basalt thickness there is about 6,000 ft. Several thick interbeds were encountered near the base of the basalt that should be included as part of the Ellensburg Formation. One or two mudflows were penetrated directly beneath the basalt. These may belong to the Ellensburg Formation, but are included here with the Wildcat Creek sediments because they interfinger with lavender and red shales common to Wildcat Creek rocks.

No Wenatchee Formation rocks are thought to exist in the 1-33 Yakima Minerals well. Wildcat Creek sediments are approximately the same age, are more tuffaceous, and exhibit distinctive green-red-lavender mottling. Surprisingly, the Ohanapecosh Formation (related to Cascade volcanism) extends eastward to the 1-33 well. The closest surface outcrops of these volcaniclastics are 25 mi to the west.

The Roslyn Formation contains a large number of coal beds, more than those exposed at the surface at Cle Elum but less than encountered during core drilling of the Roslyn coal field. This report divides the coals into five groups, A through E, for use in correlation between well sites. On the basis of studies performed by Walker (1980), only the upper and part of the middle Roslyn is present in the well.

The Teanaway "basalt" (now called Teanaway Formation by Tabor et al. 1984) is present but no basalt flows are encountered in the well. The type Teanaway contains only 10% lava; what remains is tuff, breccia, and other pyroclastics.

The Swauk Formation is encountered at 13,980 ft and the well probably bottoms in this formation. A greenish-white serpentinized zone, probably part of a shear zone typical of those found in Manashtash rocks to the west around Manashtash Creek, is found between 15,728 and 16,000 ft. The Manashtash Formation is considered by Tabor et al. (1984) and by Walker (1980) as age-equivalent to the Swauk Formation. The shears (Walker 1984; Tabor et al. 1984) are associated with a series of pre-basalt fault zones that trend southwesterly toward the Columbia Basin center. The shear encountered in the 1-33 Yakima Minerals well suggests that one pre-basalt structure might extend 30 mi under the Yakima Fold Belt. However, the relationship between this shear and the overlying Selah Butte anticline is unknown. It also is unclear whether this shear aligns with those mapped along the basalt margin as part of the Cle-Elum-Wallula-Lineament (CLEW)-Straight Creek Splay System (Tabor et al. 1984).

2-33 Yakima Minerals Well

The 2-33 Yakima Minerals well is drilled only a few hundred feet from the 1-33 Yakima Minerals well and, as expected, correlates almost exactly. Mudflows are more abundant in this well. One lahar contains cobbles nearly 2 in. in size. The well bottoms in Wildcat Creek sediments.

1-29 Bissa Well

The 1-29 Bissa well passes from Columbia River basalt directly into Roslyn Formation, confirming a pre-basalt high aligned with the Naneum Ridge cross-structure. Based on the correlation shown in figure 5, this well contains 9,040 ft of Roslyn Formation with no Swauk Formation present. Walker (1980) indicates the thickness of the Roslyn Formation in the Cle Elum area is nearly 9,000 ft. In contrast, Bentley (1983) assigns a Roslyn Formation thickness of 3,800 ft, placing the Roslyn-Swauk contact at 8,400 ft in the well. This report maintains that the entire section is Roslyn Formation and that the Swauk Formation is missing for the following reasons.

1. No Teanaway Formation is present.
2. Black shales common in surface Swauk Formation are absent.
3. Sandstones are cleaner and more quartz-rich than typical Swauk sandstone.
4. The total thickness approximately matches that of Walker's Roslyn Formation at Cle Elum.
5. Wire-line logs between the Swauk Formation in the 1-33 Yakima Minerals well and sediments in the 1-29 Bissa well show absolutely no correlation. (This is, however, often the case in fluvial sediments.)

In keeping with the concept of a pre-basalt high, it is tempting to interpret the lower Roslyn Formation as Swauk Formation (a slight increase of dark shale does occur at approximately 8,840 ft), but available evidence does not justify this interpretation. However, even using a 9,040-ft thickness, the base of the Roslyn Formation in the 1-29 Bissa well is more than 2,000 ft higher than in the 1-33 Yakima Minerals well.

The five coal units indicated in the 1-33 Yakima Minerals well correlate reasonably well with the 1-29 Bissa well (see fig. 4). On this and other gross characteristics the Roslyn Formation is divided into lower, middle, and upper members.

Marine rocks thought to be Cretaceous in age were encountered by the 1-29 Bissa well. Dark brown and black shales containing a few thin limestones and ore sandstone occur from 13,610 to 14,900 ft. While the Mesozoic Ingalls metamorphic complex crops out 25 mi to the northwest, the closest Cretaceous marine rocks are in the Methow graben far to the north.

Below the marine sequence, the well bottoms in granitics. It is unclear whether these rocks are related to either the Stuart batholith or the granitic megaconglomerate at Mission Ridge near Wenatchee.

1-A Moses Lake Well

Drilling of the Snowbird Resources 1-A Moses Lake well is presently suspended at a depth of 6,979 ft awaiting financial backing to continue drilling operations. Little information is available on this well, but the owners have indicated that the well is still in Columbia River basalt.

1-9 BN Saddle Mountains Well

Although very little data are available, local newspapers have indicated that the Columbia River basalt is 11,485 ft thick. The well encounted sediments of unknown age to at least 15,000 ft.

Shell completed drilling the 1-9 BN Saddle Mountains well after reaching a depth of 17,518 ft. The well was tested extensively for several months as a gas producer but was pronounced noncommercial and abandoned in October 1984. Wire-line and mud logs for this well will not be available until March 1986.

TESTING PROCEDURES

This section describes tests and analyses run either during or after drilling operations to detect hydrocarbons. Discussion of the test results of each well follows this general description.

TESTS CONDUCTED DURING DRILLING OPERATIONS

Mud Logging

Mud logging provides information about potential hydrocarbon-bearing formations without interrupting routine drilling. The procedure is to examine the drilling mud and well cuttings, which provide an accurate log of drilling time. Logging equipment includes a gas detection system, a gas chromatograph, an ultraviolet viewer, and cleaning equipment for cuttings.

Gas Monitoring

The gas detection system contains a trap near the mud flow line that is used to sample mud as it reaches the surface. In the trap, mud passes over hot filaments. (Shell's mud logs call it the hot wire.) Gas readings, recorded on a strip chart, are shown as gas and air concentration units where 30 units = 1% gas in air. Because of changes in mud type and sampling methods from well to well, however, gas shows in one well usually cannot be related to those in another well (or formation); that is, correlation by gas kicks is not possible. The graph for a typical gas kick due to formation gas in the 1-33 Yakima Minerals well is displayed in figure 6.

The gas chromatograph measures the mud gas content by analyzing the gas from a specific volume of mud. The sample is usually collected by injecting steam into the mud to drive out the hydrocarbons. After the sample is collected, it is placed in the chromatograph that splits the gas into five fractions: C1, methane; C2, ethane; C3, propane; C4, butane; and C5, all heavier gases. The gases are shown separately on a strip chart so that the relative increase of each gas can be detected. Strong kicks are recorded in parts per million and compared to a calibrated background gas content to give a comparison between zones (fig. 7). Toxic gas such as hydrogen sulfide may also be monitored; all excess gas escaping from the mud or formation is flared during drilling. The chromatograph can also be used for advanced techniques such as determining shale density and water-oil contacts, which are not discussed here.

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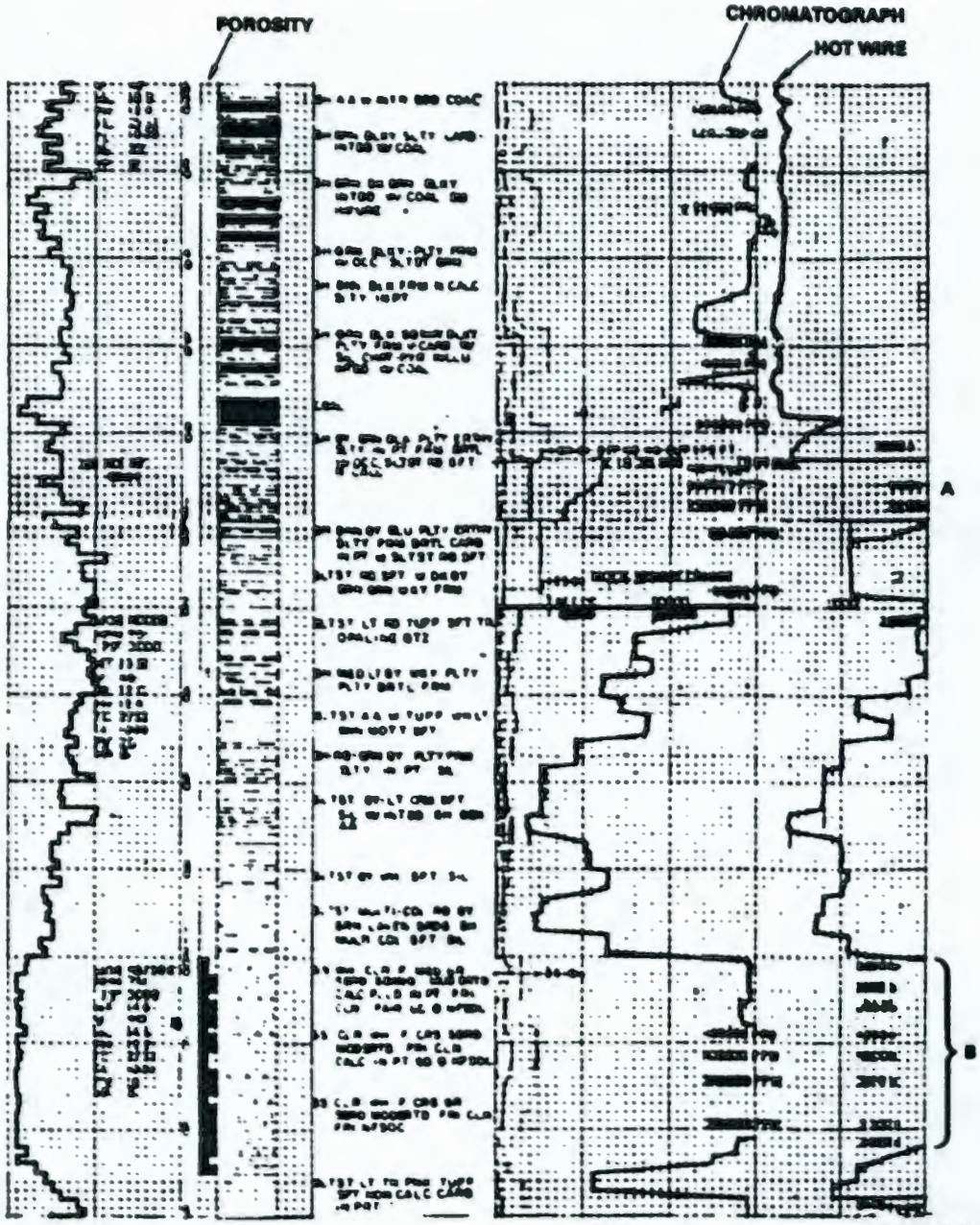

Figure 6. Typical Mud Log Gas Kicks in the Shell 1-33 Well.

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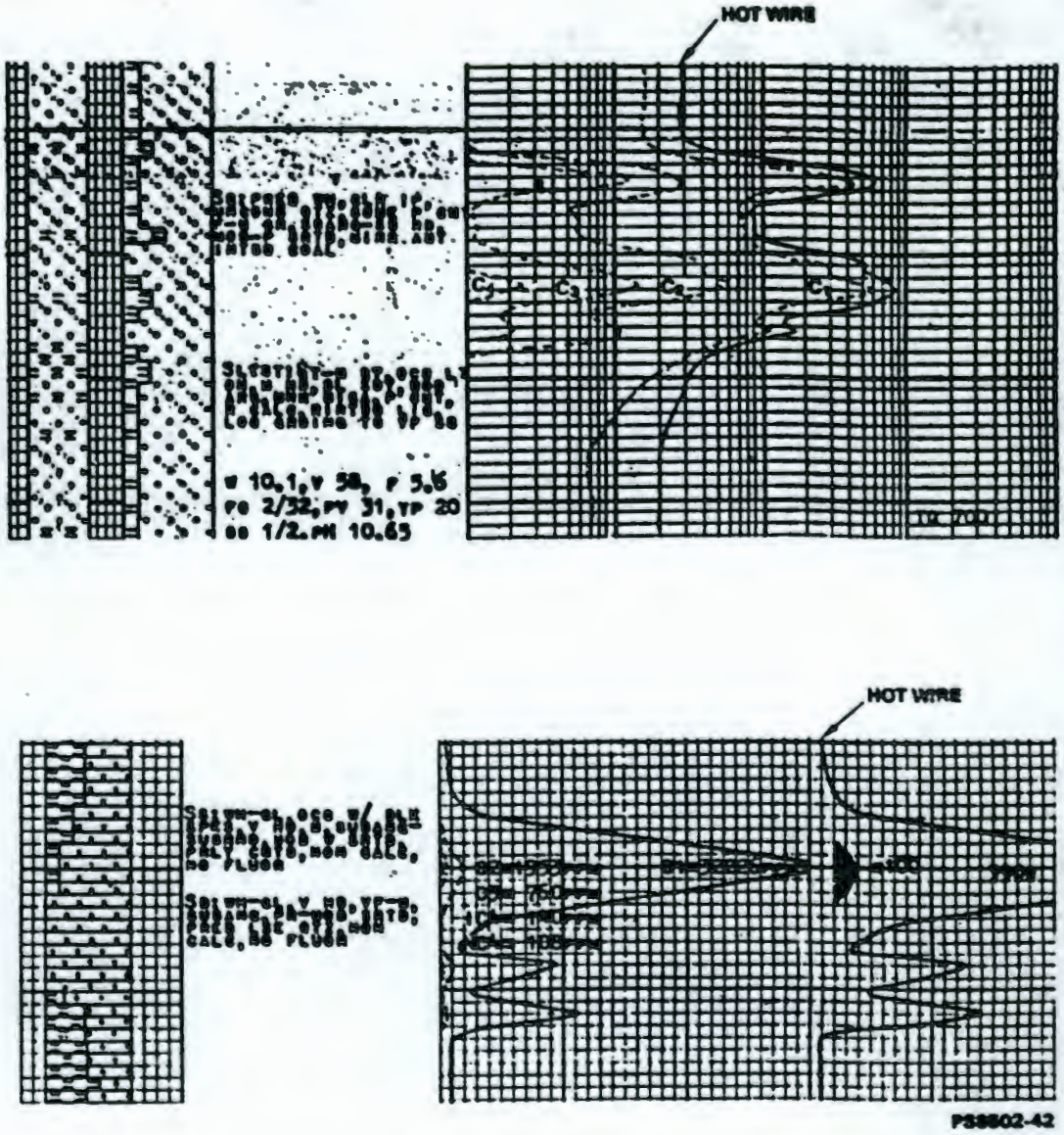

Figure 7. Typical Mud Log Gas "Kick" Showing Split of Gas Types by the Chromatograph, 1-29 Well.

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The well logs show a number of smaller kicks variously labeled connection (conn) gas and trip gas. Connection gas, formed when a section of pipe is added to the drill stem, can be used as a tool to estimate formation pressure. When a gas kick occurs during a connection, it is because exposed formations are releasing gas into the borehole due to reduced bottom hole pressure. Small kicks are expected, but large kicks indicate that an increase in mud density is required before continuing drilling. Figure 8 shows examples of conn and trip gas in the 1-33 Yakima Minerals.

Trip gas occurs when the drill string is pulled from the hole; the swabbing effect of the moving drill string pulls gas into the hole, creating increased gas shows in the mud log.

Cuttings Analysis

Cuttings are retrieved from the shale shaker at specific intervals (2 ft in Shell wells) to be washed and identified. Part of the cuttings are described at the well site (the logs released by Shell) and the rest is shipped back to headquarters for a detailed analysis. The remaining samples are identified as to rock type, color, texture, grain size, cement, and porosity. Each sample is plotted on the mud log using industry-wide standard symbols and abbreviations (fig. 9). A common problem occurs with downhole cave-ins that contaminate the sample and mask new formations. Some operators run a continuous sand-shale ratio to aid in separating units in very soft rock formations.

The samples are examined under an ultraviolet lamp. Hydrocarbons are separated from any fluorescing minerals by leaching the cuttings with a solvent. If the solvent also fluoresces, oil is present in the cuttings. Fluorescence from grease and lubricants used in drilling rig maintenance can give false shows; comparing grease samples taken from the rig will help avoid an error.

TESTING CONDUCTED AFTER DRILLING COMPLETION

Formation Testing

Formation (or drill stem) testing can be performed either before completion of drilling or after casing is set. In the first three wells, most of the testing was done after the drilling was complete and the wells were cased. In a typical test, the casing is perforated at a desired interval and the zone sealed off by packers or plugs, allowing fluids and gases to enter the well bore (or tubing). Flow rates and pressures are monitored through a choke at the surface (24/64 in. in the Shell wells). If gas is encountered, standard procedure is to flare the gas to prevent explosive conditions and eliminate toxic gas.

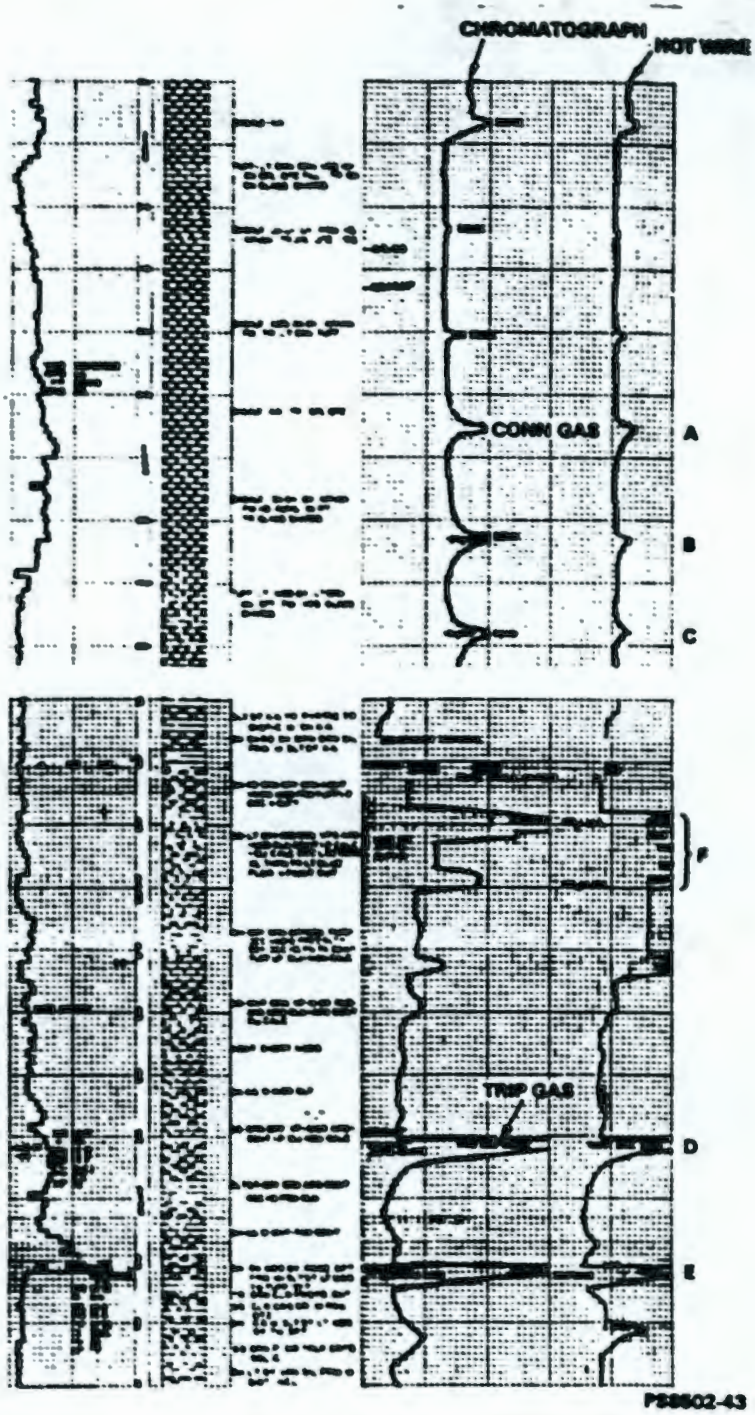

Figure 8. Examples of Conn and Trip Gas in the 1-33 Well.

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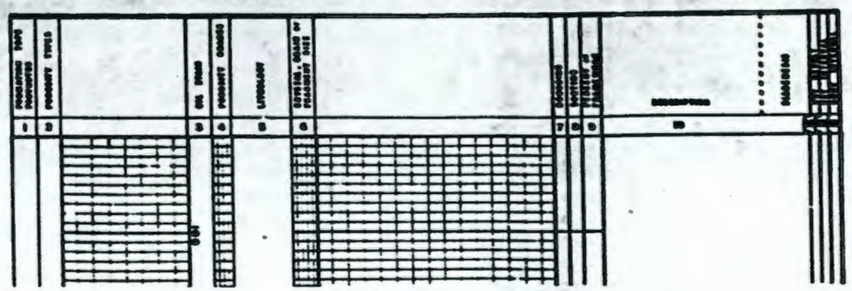
LITHOLOGIC SYMBOLS AND COMMON ABBREVIATIONS

LOG FORM



COLUMN 1

FORMATION TOPS — Abo

FOOTNOTES — 1

FAULTS — Normal; Reverse; Overturned strata

COLUMN 2

POROSITY TYPES

- I INTERCRYSTALLINE, INTERGRANULAR, INTERFRAGMENTAL
- O ORGANIC-bridged, intraskeletal
- ◊ INTEROOLITIC, INTERPELLETOID
- F FRACTURE
- V VUGGY-voids greater than 1/16mm
- ○ EARTHY-low permeability, erratic less than 1/16mm
- P PINPOINT-voids less than 1/16mm
- ▯ FENESTRAL-voids from gas bubbles, shrinkage cracks & birdseye texture
- J MOLDIC

COLUMN 3

OIL SHOWS

STAIN PRESENT

- Even staining, fluorescence in solvent
- Spotted staining, fluorescence in solvent
- Dead, asphaltic, bitumen, etc.
- Questionable, no fluorescence in solvent

NO STAIN PRESENT

- Oil sand (from production data)
- Gas sand (from production data)

COLUMN 4

POROSITY GRADES

FOUR DIVISIONS — bright to total

Division 1 3% — 6% Poor porosity with low permeability

Division 2 6% — 12% Fair porosity

Division 3 12% — 20% Good porosity

Division 4 OVER 20% Excellent porosity

COLUMN 5

ROCK TYPE

BRECCIA
CONGLOMERATE
SANDSTONE
SILTSTONE
SHALE, gray
SHALE, black
SHALE, colored
LIMESTONE, gray
LIMESTONE, colored
DENSTONE
CHERT, bedded
MARLSTONE, calcareous
LIMESTONE, mudsupported (FW < 1)
LIMESTONE, grainsupported (FW 1 or >)
MARLSTONE, dolomitic
DOLOMITE
INCOGNITE, LIMONITE, or HEMATITE
ANHYDRITE, primary
ANHYDRITE, secondary
GYPSUM
SALT
COAL, pure and interbedded
GLACIAL TILL
TUFFACEOUS SANDSTONE, basic
TUFFACEOUS SANDSTONE, acidic
TUFF
WELDED TUFF
METAMORPHIC

ACCESSORIES

1 symbol=10% or 20%
2 symbols=20% or 40%
3 symbols=60%

SANDY
SANDSTONE, stringers
SILTY
SILTSTONE, stringers
PEBBLES > 2 mm.
SAND GRAINS > 1 to 2 mm.
ARGILLITE GRAINS
FELDSPAR
BRECCIA, fragment
SILICEOUS
CHERT, light and dark
CHERT, translucent
ARGILLACEOUS
SHALE, laminae
CARBONACEOUS FLAKES
COAL, thin beds
CEMENTING DIFFERENCES SUBSTANCE
CALCAREOUS
MARLSTONE, stringers- calc.
LIMESTONE, stringers
DOLOMITIC
MARLSTONE, stringers-dol.
DOLOMITE, stringers
ANHYDRITIC
ANHYDRITE, stringers
GYPSIFEROUS
GYPSUM, stringers
SALT CAST or INFILL
PHOSPHATE PELLETS
FERRUGINOUS GRAINS or PELLETS
FERRUGINOUS
FERRUGINOUS, stringers
NODULES
TUFFACEOUS

SYMBOLS USED FOR SIGNIFICANT OCCURRENCES (Only to less than 10%)

HEAVY, DARK MINERALS
GLAUCONITE
DENTONITE
PYRITE
KAOLIN
PLANT SPORES
PLANT DEBRIS
FISH DEBRIS
MINERAL CRYSTALS

ROCK BUILDERS

FW=20%
1 symbol=20 to 30%

2 symbols=40 to 70%
3 symbols=70 to 100%

ORGANIC

FORAMINIFERA
CANNON
PELECYPOD
BIOCLASTIC or FRAGMENTAL
AMPHIPORA
CORAL
STROMATOPOROID
BRYOZOA
BRACHIOPOD
OSTRACOD
CEPHALOPOD
GASTROPOD
SCAPHOPOD
BELEMNITE
ECHINOID
FOSSILS < 20%

ORGANIC or NON ORGANIC

OOLITES
PISOLITE 2mm. or over
PSEUDO OOLITES or PELLETS
INTRACLASTS

FRAMEWORK ALGAE

SKELETAL
BYTOID

NON-FRAMEWORK ALGAE

NON-DESCRIPT
LAMINATED

MISCELLANEOUS

KARST TOPOGRAPHY
NO SAMPLES
CANNOT INTERPRET, caving etc.
QUESTIONABLE INTERPRETATION

TEXTURES

EARTHY
CHALKY
LITHOGRAPHIC
CRYPTOCRYSTALLINE

COLUMN 6

CRYSTAL, GRAIN or FRAGMENT SIZE

FIVE DIVISIONS left to right WENTWORTH SCALE

Division 1 .004mm — .0625mm Silt

Division 2 .0625mm — .125mm Very fine

Division 3 .125mm — .250mm Fine

Division 4 .250mm — .500mm Medium

Division 5 .500mm — 2.000mm Coarse

COLUMN 7

ROUNDING

- A ANGULAR
- R ROUNDED
- a SUBANGULAR
- r SUBROUNDED

COLUMN 8

SORTING

- W WELL — 1 or 2 oloogrodes
- M MEDIUM — 3 or 4 oloogrodes
- P POOR — 5 or more oloogrodes

COLUMN 9

FRAMEWORK

FRAMEWORK IS A RATIO BETWEEN CLASTIC MATERIAL OVER 1/16mm AND PRIMARY VOID FILLER OR MATERIAL 1/16mm AND LESS. ORGANIC DEPOSITS (fossils) ARE CONSIDERED AS FRAMEWORK WHETHER GROWING IN PLACE OR TRANSPORTED.

0	0 to 5%	5	50%	C	100%
1	10%	6	60%	?0	QUESTIONABLE INTERPRETATION
2	20%	7	70%		
3	30%	8	80%	?	UNINTERPRETABLE
4	40%	9	90%		

COLUMN 10

DESCRIPTION

USED FOR INFORMATION THAT CANNOT BE PRESENTED IN COLUMNS 1 THROUGH 9, E.G. COLOR, SPECIFIC FOSSIL IDENTIFICATION, OBSERVATIONS ON BEDDING, INDURATION, HARDNESS, STRUCTURE, ETC.

DESCRIPTIVE TERMS ARE ABBREVIATED. (see abbreviation list)

DIAGENESIS To the right of written description

TYPE

M	METASOMATISM		SECONDARY CEMENTATION
D	DOLOMITIZATION	A	ANHYDRITE
R	RECRYSTALLIZATION	S	SILICA
F	FRACTURING	K	KAOLIN
L	LEACHING	C	CARBONATE and OTHERS

DEGREE

1	10%	5	50%	9	90%
2	20%	6	60%	C	100%
3	30%	7	70%	?	Uninterpretable
4	40%	8	80%		

COLUMN 11

DRILL STEM & WIRELINE TEST RESULTS

- GAS RECOVERY
- OIL RECOVERY
- WATER RECOVERY
- GAS, OIL & WATER RECOVERY

COLUMN 12

DRILL STEM & WIRELINE TEST INTERVALS

- DRILL STEM TEST INTERVAL
- WIRELINE TESTED ZONE

COLUMN 13

CORED INTERVALS

- CORED INTERVAL
- SIDEWALL CORE

PS8502-44

Figure 9. Example Chart of Symbols Used in Well Log Analysis. (sheet 1 of 2)

COMMON ABBREVIATIONS

@	At
abnt	Abundant
abv	Above
acic	Acicular
aft	After
aglm	Agglomerate
Alg	Algae (al)
alt	Altered (ing)
amb	Amber
amor	Amorphous
Amph	Amphibole
amt	Amount
ang	Angular
anhed	Anhedral
anhy	Anhydrite (ic)
app	Appear
apr	Apparent
aprox	Approximate (ly)
arg	Argillaceous
argl	Argillite
ark	Arkose (ic)
asph	Asphalt (ic)
bar	Barite (ic)
bcm	Become (ing)
bd	Bed
bdd	Bedded
bdeye	Birdseye
bdg	Bedding
Belm	Belemnites
bent	Bentonite (ic)
bf	Buff
biocl	Bioclastic
biot	Biotite
bioturb	Bioturbated
blt	Bitumen (inous)
bl	Blue (ish)
bldr	Boulder (256 mm +)
blk	Black
blky	Blocky
bnd	Band (ed)
boudg	Boudinage
Brac	Brachiopod
brhg	Branching
broc	Breccia (ted)
bri	Bright
brit	Brittle
brd	Bored
brn	Brown
Bry	Bryozoa
bulb	Bulbous
bur	Burrowed
c	Coarse (ly)
¢	Core
calc	Calcite (areous)
carb	Carbonaceous
Casph	Calcisphaera
cbl	Cobble (64-256 mm)
Ceph	Cephalopod
cgl	Conglomerate
Chaet	Chaetetes
chal	Chalcedony
Chara	Charophytes
chit	Chitin (ous)
chk	Chalk (y)
chlor	Chlorite
cht	Chert
chty	Charty
Chtz	Chitinozoa
cl	Clastic
cln	Clean
clr	Clear
clus	Cluster
cly	Clay (ey)
clyst	Claystone
cmt	Cement (ed)
cncn	Concentric
cntr	Center (ed)
col	Color (ed)
coln	Colonial
com	Common
conc	Concretion (ary)
conch	Conchoidal
Cono	Conodont
contm	Contaminated
coq	Coquina
Cor	Coral
crbnt	Carbonate
Crin	Crinoid (al)
crm	Cream
crpxl	Cryptocrystalline
ctd	Coated
ctc	Contact
cvg	Cavings
Cyxr	Cyxridonis
dd	Dead
deb	Debris
decr	Decrease (ing)
dend	Dendrite (ic)
dess	Desiccation
dism	Disseminated
dk	Dark (er)
dns	Dense (er)
dol	Dolomite (ic)
dolst	Dolostone
drsy	Drusy (y)
dtrl	Detrital (us)
Ech	Echinoid
elg	Elongate
Endo	Endothyra
euhed	Euhedral
Euryamph	Euryamphiopora
f	Fine (ly)
fau	Fauna
Fe	Iron-Ferruginous
Fe-mag	Ferro-magnesian
fenst	Fenestral
Fe-st	Ironstone
fib	Fibrous
fis	Fissile
fl	Fill (ed)
fld	Feldspar (thic)
flk	Flake
flky	Flaky
flor	Fluorescence
fls	Flesh
flt	Fault (ed)
fltg	Floating
fnt	Faint (ly)
Foram	Foraminifera
fos	Fossil (iferous)
fr	Fair
frac	Fracture (ed)
frag	Fragment (al)
fri	Friable
frmwk	Framework
fros	Frosted
Fus	Fusulinid
Fvst	Favosites
g	Good
Gal	Galeolaria
Gast	Gastropod
gil	Gilsonite
Girv	Girvanella
gl	Glass (y)
glau	Glauconite (ic)
Glob	Globigerina
glos	Gloss (y)
gn	Green
gns	Gneiss
gr	Grain (ed)
gran	Granular
Grap	Graptolite
grd	Grade (ed)
grdg	Grading
grnl	Granule
grnt	Granite
grnt.w	Granite wash
gsy	Greasy
grvl	Gravel
gy	Gray
gyp	Gypsum (iferous)
gywk	Graywacke
hd	Hard
hem	Hematite (ic)
hex	Hexagonal
hi	High
hornbd	Hornblende
hrtl	Horizontal
hvy	Heavy
hydc	Hydrocarbon
ig	Igneous
imbd	Imbedded
imp	Impression
incl	Included (sion)
incr	Increase (ing)
ind	Indurated
indst	Indistinct
Inoc	Inoceramus
intbd	Interbedded
intcl	Intraclast (s)
int'frag	Interfragmental
intgran	Intergranular
intgwn	Intergrown
intlam	Interlaminated
intpt	Interpretation
intr	Intrusion (ive)
intstl	Interstitial
intv	Interval
intxl	Intercrystalline
irreg	Irregular
irid	Iridescent
Ivan	Ivanovia
kao	Kaolin
lam	Laminated
lav	Lavender
lchd	Leached
len	Lentil (icular)
lig	Lignite (ic)
lith	Lithographic
lmn	Limonite (ic)
lmpy	Lumpy
lmy	Limy
lrg	Large (er)
ls	Limestone
lse	Loose
lstr	Lustre
lt	Light (er)
m	Medium
magn	Magnetic
magnt	Magnetite
mar	Maroon
mas	Massive
mat	Material,matter
meta	Metamorphic
mica	Mica (ceous)
mic	Micro
mky	Milky
mnr	Minor
mnrl	Mineral (ized)
mnut	Minute
Mol	Mollusca
mot	Mottled
mrlst	Marlstone
mrly	Marly
msm	Metasomatic
mtx	Matrix
musc	Muscovite
n	No,none
nod	Nodule
num	Numerous
o	Oil
occ	Occasional
och	Ochre
od	Odor
olvn	Olivine
onc	Oncolites
ooc	Oocast (ic)
ool	Oolite (ic)
oom	Oomold (ic)
op	Opaque
org	Organic
orng	Orange
orth	Orthoclase
Ost	Ostracod
ovgth	Overgrowth
ox	Oxidized
p	Poor (ly)
Para	Paraparchites
pbl	Pebble
pel	Pellet
Pent	Pentamerus
perm	Permeability
pet	Petroleum (iferous)
phos	Phosphate (ic)
piso	Pisolite (ic)
pit	Pitted
pk	Pink
plag	Plagioclase
plas	Plastic
Plcy	Polecypod
pl	Plant
plty	Platy
pol	Polish (ed)
por	Porous (sity)
pos	Possible (sibly)
p-p	Pin point
pred	Predominant (ly)
pres	Preserved (ation)
prim	Primary
pris	Prism (atic)
prly	Pearly
prob	Probable (ly)
prom	Prominent (ly)
prphy	Porphyry
pseo	Pseudo
pt	Part (ly)
ptch	Patch (es)
ptg	Parting
purp	Purple
pyr	Pyrite (ic) (ized)
pyrbit	Pyrobitumen
pyrxn	Pyroxene
qtz	Quartz
qtzc	Quartzitic
qtzs	Quartzose
qtzt	Quartzite
rad	Radiate (ing)
rd	Round (ed)
Rep	Renalcis
repl	Replaced(ing) (ment)
resd	Residue (al)
rexl	Recrystallize (ation)
rhmb	Rhomb (ic)
rmn	Remains (nant)
rr	Rare
rsns	Resinous
rthy	Earthy
rug	Rugose (Rugosa)
s	Small
sa	Salt
sa-c	Salt cast (ic)
S	Sulphur
s&p	Salt & pepper
sat	Saturated
sb	Sub
sc	Scales
Scaph	Scaphopod
scat	Scattered
sch	Schist
Scol	Scolecodonts
sd	Sand (1/16-2 mm)
sdy	Sandy
sec	Secondary
sed	Sediment (ary)
sel	Selenite
sept	Septate
sft	Soft
sh	Shale
shad	Shadow
shy	Shaly
sid	Siderite (ic)
sil	Silica (ceous)
sks	Slickensided
sl	Slight (ly)
sln	Solution
silky	Silky
slt	Silt
sltst	Siltstone
slty	Silty
sm	Smooth
sol	Solitary
Solen	Solenopora
sp	Spot (ted) (ty)
spec	Speck (led)
Spg	Sponge
sph	Spherules
Sphaer	Sphaeracodium
sphal	Sphalerite
spin	Spinule (ar)
spl	Sample
spltry	Splintery
Spr	Spore
srt	Sort (ed) (ing)
ss	Sandstone
Stach	Stachyodes
strmg	Streaming
stn	Stain (ed) (ing)
str	Streak
strg	Stringer
stri	Striated
Strom	Stromatoporoid
stromlt	Stromatolite
struc	Structure
styl	Stylolite (ic)
Stylin	Stylolina
suc	Sucrosic
sug	Sugary
surf	Surface
Syrin	Syringopora
sy-Ca	Sparry calcite
sz	Size
tab	Tabular
Tes	Tesmenites
Tent	Tentaculites
tex	Texture
Them	Thamnopora
thk	Thick
thn	Thin
thru	Throughout
tns	Tension
tr	Trace
trip	Tripoli (ic)
trscd	Transluscent
trasp	Transparent
tt	Tight (ly)
tub	Tubular
tuf	Tuffaceous
uncons	Unconsolidated
unident	Unidentifiable
up	Upper
v	Very
var	Variable
vcol	Varicolored
ves	Vesicular
vgt	Variegated
vit	Vitreous
vn	Vein
volc	Volcanics
vps	Very poor samples
vrtl	Vertical
vrvd	Varved
vug	Vug (ey) (ular)
/	With
w	Well
wh	White
wk	Weak
wthrd	Weathered
wtr	Water
wvy	Wavy
wxy	Waxy
xbd	Cross-bedded
xbdg	Cross-bedding
xl	Crystal (line)
xlam	Cross-laminated
yel	Yellow
zeo	Zeolite
zn	Zone

ENGINEERING ABBREVIATIONS

AOF	absolute open flow
BHFP	bottom hole flow pressure
BHP	bottom hole pressure
BHSIP	bottom hole shut in pressure
BHT	bottom hole temperature
BO	barrels of oil
BOPD	barrels of oil per day
BOPH	barrels of oil per hour
brk	brackish
BW	barrels of water
BWPD	barrels of water per day
BWPH	barrels of water per hour
circ	circulate (ed) (tion)
ck	choke
comp	completed (tion)
crd	cored
csg	casing
(D)	development
D & A	dry and abandoned
decr	decreasing
DF	derrick floor
dist	distillate
drlr	driller
DST	drill stem test
est	estimated
FTAB	faint air blow
FAB	fair air blow
fl/	flowed (ing)
FP	flowing pressure
ga	gauged
G&OCM	gas and oil cut mud
GCM	gas cut mud
GCW	gas cut water
GAP	good air blow
GIP	good initial puff
GOR	gas-to-oil ratio
GR	ground
GTS	gas to surface
gty	gravity
HO	heavy oil
IAB	initial air blow
IP	initial production
KB	kelly bushing
loc	location
LSD	legal subdivision
MCFG	thousand cubic feet of gas
MMCFG	million cubic feet of gas
MCO	mud cut oil
MCW	mud cut water
O&G	oil and gas
O&SW	oil and salt water
OC	oil cut
OCM	oil cut mud
OFM	oil flecked mud
op	open
OTD	old total depth
OTS	oil to surface
OWDD	old well drilled deeper
OWPB	old well plugged back
OWWO	old well worked over
PB	plugged back
perf	perforated
PD	per day
PH	per hour
pkr	packer
psi	pounds per square inch
rec	recovered
RT	rotary table
SAB	strong air blow
SGCM	slight gas cut mud
SGCW	slight gas cut water
SI	shut in
SIP	shut in pressure
SO	show of oil
SO&G	show of oil and gas
SO&W	show of oil and water
SOCM	slight oil cut mud
SOCW	slight oil cut water
sqz	squeezed
SSO	slight show of oil
SW	salt water
swbd	swabbed
T.D.	total depth
TSTM	too small to measure
tstg	testing
V.op	valve open
(W)	wildcat
WAB	weak air blow
WCM	water cut mud
WIP	weak initial puff
wtr	water
wtr cush	water cushion

MECHANICAL LOG ABBREVIATIONS

BHCS	bore hole compensated sonic
Cal	caliper
CN	compensated neutron
DI	dual induction log
DIL	dual induction laterolog
DLL	dual laterolog
DL	density log
ES	electric
IES	induction electric
FDL	formation density log
GL	guard log
GR	gamma ray
LL	laterolog
LL8	laterolog-8
ML	microlog, minilog
MLL	microlaterolog
N	Neutron
S	sonic, acoustilog
SNP	sidewall neutron porosity log
SP	spontaneous potential
PL	proximity log

Figure.9. Example Chart of Symbols Used in Well Log Analysis. (sheet 2 of 2)

When testing follows drilling, the zones are checked in sequence from the deepest upward. This allows sealing of each lower zone to prevent upward leakage of fluids and gas. Before testing, zones are often treated with acid (acetic or hydrochloric) or are hydraulically fractured and propped with small spheres to improve permeability. Table 4 shows the results of tests in the Shell wells.

Wire-Line Logging

After each drilled interval is completed, and before casing, wire-line logs are run in the hole (some logs may be run in cased holes). A wide variety of logs are available, each with specific purposes. Table 5 lists the logs run in each Shell well. All logs were not run from top to bottom in the hole. It is not the intent of this report to explain well logging in detail, but Table 5 lists the common uses of each log run in the wells.

Table 4. Results of Formation Testing in Shell Wells.

Well	Interval (ft)	Formation	Gas (Mcpfd)	Fluids (bbl/d)	Pressure (lb/in^2)	Acid, 10% acetic (gal)
1-33 Yakima Minerals	15,540-15,466	Swauk	Small amount	--	--	3,200
	13,568-12,976	Roslyn-Teanaway	570	5,400 water	3,250	--
	12,460-12,350	Roslyn	500 (drop to 150)	--	--	7,560 + hydro-fracture
	11,686-11,564	Roslyn	75	--	--	7,500
	11,286-11,162	Roslyn	85	--	--	6,700
	10,930-10,604	Roslyn	10	--	--	--
	8,040-7,535	Ohanapecosh	27	1,700 water	--	--
	5,880-5,770	Wildcat Creek	Small amount	1,030 water	--	--
2-33 Yakima Minerals	5,397-5,360	Wildcat Creek	50	--	--	6,000
	5,322-5,282	Wildcat Creek	Small amount	--	--	--
	5,174-5,133	Wildcat Creek	Small amount	--	--	--
1-29 Bissa	10,898-10,314	Roslyn	Small amount	--	--	20,000
	9,830-9,436	Roslyn	Small amount	--	--	--
	8,800-8,486	Roslyn	Small amount	--	--	--

Table 5. List of Wireline Logs Run in Shell Wells. (sheet 1 of 2)

Log type*	1-33 Yakima Minerals well	2-33 Yakima Minerals well	1-29 Bissa well	Use
Dual induction	Yes	Yes	Yes	Effective porosity, permeability, detect fluid in thin beds
Borehole compensated sonic	Yes	Yes	Yes	Total porosity, seismic survey
Neutron formation density	Yes	Yes	Yes	Relative porosity, lithology, gas-water contact
Non-compensated dip meter	Yes	Yes	Yes	Formation dip and strike
Natural gamma spectroscopy	Yes	Yes	Yes	Lithology, shaleyness, correlation
Proximity micro log	Yes	Yes	Yes	Locate thin permeable zones
Repeat formation tester	Yes	Yes	Yes	Mini drill stem test, test for fluid content and pressure
Litho density	Yes	Yes	Yes	Specific gravity of rock, porosity of shaley sands
Cyber look	Yes	No	No	Computer run, effective porosity
Directional	Yes	No	Yes	Well hole deviation
Temperature	Yes	No	No	Detect fluid placement during fracturing, detect abnormal pressure
Caliper	Yes	No	No	Borehole diameter, rock hardness, porosity calculations

Table 5. List of Wireline Logs Run in Shell Wells. (sheet 2 of 2)

Log type*	1-33 Yakima Minerals well	2-33 Yakima Minerals well	1-29 Bissa well	Use
Microlog	Yes	No	No	Locate thin permeable zones
Correlated side wall core	Yes	No	No	Correlation, porosity and permeability
Dual microlaterolog SFL	No	No	Yes	Effective porosity
Sonic	No	No	Yes	Total porosity, seismic calibration
Cyber dip	No	No	Yes	Computer run, continuous dip
Dual spacing - thermal neutron decay time	No	No	Yes	Porosity and fluid data-encased hole

*Log names are trade names.

DISCUSSION OF TEST RESULTS

1-33 YAKIMA MINERALS WELL

The 1-33 Yakima Minerals well was nearly a commercial discovery. Gas recovered from all zones of the 1-33 Yakima Minerals well totaled nearly 1.3 MMcfpd. Unfortunately, a high water volume and rapid pressure drops were experienced (500 to 150 Mcfpd in one zone in 5 d). The 1-33 Yakima Minerals well showed clearly that commercial quantities of gas may exist under the basalt. The results also indicate that source beds are present and that reservoir rocks are available at moderate depths. The well confirmed that the Columbia River basalt is an effective cap rock but that other deeper impermeable rocks can effectively trap hydrocarbons.

The 1-33 Yakima Minerals well data indicate that the Roslyn Formation is the best reservoir rock for gas but that other rocks are also capable reservoirs, including zones in volcaniclastic rocks. Stratigraphically, the well shows that Cascade Province volcanic rocks extend as far east as Yakima and there interfinger with deltaic, fluvial rocks. As expected, the 1-33 Yakima Minerals well alone gives few clues as to the structure of the pre-basalt rocks. Although a few insignificant, fluorescent, oil-stained rocks were encountered, the well failed to cut thick pay zones or zones containing oil.

2-33 YAKIMA MINERALS WELL

The 2-33 Yakima Minerals well encountered gas directly under the basalt. Problems with heavy mud may have prevented this zone from being tested in the 1-33 Yakima Minerals well. In spite of a very strong gas kick on the mud log, test results were poor. This may have resulted from a lack of permeability or small reservoir capacity.

1-29 BISSA WELL

The 1-29 Bissa well should have produced more gas than the 1-33 Yakima Minerals well for two reasons: good reservoir rocks (Roslyn Formation) lie directly under the basalt in the 1-29 Bissa well and the top of the Roslyn is structurally higher at the 1-29 than at the 1-33 Yakima Minerals well. Instead, the 1-29 well produced only poor gas shows. The reason for this is unclear; there are six possible explanations.

1. Gas escaped out of the north end of the Naneum anticline.

2. High hydrostatic pressure from groundwater pushed gas off the crest of the fold.

3. A large fault system (Leavenworth or CLEW) prevented migration of gas upward onto the fold crest or leaked gas along a fault zone.

4. Gas is not derived from coal in the Roslyn Formation but from Swauk, Ohanapecosh, or other formations not present in this well.

5. The 1-33 Yakima Minerals well intersected old stream channels or other lenticular beds not present beneath the Whiskey Dick fold.

6. Combinations of the above.

From a stratigraphic standpoint, the 1-29 Bissa well is important. It confirms the presence of a pre-basalt high and raises the possibility that stratigraphic traps or pinchouts may exist on either side of the high. In addition, probable Cretaceous marine rocks, including limestone, were found in the 1-29 Bissa well, the first in central Washington. This increases the chance that marine reservoirs can exist southeastward under the basalt and also improves the chance of finding oil or condensate.

One major structural problem involves the absence of Swauk and Teanaway Formation rocks here. The absence of these rocks might be explained by the pre-basalt high, which would prevent the Swauk and Teanaway Formations from being deposited; however, the Swauk Formation is involved with the Leavenworth fault and associated pre-basalt high only 20 mi to the northwest at the basalt margin. In addition, one would expect the Roslyn Formation to be thinned over the high. This is not the case. Perhaps the Swauk Formation is omitted by faulting; the problem is unsolved at present.

GAS IN THE COLUMBIA RIVER BASALT

Results from the three wells indicate that interbeds in the Columbia River basalt, including those near the base of the basalt, contain little gas, although many of the lowermost interbeds are coarser grained than those higher in the section. This attests to the impermeability of the basalt and may indicate that interbeds are not a source of commercial gas. The zones within the basalt that produced formation gas, after eliminating trip-, conn-, and equipment-caused gas kicks, are listed below:

- <u>1-33 Yakima Minerals Well</u>
  - 550 to 560 ft
  - 1,300 to 1,308 ft
- <u>2-33 Yakima Minerals Well</u>
  - 2,450 to 2,455 ft
  - 2,670 to 2,690 ft
  - 2,870 to 2,890 ft
  - 2,190 to 4,240 ft
  - 4,400 to 4,480 ft.

The 2-33 Yakima Minerals well produced more gas shows than the 1-33 Yakima Minerals well because lighter mud was used in the hole; the 1-29 Bissa well produced no gas shows. The only strong kick came from the lowermost interbed, and many interbeds were gas free.

Interbeds are still capable of producing small amounts of gas; therefore, large-diameter holes drilled into the basalt should have these zones sealed off. This should be practical because 11-lb mud in the 1-33 Yakima Minerals well shut off most gas zones. There seems to be little, if any, hydrogen sulfide generated in the basalt; however, this has not been confirmed by Shell.

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FUTURE CONSIDERATIONS

POSSIBLE NEW DRILLING SITES

At present, Shell has only one permitted site left undrilled in Washington, the 1-5 BN Saddle Mountains well, located on the Frenchman Hills anticline. Shell also has the option to reopen the RSH-1 Rattlesnake Hills well and complete drilling through the basalt (about 2,000 ft). Whether Shell will follow through with their original four-well program is not known. With the completion of the 1-9 BN Saddle Mountains well, Shell will have sampled both sides and the top of the pre-basalt high and is now in a better position to evaluate the stratigraphy. Another factor that merits consideration is the large blocks of land presently off-limits to drilling: protected fish and game lands, the Yakima Firing Range, the Hanford Site, and the Yakima Indian Reservation. A change in the lease status of any of these lands would probably change drilling strategy.

Other companies with large acreage holdings (Sohio, Canadian Hunter, Tyrex, ARCO, Exxon) seem to be less likely to begin drilling unless Shell is successful. Snowbird Resources will reenter the 1-A Moses Lake well only if they succeed in raising several million dollars for drilling costs.

One factor that could alter the present status would be the development of a new exploration tool capable of successfully penetrating the basalt and interpreting pre-basalt structure and stratigraphy in detail. Present methods, including magnetotelluric surveys, will not do this. Based on present economic conditions in the oil industry and on today's subsurface techniques, this report maintains that if Shell does not strike gas in large volumes (several MMcfpd) in the next well, the exploration play will end.

Based on present, limited knowledge, simple closed-surface anticlines are still the best drill sites in the Columbia Basin. Undrilled folds with these characteristics include parts of Rattlesnake, Ahtanum, Yakima, Manashtash, and Toppenish Ridges and possibly the Horseheaven and Columbia Hills anticlines. Because of the poor shows at the 1-29 Bissa well, ridge segments south of the 1-33 Yakima Minerals well, or those on the east side of the Naneum Ridge-Hog Ranch High, appear most favorable at this time (e.g., West Yakima Ridge, Ahtanum Ridge, and Rattlesnake Ridge).

HYDROCARBON POTENTIAL IN THE PASCO BASIN

The released well log data from the 1-9 BN Saddle Mountain well will allow a more accurate prediction of what lies beneath the Pasco Basin. All that is known for certain is that a thick sequence of sediments exists beneath the basalt. This evidence is based on poor quality magnetotelluric data; better quality magneto-telluric surveys have been run but these are presently proprietary or otherwise unobtainable. Even high-quality magnetotelluric surveys may show only gross features, not detailed structure and stratigraphy.

Rock Types

Some general observations are apparent from the present well data. Based on the existence of the Naneum high, which should effectively block the eastward movement of Cascade-type volcaniclastics, rocks such as the Ohanapecosh and Wildcat Creek Formations would not be expected as far east as the Pasco Basin. While the Roslyn Formation appears to cross the Naneum high and, therefore, could reach as far east as the Hanford Site, it is more likely that rocks found in the Chiwaukum graben--Chumstick and Wenatchee Formations--extend southward to the Pasco Basin.

The Pasco Basin lies at the western edge of the Palouse slope. The Columbia River basalt moved down this slope in Miocene times. It is reasonable to assume that sediments in early Tertiary time could also have moved westward down the Palouse slope into the Pasco Basin. The nature of these rocks, if they exist, is unknown.

The likelihood of Cretaceous rocks underlying the Pasco Basin seems remote, yet this possibility is enhanced by the discovery of probable Cretaceous marine sediments in the 1-29 Bissa well. If rocks found in the Naches, Roslyn, and Chiwaukum "basins" thin southeastward, Cretaceous rocks may be within reach of the drill under the Pasco Basin.

Structure

No clear evidence exists for the orientation of pre-basalt folds in a direction other than those seen at the surface in Columbia River basalt. While one can speculate on potential north-south, pre-basalt folds paralleling the Naneum high, such structures have not been found. Therefore, data indicate that anticlinal traps are not likely in sedimentary rocks under the Pasco Basin structural low (plate 1). Hydrocarbons generated under the Pasco Basin should migrate away from the basin center where the basalt is thickest. The extreme basalt thickness is a detriment to drilling economics; at today's high drilling costs and with most surface anticlines undrilled, the Pasco Basin is a poor drilling prospect. Not enough is known about fault or stratigraphic traps to make any judgment about their potential in the Pasco Basin. If stratigraphic traps exist along the east side of the Naneum high, they should be restricted to the extreme northwestern edge of the Pasco Basin.

The Columbia River basalt should not be considered a reservoir for gas (fig. 10). Although a small gas "field" was discovered on a satellite fold of the Rattlesnake Hills anticline, other shallow wells drilled in the Pasco Basin have not produced significant gas. At today's economics, the old Rattlesnake gas field would be noncommercial.

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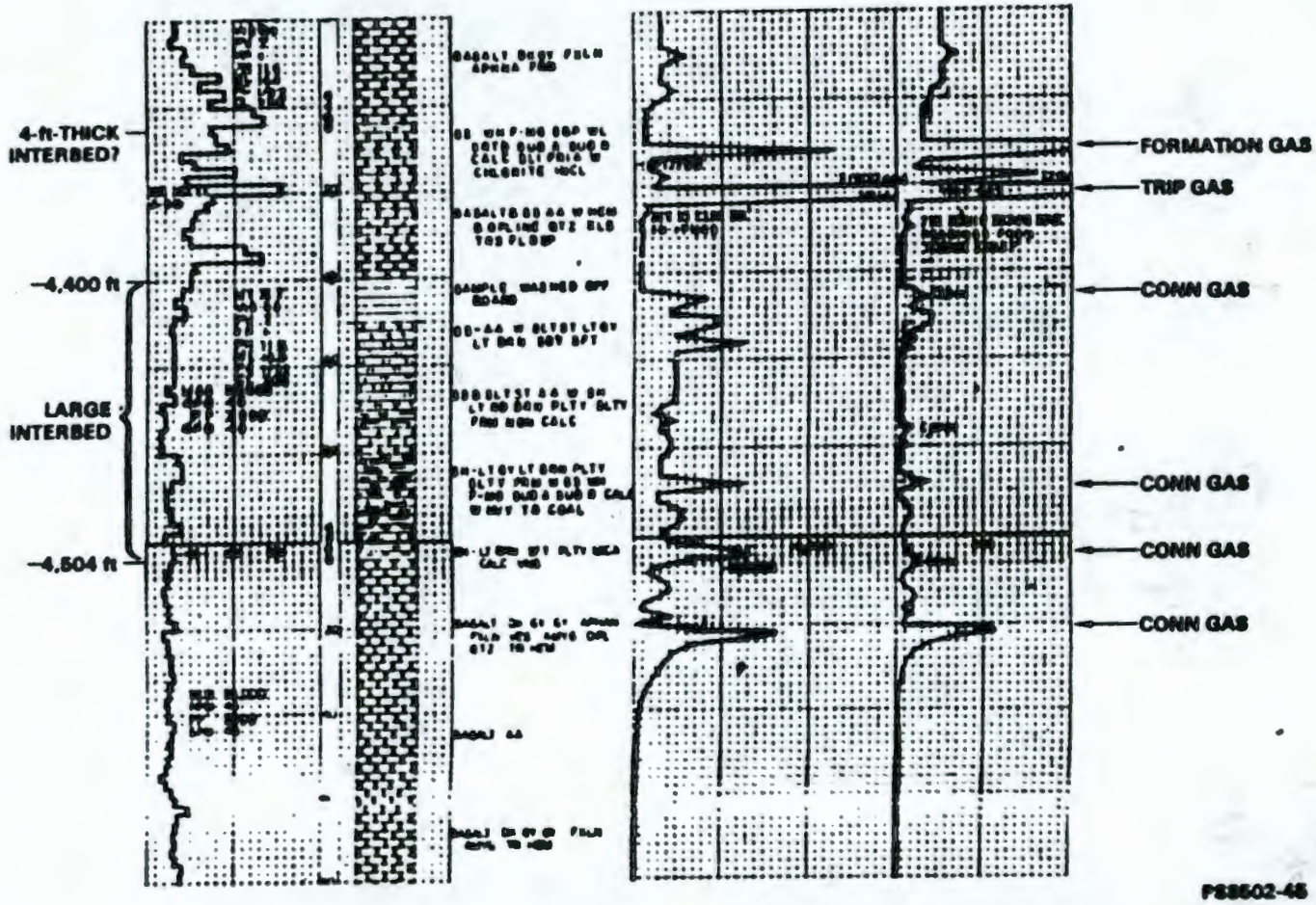

Figure 10. A Typical Gas Kick in an Interbed, 1-33 Well.

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CONCLUSION

Information derived from the drilling of three wells in the northwestern Columbia Basin has greatly improved our knowledge of the pre-basalt rocks located there. Correlation of rocks along the basalt margin with those in the wells indicate the following.

1. The presence of a Naneum pre-basalt "high" affects lithologies across the Columbia Basin, west to east.

2. Cascade Province volcaniclastics extend much further east than previously thought.

3. Both source beds and reservoir rocks are present beneath the basalt, usually in fluvial deltaic sediments of early Tertiary age.

4 Marine rocks of probable Cretaceous age exist under parts of the Columbia Basin.

The 1-33 Yakima Minerals well proved the existence of large quantities of gas under the basalt, greatly increasing the chances that a commercial gas field will someday be discovered in the Columbia Basin. The drilling confirmed that the Columbia River basalt is an excellent seal to the migration of fluids and gases. The basalt yielded only small amounts of gas, typical of what might be encountered in any deep-water well in the Columbia Basin.

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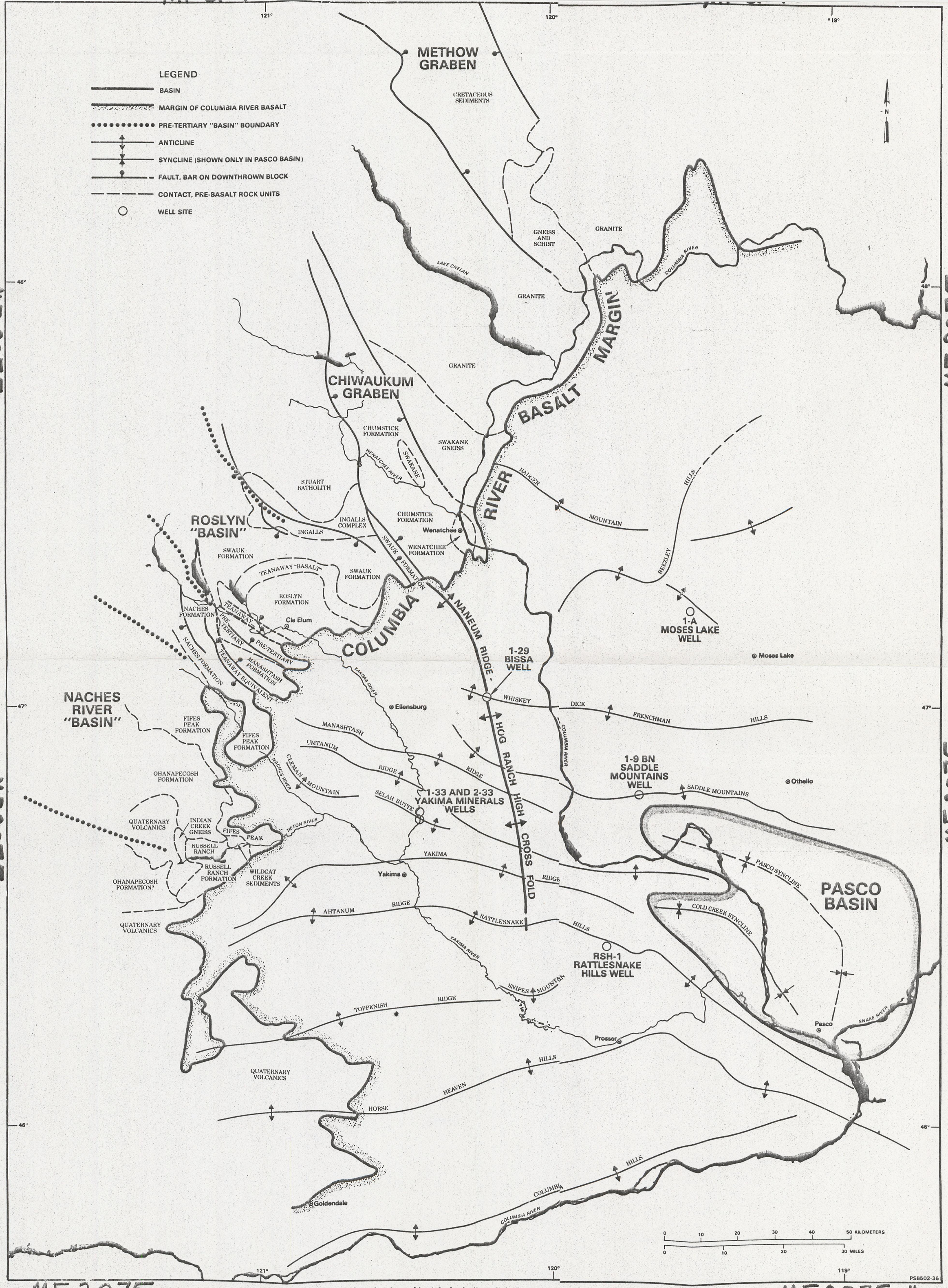

Plate 1. Generalized Geologic Map of the Northwest Columbia Basin Showing Pre-Basalt Rocks and Major Depositional Basins.

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