WASHINGTON DIVISION OF GEOLOGY AND EARTH RESOURCES
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GEOLOGIC MAP OF THE ASTORIA AND ILWACO QUADRANGLES, WASHINGTON AND OREGON

Compiled by
TIMOTHY J. WALSH

WASHINGTON DIVISION OF GEOLOGY AND EARTH RESOURCES

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This report has not been edited or reviewed for conformity with Division of Geology and Earth Resources standards and nomenclature.

WASHINGTON STATE DEPARTMENT OF
Natural Resources
Brian Boyle · Commissioner of Public Lands
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INTRODUCTION

This map is one of a series of 1:100,000-scale geologic maps compiled by staff geologists of the Division of Geology and Earth Resources and used as source maps of the southwest quadrant of the geologic map of Washington (Walsh and others, in press). Other maps in the series are available for all 1:100,000-scale quadrangles within the southwest quadrant, that is south of 47°15' north latitude and west of 120°30' west longitude.

The 1:100,000-scale maps in this series that have been released to date are:

Korosec, M. A., compiler, 1987, Geologic map of the Mount Adams quadrangle, Washington: Washington Division of Geology and Earth Resources Open File Report 87-5, 41 p., 1 pl., scale 1:100,000

Korosec, M. A., compiler, 1987, Geologic map of the Hood River quadrangle, Washington and Oregon: Washington Division of Geology and Earth Resources Open File Report 87-6, 42 p., 1 pl., scale 1:100,000

Logan, R. L., compiler, 1987, Geologic map of the Chehalis River and Westport quadrangles, Washington: Washington Division of Geology and Earth Resources Open File Report 87-8, 18 p., 1 pl., scale 1:100,000

Logan, R. L., compiler, 1987, Geologic map of the south half of the Shelton and the south half of the Copalis Beach quadrangles, Washington: Washington Division of Geology and Earth Resources Open File Report 87-9, 17 p., 1 pl., scale 1:100,000

Phillips, W. M., compiler, 1987, Geologic map of the Mount St. Helens quadrangle, Washington and Oregon: Washington Division of Geology and Earth Resources Open File Report 87-4, 63 p., 1 pl., scale 1:100,000

Phillips, W. M., compiler, 1987, Geologic map of the Vancouver quadrangle, Washington and Oregon: Washington Division of Geology and Earth Resources Open File Report 87-10, 32 p., 1 pl., scale 1:100,000

Phillips, W. M.; Walsh, T. J., compiler, 1987, Geologic map of the northwest part of the Goldendale quadrangle, Washington: Washington Division of Geology and Earth Resources Open File Report 87-13, 9 p., 1 pl., scale 1:100,000

Schasse, H. W., compiler, 1987, Geologic map of the Centralia quadrangle, Washington: Washington Division of Geology and Earth Resources Open File Report 87-11, 27 p., 1 pl., scale 1:100,000

Schasse, H. W., compiler, 1987, Geologic map of the Mount Rainier quadrangle, Washington: Washington Division of Geology and Earth Resources Open File Report 87-16, 43 p., 1 pl., scale 1:100,000

Walsh, T. J., compiler, 1986, Geologic map of the west half of the Toppenish quadrangle, Washington: Washington Division of Geology and Earth Resources Open File Report 86-3, 8 p., 1 pl., scale 1:100,000

Walsh, T. J., compiler 1986, Geologic map of the west half of the Yakima quadrangle, Washington: Washington Division of Geology and Earth Resources Open File Report 86-4, 12 p., 1 pl., scale 1:100,000

Walsh, T. J., compiler, 1987, Geologic map of the Astoria and Ilwaco quadrangles, Washington and Oregon: Washington Division of Geology and Earth Resources Open File Report 87-2, 30 p., 1 pl., scale 1:100,000

Walsh, T. J., compiler, 1987, Geologic map of the south half of the Tacoma quadrangle, Washington: Washington Division of Geology and Earth Resources Open File Report 87-3, 12 p., 1 pl., scale 1:100,000

ACKNOWLEDGMENTS

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STRATIGRAPHIC NOMENCLATURE

Stratigraphic nomenclature in this report follows the most recent usage, although this is in conflict with some nomenclature shown in U.S. Geological Survey lexicons. Therefore, a discussion of several units is in order.

Cowlitz Formation

The Cowlitz Formation is used herein in the sense applied by Wells (1981) for rocks exposed in Olequah Creek between the towns of Winlock and Vader. The Cowlitz was originally named by Weaver (1912) for exposures east of Little Falls [now called Vader (Meany, 1923)] that he considered older than the Tejon Formation, although in his early mapping (Weaver, 1916), he called all of the marine Eocene of western Washington "Tejon formation". He did, however, designate as the Eocene "type marine section for western Washington" (Weaver, 1916, p. 92) a section of marine and brackish water sedimentary rocks interbedded with volcanic rocks at their base between Winlock and Castle Rock.

Much later, Weaver (1937, p. 97) designated a type section for the Cowlitz Formation in Olequah Creek, consisting of 3,745 feet of sandstone and shale, and stated that "when the Cowlitz formation was first described by the writer in 1912 and 1916, it was the intention that the type section of the Cowlitz formation should include the series of exposures along Olequah Creek between Winlock and Vader together with the 200-foot section in the bank of the Cowlitz River...". Weaver's Olequah Creek type section for the Cowlitz Formation is essentially the same as that designated for the Olequah formation (Arnold and Hannibal, 1913) which was abandoned with no explanation. In discussing the Cowlitz Formation, Weaver (1937) stated "The actual base of the Eocene exposures cannot be observed because of lack of continuous outcrops. There may be several thousand feet of shales between the base of the measured section and the top of the Metchosin volcanics." It was not made clear if Weaver intended Cowlitz to include all Eocene shales above the Metchosin. Still later, Weaver (in Weaver and others, 1944) describes Cowlitz Formation as "composed of about 8,000 feet of marine grayish-brown sandstone and sandy shale containing well-preserved molluscan fossils." The correlation diagram for that work (Weaver and others, 1944) shows Cowlitz resting on Metchosin. Weaver (1945) then extended Crescent Formation to the volcanic rocks in the Willapa Hills, but showed Cowlitz resting on Crescent. Because there are only about 4,000 feet of strata exposed at this type section, it is evident that, at least late in his career, Weaver intended that the Cowlitz Formation include all of the Eocene marine and estuarine deposits above the Metchosin or Crescent Formations, as well as interbedded tuffs, and below the Lincoln Creek Formation. However, Weaver never made extensive fossil collections from the lower strata.

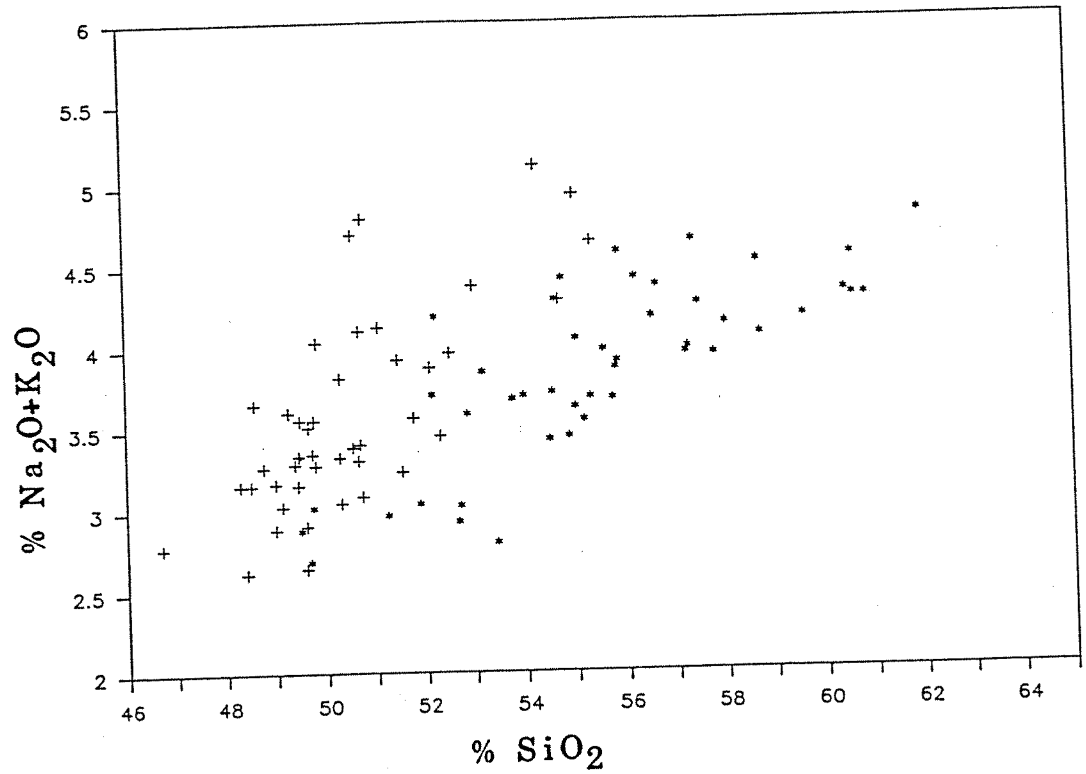
In the Centralia coalfield, about 30 miles north of the Cowlitz Formation type section, Snavely and others (1951a, 1951b) defined three formations, the McIntosh, Northcraft, and Skookumchuck, of middle and late Eocene age, and correlated the Skookumchuck with the Cowlitz Formation. Much of the area mapped as Skookumchuck Formation by Snavely and others (1951b) had previously been mapped in reconnaissance by Weaver (1937) as Cowlitz formation. Weaver's mapping did not extend to rocks later assigned to the subjacent Northcraft and McIntosh Formations. On the basis of foraminiferal studies, McIntosh Formation (Snavely and others, 1951a) was referred to Laiming's B-1A Zone and correlated with the Domengine Stage of California. By this age assignment, McIntosh was older than Cowlitz, which had frequently been correlated with the Tejon. Subsequent investigations of the McIntosh (Snavely and others, 1958) led to an expansion of its age range both older (tentatively to Laiming's Zone B-1) and younger (to Tejon stage) although the older rocks are no longer considered part of the McIntosh (Pease and Hoover, 1957; Armentrout and others, 1983) and are assigned either to the Crescent Formation or to unit Tme.

In subsequent mapping of the lower Cowlitz River valley, Henriksen (1956, p. 36) stated that Weaver "certainly left room for the expansion of the type Cowlitz formation, if subsequent work should show (as it has shown) that the emendation is desirable, to include the Eocene sediments and subordinate volcanic rocks exposed along Stillwater Creek above the Metchosin." Henriksen (1956) explicitly defined Cowlitz Formation to include all of the sedimentary and volcanic rocks in the lower Cowlitz River valley lying above the middle Eocene pillow basalts (then called Metchosin, now called Crescent Formation) and below the Oligocene sedimentary and volcanic rocks exposed at Winlock. He subdivided the Cowlitz into the sedimentary Stillwater Creek and Olequah Creek members and into the volcanic Pe Ell and Goble Volcanics members. Henriksen (1956, p. 44) considered "the Stillwater Creek member...to be correlated, at least in part, with the McIntosh formation," although in his correlation chart he showed McIntosh as strictly older than Cowlitz Formation. Rau (1958) showed the Stillwater Creek section to be the same age as the type section of the McIntosh Formation, and he placed the Stillwater Creek member of Henriksen (1956) within the McIntosh Formation.

In the most recent mapping of the lower Cowlitz River valley, Wells (1981) adopted the usage of Rau (1958), reserving Cowlitz Formation for those rocks which correlate with the type section in Olequah Creek.

Grays River Volcanic Rocks

Rocks shown on this map as the Grays River volcanic rocks have previously been called Goble Volcanics (Livingston, 1966;



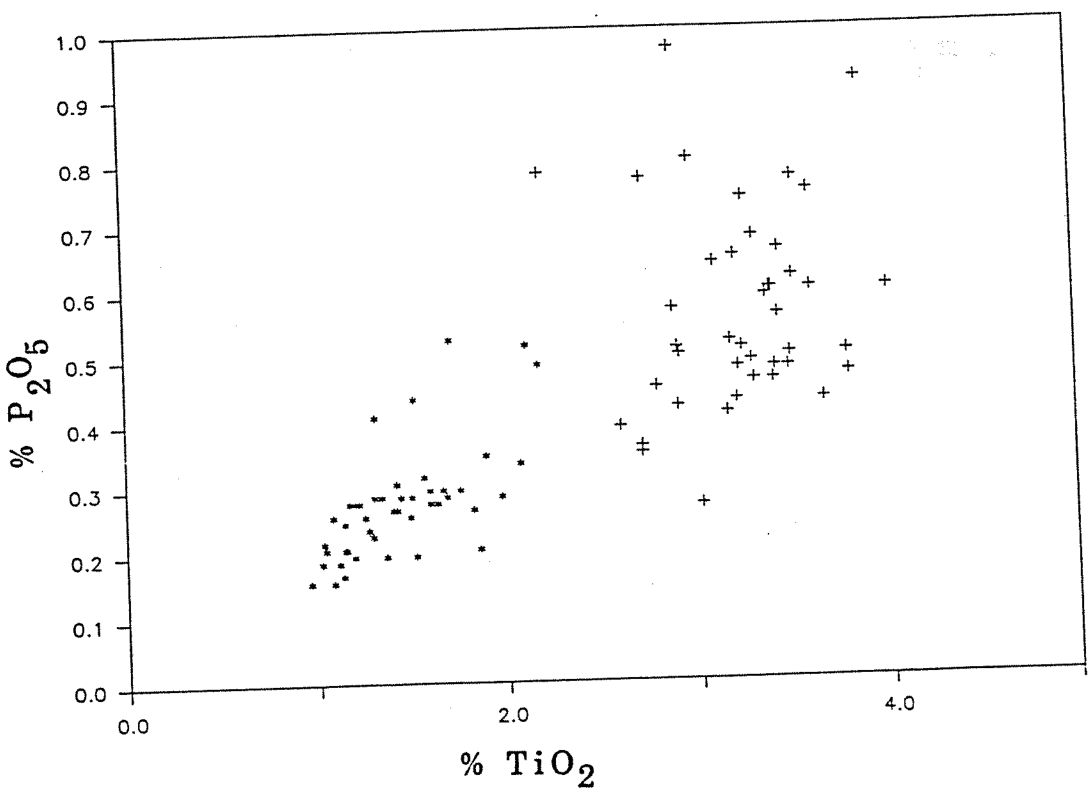


Figure 1. Bivariate plots discriminating Grays River volcanic rocks (+) from Goble volcanics (*). Data from Table 1 and Phillips (1987a; 1987b)

Major Element Analyses of Igneous Rocks in Astoria 1:100,000 Quadrangle

SAMPLE NO.	UNIT	SiO2	Al2O3	TiO2	Fe2O3	FeO	MnO	CaO	MgO	K2O	Na2O	P2O5	TOTAL	QSEC		SEC	TWP	RGE	COMMENTS
TW111684H	Tsp	52.38	15.31	1.74	2.00	8.70	0.18	10.16	6.41	0.57	2.33	0.24	100.02	SW/4	SW/4	04	09N	04W	
TW0918851	Twf	52.02	14.28	2.94	2.00	12.31	0.23	8.12	4.45	1.07	2.09	0.49	100.00	NW/4	NE/4	29	08N	03W	
KK0801851	Twf	52.33	13.19	2.88	6.74	7.72	0.21	8.37	4.54	0.93	2.53	0.57	100.01	NE/4	SW/4	11	09N	07W	
TWCL1	Tgr	54.93	15.82	2.27	2.00	8.46	0.20	7.79	4.01	1.49	2.73	0.31	100.01	SW/4	NW/4	05	06N	03W	
KK0801854	Tgr	55.09	14.15	1.73	5.52	6.32	0.19	8.58	4.58	0.95	2.56	0.32	99.99	SE/4	SW/4	11	09N	07W	
TWKN6	Tgr	55.18	14.99	2.08	2.00	10.42	0.19	6.64	3.70	1.94	2.54	0.32	100.00	NE/4	SE/4	04	09N	09W	Boulder in Tasn
KK0801853	Tgr	55.25	14.18	1.72	5.48	6.27	0.18	8.67	4.34	0.90	2.68	0.32	99.99	NE/4	SE/4	11	09N	07W	
TW0315853	Tgr	56.45	13.58	1.96	5.87	6.73	0.20	7.03	3.46	1.79	2.59	0.34	100.00	SE/4	NW/4	02	07N	04W	
TW111684D	Tgr	56.62	15.47	2.22	2.00	8.17	0.21	6.91	3.39	1.78	2.89	0.34	100.00	NE/4	NE/4	05	09N	04W	
KK0626855	Tgr	57.28	13.81	1.98	5.50	6.30	0.18	7.08	3.59	1.49	2.45	0.34	100.00	SW/4	NW/4	20	08N	03W	
TW0315852	Tgr	57.72	13.96	1.97	5.09	5.83	0.18	6.93	3.49	1.73	2.77	0.34	100.01	SE/4	NW/4	02	07N	04W	
BP0529851	Tgv	48.41	15.15	3.02	6.87	7.87	0.22	9.65	5.94	0.19	2.43	0.27	100.02	NW/4	NW/4	27	08N	03W	
BP0523857	Tgv	48.52	17.45	2.90	5.43	6.22	0.19	11.15	4.48	0.42	2.74	0.51	100.01	SW/4	NE/4	35	10N	04W	
BP0523853	Tgv	48.78	15.86	3.26	6.13	7.02	0.21	9.79	4.94	0.65	2.62	0.74	100.00	SE/4	SW/4	22	10N	04W	
BP1204842	Tgv	49.01	14.68	3.16	6.16	7.06	0.17	10.08	6.10	0.48	2.69	0.41	100.00	NW/4	NE/4	11	10N	03W	
TW0404851	Tgv	49.28	14.54	3.87	6.21	7.11	0.18	9.85	4.45	0.62	2.99	0.92	100.02	NW/4	SW/4	06	07N	04W	
KK0626853	Tgv	49.60	14.47	2.79	6.06	6.94	0.18	10.39	6.47	0.35	2.30	0.45	100.00	NW/4	NW/4	28	08N	03W	
BP0108851	Tgv	49.62	14.16	2.90	6.01	6.89	0.19	10.71	6.20	0.42	2.49	0.42	100.01	SE/4	SW/4	25	08N	03W	
BP0523855	Tgv	49.75	15.14	3.22	6.16	7.05	0.18	9.81	4.85	0.65	2.70	0.48	99.99	NE/4	SW/4	21	10N	04W	
BP1205842	Tgv	49.78	15.20	3.41	5.82	6.66	0.17	9.88	5.04	0.76	2.80	0.48	100.00	SW/4	NW/4	01	10N	03W	
BP05238510	Tgv	49.81	14.63	3.21	6.53	7.48	0.20	9.53	4.91	0.72	2.56	0.43	100.01	SE/4	SE/4	02	09N	04W	
KK0626851	Tgv	50.32	13.75	3.39	6.46	7.40	0.20	9.46	5.35	0.57	2.48	0.60	99.98	NW/4	NW/4	34	08N	03W	
BP0523859	Tgv	50.71	15.25	3.52	5.69	6.52	0.16	9.05	4.21	1.06	3.05	0.77	99.99	NW/4	NW/4	13	09N	04W	
BP0801851	Tgv	51.48	14.20	3.40	6.18	7.07	0.24	8.75	4.15	0.84	3.09	0.60	100.00	SE/4	SE/4	03	10N	06W	
KK0626852	Tgv	51.55	13.97	3.51	6.27	7.18	0.20	8.94	4.52	0.72	2.52	0.62	100.00	NW/4	SE/4	28	08N	03W	
BP0523858	Tgv	52.13	15.45	2.91	5.75	6.58	0.19	8.50	4.11	0.95	2.93	0.50	100.00	NW/4	NE/4	35	10N	04W	Sill
BP0523856	Tgv	52.53	14.71	2.98	5.69	6.52	0.19	8.33	4.28	1.07	2.90	0.80	100.00	SE/4	NW/4	26	10N	04W	Dike
BPO109851	Tgv	53.02	14.30	3.31	5.82	6.67	0.20	8.19	3.43	1.19	3.19	0.68	100.00	NW/4	SW/4	24	10N	05W	
BP0523854	Tgv	54.71	14.92	2.73	5.45	6.24	0.17	7.40	3.33	1.30	2.99	0.77	100.01	NE/4	SW/4	21	10N	04W	
BP0523852	Tgv	55.36	14.66	2.21	5.89	6.75	0.23	6.31	3.17	1.46	3.19	0.78	100.01	SE/4	NE/4	16	09N	03W	
TW111684I	Tgv	74.12	12.32	0.34	2.19	2.51	0.20	0.74	0.61	3.56	3.34	0.08	100.01	SE/4	NW/4	05	09N	04W	Fault breccia
TW111684J	Tgv	74.77	13.55	0.37	1.19	1.36	0.06	0.79	0.00	3.73	4.10	0.08	100.00	SE/4	NW/4	05	09N	04W	Fault breccia
TWRW11	Tgv?	54.28	16.13	2.71	2.00	8.00	0.17	6.81	4.42	1.49	3.63	0.36	100.00	NW/4	SW/4	28	10N	04W	Xenolith in Tiqm
TWRW14	Tiqm	66.80	17.40	0.82	2.00	2.05	0.10	0.13	0.32	4.84	5.43	0.12	100.01	NW/4	SW/4	33	10N	04W	
TWRW14	Tiqm	68.59	14.77	0.62	2.31	2.65	0.10	1.05	0.51	4.46	4.84	0.10	100.00	NW/4	SW/4	33	10N	04W	

Table 1. Major and minor element analyses by XRF, Dept. of Geology, Washington State University. All analyses are normalized on a volatile free basis with the oxidation state of iron set at the arbitrary ratio of Fe_2O_3/FeO = 0.87 for samples analyzed with Columbia River Basalt standards, Fe_2O_3 is arbitrarily set at 2.00

Wells, 1981), volcanic rocks of Unit B (Wolfe and McKee, 1968), or Cowlitz basalts (Phillips and Kaler, 1985). The name adopted herein follows a suggestion from R. E. Wells, U.S. Geological Survey,who is responsible for much of the original mapping of these rocks (Wells, 1981).

The original designation of Goble Volcanic Series was applied by Warren and others (1945) for a "section of widespread basic flows and pyroclastic rocks with some associated sediments, totaling 5,000 feet or more in thickness,...along U.S. Highway 99 between Woodland and Kelso, Wash. This volcanic series crops out along both the Oregon and Washington sides of the Columbia River. On the Washington side it extends almost continuously northward from the mouth of the East Fork of the Lewis River to Walker Island. The series was named for its excellent exposures in the vicinity of Goble, Ore., in the St. Helens quadrangle."

Investigation of the section at Rainier, Oregon, where both units are exposed (Phillips, in press [b]) shows the Goble Volcanics to be mostly higher in the section than the Grays River volcanic rocks. Additionally, major element chemistry of the type Goble Volcanics (table 1) is distinct from that of the Grays River volcanic rocks. Grays River volcanic rocks have a significantly higher TiO_2 and P_2O_5 content (Fig. 1) and are enriched in total alkalis relative to Goble Volcanics (Fig. 1). For additional discussion of Grays River volcanic rocks and Goble Volcanics, see Phillips (in press [a,b]).

Astoria Formation

"Astoria Formation" is another name that has a long and controversial history. The name was first used in print by Cope (1880) who cited unpublished notes of "Prof. Condon formerly State Geologist [stating that] the backbone of the Coast Range consists of argillaceous shales, which contain invertebrate and vertebrate fossils, frequently in concretions.... To the formation, Dr. Condon gives the name of Astoria shales." Dall and Harris (1892) extended the name to sandstones, as well as to shales, which are exposed on both sides of the Columbia River upstream of the city of Astoria. They assigned the rocks to the Oligocene series, but separated out the lower beds, which contained <u>Aturia</u>, as Eocene. They (Dall and Harris, 1892, p. 224) also <u>noted</u> that the "gradings, wharfage, buildings, etc., have concealed to a considerable extent many of these exposures."

Howe (1926) included <u>Aturia</u>-bearing beds in the Astoria and assigned the entire <u>sequence</u> a middle Miocene age. Arnold and Hannibal (1913) and Weaver (1937) extended the usage as far north as the Grays Harbor and Puget basins (although it is no longer applied in the Puget basin). Rau (1948) referred the Astoria Formation in the Grays Harbor area to the Saucesian Stage on the basis of foraminiferal studies, and later (Rau, 1967) extended the formation in that area to the Relizian and possibly Luisian Stages. Snavely and others (1958, p. 54) mapped marine Miocene rocks in the Centralia-Chehalis area and stated that "The Astoria formation, as described and mapped by Etherington [1931] and Weaver, is accepted with reservation by the authors as beds of middle Miocene age in the Centralia-Chehalis area cannot be traced, without interruption, into the type section of the Astoria formation of Oregon. The Astoria (?) formation of this report, therefore, may not occupy a stratigraphic position identical to that of the Astoria formation of Oregon."

Until the middle 1950s, most of southwestern Washington had been mapped only in reconnaissance, and the extent of the Miocene was not known in detail. Since that time, it has been customary to query the name "Astoria Formation" in the Chehalis and Grays Harbor basins; however, the Astoria Formation shown on this map includes or is approximately contiguous with the exposures cited by Dall and Harris (1892), and the "?" is regarded as unnecessary. In addition, substantial subsequent mapping (Wagner, 1967a, 1967b; Wolfe and McKee, 1968; Rau, 1966, 1967, 1986; Wells, 1979, 1981) has more firmly established the distribution, continuity, and biostratigraphic and lithostratigraphic position of these rocks. It appears appropriate to drop the "?" from the name Astoria Formation throughout southwestern Washington.

RESOURCE POTENTIAL

Coal

Coal has been known in this area since at least as early as 1833 (Roberts, 1958) when Dr. Tolmie of the Hudson's Bay Company noted the presence of coal outcrops in the banks of the Cowlitz River just to the east of this map area. Several mines were developed, although none was ever a major coal producer (Culver, 1919). Only one mine, the Coal Creek mine in sec. 27, T. 9 W., R. 3 W., was located in the Astoria quadrangle. Although it had no official record of production, the Coal Creek mine was active in 1902 (Landes and Ruddy, 1903) and in 1903 or 1904, when it was visited by J. S. Diller (1905). Diller reported that the slope entry was 400 feet long, with short turnouts in both directions. The coal seam was reported to be 9 feet thick, including a 2-foot-thick bed of shale (Landes and Ruddy, 1903). The mine had been abandoned for several years by the time it was visited by Collier (1913) and has since been backfilled by the U.S. Office of Surface Mining.

In 1982 and 1983, Kennecott Minerals Exploration Group, in a joint venture with GCO Minerals, a subsidiary of International Paper, explored the Cowlitz Formation in the northeastern corner of the Astoria quadrangle and adjacent quadrangles. Their

SAMPLE NUMBER	AS RECEIVED BASIS						MOISTURE FREE BASIS				
	% H_2O	% ASH	% S	% VM	% FC	BTU	% ASH	% S	% VM	% FC	BTU
147.0-156.4	32.35	24.26	0.28	23.58	19.81	5098	35.86	0.41	34.85	29.29	7536
156.4-157.4	26.44	62.07	0.10	7.31	4.18	1075	84.38	0.13	9.94	5.68	1462
157.4-159-9	32.60	21.35	0.28	24.00	22.05	5327	31.67	0.41	35.61	32.72	7903
159.9-161.6	23.21	73.43	0.01	3.04	0.32	<100	95.63	0.01	3.96	0.41	<100
161.6-164.0	32.93	18.63	0.46	27.01	21.43	5756	27.77	0.68	40.27	31.96	8582
164.0-164.7	24.50	69.44	0.04	5.10	0.96	<100	91.98	0.05	6.76	1.26	<100
164.7-177.3	33.25	23.16	2.49	25.79	17.80	5201	34.70	3.73	38.64	26.66	7792
177.3-179.9	19.28	69.02	2.28	8.36	3.34	1102	85.51	2.83	10.36	4.13	1365
179.9-181.3	27.74	38.65	3.97	20.07	13.54	3721	53.49	5.49	27.78	18.73	5150
181.3-184.8	19.39	62.71	0.83	12.59	5.31	1370	77.80	1.03	15.62	6.58	1699
212.0-215.1	27.80	40.52	1.08	18.97	12.71	3645	56.12	1.49	26.27	17.61	5048
215.1-217.3	37.21	9.21	0.37	31.17	22.41	6610	14.66	0.59	49.64	35.70	10527
217.3-219.9	35.50	19.00	0.28	26.40	19.10	5506	29.46	0.43	40.93	29.61	8536
219.9-221.0	19.66	74.56	0.03	5.73	0.05	< 100	92.81	0.04	7.13	0.06	<100

Table 2. Analyses of coal from core drilled 300' FSL, 46' FEL, Section 16, T. 12 N., R. 3 W. by Utah International, Inc. Analysis by Sunnyvale Minerals Laboratory

drilling indicated a strippable reserve of approximately 580 million tons of coal to a 400-foot mining depth.

In 1983, Utah International explored the same area and rotary drilled 12 holes and cored one hole on state lands. Logs from those tests indicate the presence of a seam of lignite as much as 37 feet thick and averaging 30 feet thick. Analyses of the coal (Table 2) indicate that its rank is lignite A and that it has a moderate to high ash content. Several thinner seams are also present within 100 feet of section from the thick seam. Although the publicly available drill hole data are not sufficient to estimate strippable reserves, extrapolation along strike suggests an inferred strippable resource within the Cowlitz Formation outcrop area (T. 13 N., R. 4 W. to T. 10 N., R. 2 W.) of approximately 1.5 billion tons of lignite.

Oil and Gas

The oil and gas potential of the region, particularly on the Washington side of the Columbia River, is limited by the fact that the largest anticlines are cored by Crescent Formation, which is considered to be mid-ocean ridge basalt or seamount basalt that represents economic basement in this area. Several smaller anticlines may have trapping potential, notably the east-west-trending anticline along Wilson Creek in T.9 N., R.5 W.

However, abundant faulting created many potential fault traps, and the only producing gas field in the Northwest, the Mist field on the south edge of the area, is interpreted as having mostly fault controlled gas pools (Alger, 1985).

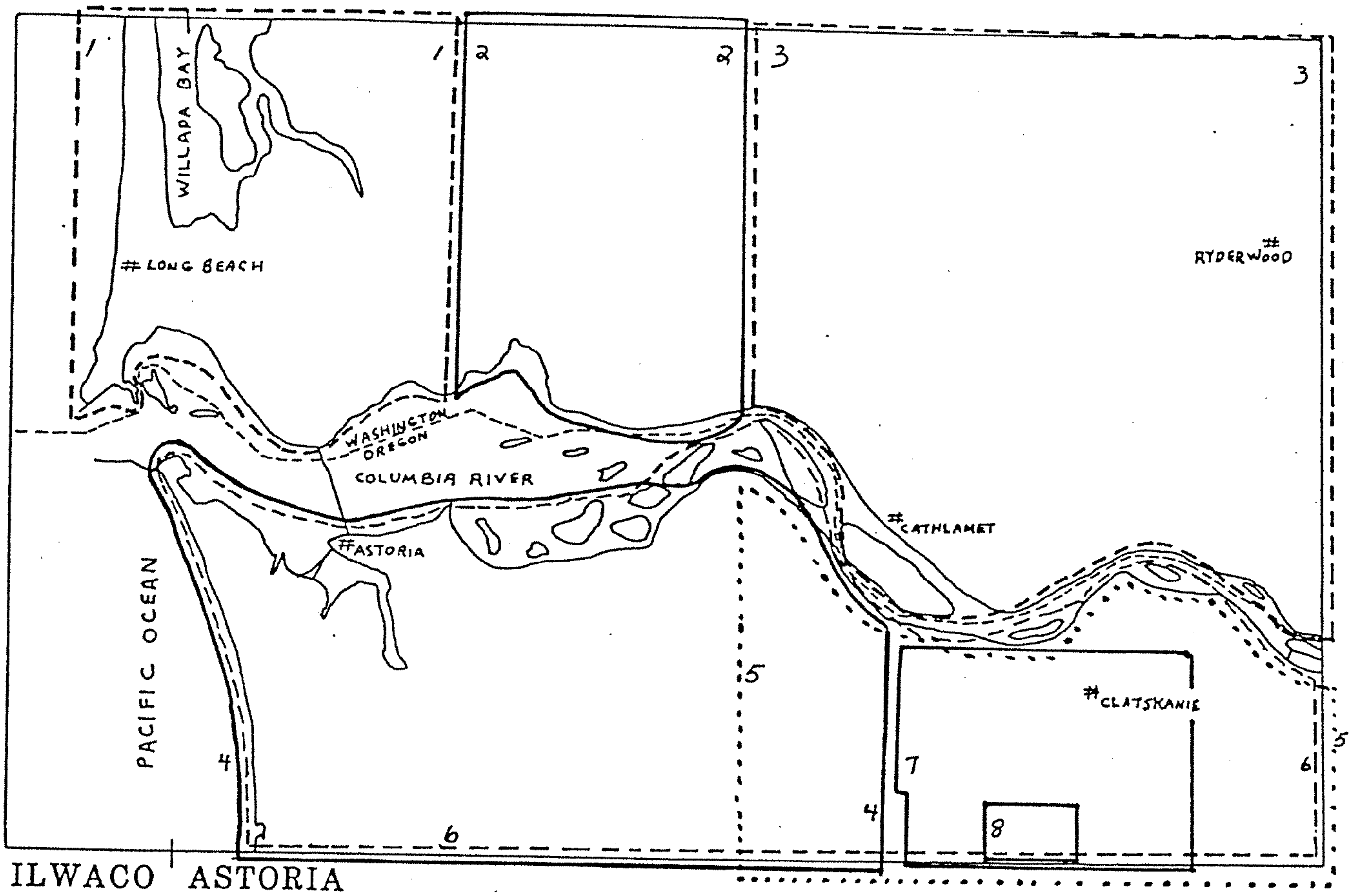
Also, potential exists for stratigraphic traps in turbidite beds of unit Tme lapping onto topographic highs of the Crescent Formation (seamounts?). No information is available on the reservoir quality of sands in unit Tme, although modal analysis indicates that the sands average 15 percent clay volume in the Grays River area (Wolfe and McKee, 1972). Some sandstones of the Cowlitz Formation are known to have good reservoir qualities. At Jackson Prairie, about 7 miles east-northeast of the Astoria quadrangle, gas is stored in the laterally equivalent Skookumchuck Formation in three sands that have an average porosity of 36 percent and measured permeabilities of 1 to 3 darcies (Wurden and Ford, 1976). In the Mist gas field, gas is produced out of the Clark and Wilson sand in the Cowlitz Formation, which has porosities of 26 to 35 percent (Olmstead, 1985) and permeabilities up to 1.3 darcies (Newton and Van Atta, 1976).

Source rocks are present in the region that have adequate richness, but only gas prone organic matter has been identified (Armentrout and Suek, 1985; Brown and Ruth Laboratories, Inc., 1982).

Rocks in the Astoria and Ilwaco quadrangles are probably thermally immature for oil generation. The upper Eocene coal recovered in the Utah International drilling (see Coal section) is Lignite A in rank. Upper Eocene coals in the nearby Centralia coal field range in rank from Lignite A to Subbituminous B but strongly tend toward lignite to the south and southwest (toward the Astoria quadrangle) (Walsh and Phillips, 1983). At Mist, shales enclosing the producing sands have vitrinite reflectances of less that 0.4 percent (Armentrout and Suek, 1985) in upper Eocene rocks of the Cowlitz Formation. On the western outskirts of the town of Cathlamet, a lignite stringer in the middle Miocene unit Tasu yielded a reflectance of R_0 = 0.17 percent.

Most of the wells drilled in this area have encountered gas shows (Niem and Niem, 1985; McFarland, 1983) with a few reported oil shows on the Long Beach peninsula (McFarland, 1983). Farther north along the coast, oil shows and even minor production (McFarland, 1983) are associated with the Hoh melange, which is characterized, at least in part, by shale diapirs (Rau and Grocock, 1974). Similar features have been identified from seismic records within approximately 12 miles of the coast at Long Beach (Wagner and others, 1986), and these may be responsible for the oil shows.

SOURCE OF DATA MAP



1. Wells, 1979; Wells, in press
2. Wolfe and McKee, 1968
3. Wells, 1981
4. Niem and Niem, 1985
5. Newton, 1976, in Newton and Van Atta, 1976
6. Warren and others, 1945
7. Kadri and others, 1981, in Kelty, 1981
8. Kadri, 1982

Figure 2. References to maps used to compile the geologic map of the Astoria and Ilwaco quadrangles

DESCRIPTION OF MAP UNITS
ASTORIA AND ILWACO QUADRANGLES, WASHINGTON

Quaternary Unconsolidated Deposits

Qal

Alluvium (Holocene)--Unconsolidated clay, silt, sand, and gravel deposited along rivers, streams, and estuaries; includes sand bars and islands in major rivers and stabilized tidal flats in Willapa Bay

Qoa

Older alluvium (Holocene and Pleistocene?)--Sand, silt, and gravel that form terrace remnants along the edges of the Grays River valley

Qt

Terraced sediments (Holocene and Pleistocene)--Clay, silt, sand, and gravel of terraces from 8 to 100 meters above sea level; formed principally as estuarine, beach, and dune deposits; locally includes older alluvium

Qb

Beach sand (Holocene)--In Oregon, "moderately well-sorted, fine- to medium-grained quartzo-feldspathic sands with heavy mineral laminae; also includes black winter-beach lag sand deposits up to a few meters thick of magnetite, ilmenite, and other heavy minerals (Twenhofel, 1946) locally developed on Clatsop Spit; unit includes basalt gravels of well-rounded pebbles, cobbles, and boulders around Miocene basalt headlands along southern coast of Clatsop County" (Niem and Niem, 1985). On Long Beach peninsula, fine to coarse sand forming beaches and several rows of stabilized longitudinal dunes; locally includes organic-matter-rich lacustrine deposits and estuarine mud and sand on Willapa Bay shoreline

Qd

Dune sand (Holocene and Pleistocene)--"Active and inactive dune sands forming several prominent north-south beach ridges on Clatsop Spit; sands are well sorted, fine grained, quartzo-feldspathic with heavy mineral laminae, and cross-bedded; unit also includes peat and lacustrine mud deposits in and around intradune lakes" (Niem and Niem, 1985)

Qls

Landslide debris (Holocene and Pleistocene)--Large deposits of mass wasting, from surface creep to coherent glide and slump blocks; many small slides not shown

Tertiary Sedimentary Rocks

Ttd

Troutdale Formation (upper Miocene and Pliocene)--Semiconsolidated conglomerate with basalt and quartzite clasts; occurs in hills above Astoria and northwest of Rainier as terrace remnants

Tgc

Gnat Creek formation of Niem and Niem (1985) (middle Miocene)--Friable, cross-bedded or bioturbated, micaceous and carbonaceous feldspathic sandstone, pebbly, coarse-grained feldspathic sandstone, thick-bedded massive sandstone with slumped siltstone blocks in channels cut into laminated carbonaceous mudstone, and rare lignite; contains diatoms referable to Subzone B of the *Denticula lauta* Zone and Subzone a of the *Denticulopsis hustedtii D. lauta* Zone (John Barron, USGS, written *commun., 1980, in* Murphy, 1981)

Tasu

Upper Astoria (?) Formation of Wells (1981) (middle Miocene)--"Thick to thin bedded; friable, very fine to medium grained, micaceous, [feldspathic] sandstone and silty sandstone; plane laminated thin bedded micaceous siltstone, some with large, low-angle cross-bedding sets; large channels in siltstone filled with very coarse sand and transported blocks of siltstone; convolute bedding and slump structures common" (Wells, 1981)

Astoria Formation

Tasy

Youngs Bay member of Niem and Niem (1985) (lower and middle Miocene)--Laminated, carbonaceous and micaceous mudstone complexly intertongued two thick bodies of clean, medium- to coarse-grained, friable feldspathic sandstone containing large mica flakes; commonly weathered yellow, iron stained, or white to medium gray (fresh); thick, very thick bedded; although generally structureless, sandstones laminated and fresh mudstone typically medium gray and contains dikes of medium-grained feldspathic sandstone, bathyal foraminifers, and a few graded, thin- to medium- bedded feldspathic sandstone beds; grades into and interfingers with Cannon Beach member (Tasc); previously called Big Creek member (Cooper, 1981) and Pipeline member (Nelson, 1978; Coryell, 1978); foraminifers referable to Saucesian Stage (W. W. Rau, in Nelson, 1978, and Coryell, 1978)

Tasc

Cannon Beach member of Niem and Niem (1985) (lower and middle Miocene)--Well-bedded sequence of laminated to massive micaceous mudstone with subordinate, rhythmically bedded feldspathic sandstone and mudstone in lower part; sandstone is fine grained, micaceous, and carbonaceous, graded and cross laminated and contains load casts and convolute bedding; previously called Silver Point member (Niem and Van Atta, 1973); contains foraminifers referable to the Saucesian or Relizian Stages (Rau, in Nelson, 1978, and Coryell, 1978)

Tasa

Angora Peak member of Cressy (1974) (lower and middle Miocene)--"Massive to laminated, fine-grained feldspathic sandstone with subordinate trough and planar cross-bedded coarse-grained volcanic sandstone; minor pumiceous- volcanic to polymict conglomerate and laminated carbonaceous mudstone with thin local subbituminous coal beds; sandstone contains abundant shallow-water mollusks assignable to Pillarian and Newportian Stages of Addicott (1976, 1981) (Cressy, 1974; Cooper, 1981)" (Niem and Niem, 1985)

Tasw

Wickiup Mountain member of Niem and Niem (1985) (lower and middle Miocene)--Structureless to laminated shallow- water feldspathic sandstone; generally fine grained, locally trough cross-bedded, and fossiliferous; sandstone is blue gray when fresh but commonly is weathered to yellowish to greenish gray; upper part consists of friable, very fine grained sandstone and micaceous mudstone capped by glauconitic sandstone; contains molluscan fossils referable to Pillarian Newportian Stages; previously called Big Creek member by Coryell (1978), Nelson (1978), Cooper (1981), Wells and others (1983); includes Tucker Creek sandstone of Nelson (1978)

Tasb

Bald Ridge member of Wells (in press) (lower and middle Miocene)--Thin-bedded, planar-laminated, abundantly micaceous and carbonaceous siltstone and lesser amounts of friable, very fine to coarse-grained micaceous feldspathic sandstone; sandstone commonly occurs as graded beds, as channel fills up to 15 m thick, and as locally abundant clastic dikes; overlies strata containing foraminifers referable to the Saucesian Stage and is cut by sills of Grande Ronde Basalt chemistry (Tigr) of middle Miocene age; unit is laterally equivalent to upper unit of Astoria Formation of Wolfe and McKee (1968) and is probably correlative in part to Youngs Bay member of Astoria Formation in the Astoria basin of northwest Oregon (Niem and Niem, 1985)

Tasn

Naselle member of Wells (in press) (lower and middle Miocene)--Thick-bedded to massive, bioturbated to wispy laminated, abundantly micaceous, carbonaceous, tuffaceous medium-gray siltstone, sandy siltstone, and lesser fine- to medium-grained feldspathic sandstone; sandstone is locally basaltic or glauconitic; locally contains calcareous concretions; contains foraminifers referable to Saucesian Stage; unit is laterally equivalent to part of lower unit of Astoria Formation of Wolfe and McKee (1968) and is similar in appearance and correlative in part to Wickiup Mountain unit of Astoria Formation in northwest Oregon (Niem and Niem, 1985)

Tasl

Lower member of Wells (1981) (lower and middle Miocene)-- Thick to thin-bedded, very fine to medium-grained, plane laminated, carbonaceous, micaceous, friable sandstone; basalt and quartzite conglomerate lenses locally common; bioturbated and containing slumped structures in places; molluscan fauna referred to Newportian or Pillarian Stages; includes part of lower Astoria Formation of Wolfe and McKee (1968)

Tso

Scappoose Formation of Van Atta and Kelty (1985) (lower and middle Miocene)--Medium- to coarse-grained, trough cross-bedded, micaceous, lithofeldspathic sandstone, micaceous, tuffaceous, fossiliferous siltstone and poorly sorted pebble to boulder conglomerate; sandstone contains rip-up clasts and large slump blocks of mudstone; conglomerate clasts composed of Grande Ronde Basalt, mudstone, granite, quartzite and phyllite

Tsmc

Smuggler Cove formation of Niem and Niem (1985) (Oligocene and lower Miocene)--Thick-bedded, bioturbated, tuffaceous claystone and siltstone with lesser graded volcanic sandstone beds, tuffs, and glauconitic sandstone; lower silty claystone contains foraminifers referable to the upper part of the Refugian Stage; upper part is structureless tuffaceous siltstone and sandy siltstone containing foraminifers referable to the Zemorrian and Saucesian Stages; previously called Oswald West mudstones (Cressy, 1974)

Tnc

Northrup Creek formation of Niem and Niem (1985) (Oligocene? and lower Miocene)--Well bedded, carbonaceous, micaceous, laminated, medium- to dark-gray mudstone and lesser thin, fine-grained to very fine grained, yellowish gray feldspathic sandstone; carbonized leaf imprints common, and well sorted, micaceous, friable, feldspathic sandstone with molluscan fossils and abundant concretions is present near top of unit; previously included in Silver Point member of Astoria Formation by Cooper (1981)

Tlc

Lincoln Creek Formation (upper Eocene and Oligocene)--Dark-gray to olive gray, indistinctly bedded, very tuffaceous siltstone and lesser feldspathic sandstone; sandstones are locally glauconitic or basaltic and are more abundant near base of formation, where they are locally mapped separately; contains foraminifers referable to the Refugian and Zemorrian Stages

Tlcs

Lincoln Creek Formation sandstone member (upper Eocene or lower Oligocene)--Fine- to medium-grained, thick- to thin-bedded, locally micaceous, feldspathic sandstone and lesser laminated siltstone; sandstone locally glauconitic or basaltic

Tpb

Pittsburg Bluff Formation (Oligocene)--Bioturbated and laminated tuffaceous and feldspathic sandstone, locally glauconitic, with lesser tuffaceous siltstone and claystone; sandstones are structureless and concretionary and contain thin, light gray tuffs; abundant molluscan fauna referable to the upper part of the Galvinian Stage of Armentrout (1975, 1981) and foraminifers referable to the upper part of the Refugian Stage (Niem and Niem, 1985)

Tsg

Sager Creek formation of Niem and Niem (1985) (Oligocene)--Laminated, micaceous and carbonaceous mudstone interbedded with thin, fine-grained feldspathic sandstone; foraminifers are referable to upper part of the Refugian Stage; previously called Vesper Church formation by Olbinski (1983), Vesper Church member of the Keasey Formation by Wells and others (1983), and lower Pittsburg Bluff Formation by Warren and Norbisrath (1946) and Kadri (1982)

Tk

Keasey Formation (upper Eocene and lower Oligocene?)--Dark-gray tuffaceous mudstone, well indurated, with abundant fossils and concretions, and lesser tuffaceous siltstone and volcaniclastic sandstone; foraminifers are referable to the Refugian Stage (McDougall, 1980)

Tcz

Cowlitz Formation (as restricted by Wells, 1981) (middle and upper Eocene)--Massive to thin-bedded, planar laminated and cross-bedded, very fine to coarse-grained feldspathic sandstone, laminated micaceous carbonaceous siltstone, tuffaceous siltstone, very coarse grained volcanic lithic sandstone, and lignite up to 11.5 m thick (Utah International Inc., written commun., 1987); foraminifers are referable to the upper Narizian Stage; this unit is equivalent to the Olequa Creek Member of the Cowlitz Formation (Henriksen, 1956)

Tmc

McIntosh Formation (middle and upper Eocene)--Massive to thin-bedded, very fine grained to coarse-grained basaltic sandstone, tuffaceous siltstone, and feldspathic sandstone; basalt cobble conglomerate and slump breccia locally present; foraminifers referable to the Narizian Stage

Tmcs

Massive to thick-bedded, plane laminated to crossbedded, fine to medium-grained feldspathic sandstone

Tsc

Siltstone of Skamokawa Creek of Wells (1981) (upper Eocene)--"Thin-bedded, laminated, burrowed, concretionary, tuffaceous siltstone; contains thin tuff beds in places; abundant foraminifera are referred to the upper part of the Narizian Stage" (Wells, 1981)

Tsb

Siltstone of Shoalwater Bay of Wells (in press) (middle and upper Eocene)--"Dark-gray, thin-bedded, laminated, indurated tuffaceous siltstone containing thin tuff beds, minor thin-bedded feldspathic sandstone, and calcareous concretions; unit is baked and altered over wide areas beneath the sill on Bear River Ridge" (Wells, in press); contains foraminifers referable to the Narizian Stage

Tom

Siltstone and sandstone at Omeara Point of Wells (in press) (middle and upper Eocene)--"Light-gray, very well bedded, laminated, indurated siltstone and thin-bedded, planar laminated and graded, to cross-laminated and graded very fine grained micaceous feldspathic sandstone, locally basaltic, carbonaceous or tuffaceous with locally abundant calcareous concretionary beds" (Wells, in press); contains foraminifers referable to the Narizian Stage

Tcp

Siltstone at Cliff Point of Wells (1979) (Middle and upper Eocene)--Green-gray to red-gray, indurated, thin-bedded and laminated tuffaceous siltstone and very fine grained volcanic lithic sandstone; foraminifers are referable to the Narizian Stage

Tse

Siltstone and sandstone (middle to upper Eocene--Thin-bedded, laminated, tuffaceous, concretionary siltstone, fine- to medium-grained micaceous feldspathic sandstone, and basaltic volcanic lithic sandstone; foraminifers referable to the Narizian Stage

Tses

Massive, fine- to medium-grained, friable, feldspathic sandstone

Tme

Sandstone and siltstone (middle Eocene)--"Light gray, indurated, thin to thick-bedded and channeled, planar-laminated and graded to locally trough-laminated or cross-laminated, very fine to medium-grained micaceous feldspathic sandstone" (Wells, in press) and well indurated, thin-bedded, dark-gray siltstone; sandstone dominates in western part of map area, but siltstone, rhythmically alternating with sandstone, dominates in Grays River area; continuous with rhythmically bedded siltstones and sandstones assigned to lower McIntosh Formation (Wagner 1967a, 1967b); includes sandstone at Megler (Wells, 1979) and Unit A of Wolfe and McKee (1968)

Tertiary Volcanic and Intrusive Rocks

Columbia River Basalt Group

Yakima Basalt Subgroup

Tsp

Saddle Mountains Basalt - Pomona Member (middle Miocene)--Single basalt flow of Pomona chemical type with wavy, irregular, columnar jointing; fine grained, with phenocrysts of plagioclase and microphenocrysts of pyroxene and olivine; in places, basalt is deeply weathered ferruginous bauxite (Livingston, 1966); magnetic polarity reversed; previously mapped as basalt of Pack Sack Lookout (Snavely and others, 1973)

Tisp

Intrusive Pomona Member (middle Miocene)--Invasive sills and dikes of olivine basalt and diabase of Pomona chemical type with associated peperites; previously mapped as basalt of Pack Sack Lookout (Snavely and others, 1973)

Twf

Wanapum Basalt - Frenchman Springs Member (middle Miocene)--At least three basalt flows of Frenchman Springs chemical type with well developed colonnades; fine grained, sparsely to abundantly phyric, with plagioclase phenocrysts up to 1.5 cm long; magnetic polarity normal; previously mapped as Cape Foulweather Basalt (Snavely and others, 1973)

Tiwf

Intrusive Frenchman Springs Member (middle Miocene)--Invasive, columnar-jointed sills, dikes, and irregularly shaped bodies of Frenchman Springs chemical type; fine grained, with sparse plagioclase phenocrysts; includes associated peperites; previously mapped as Cape Foulweather Basalt (Snavely and others, 1973)

Tgr

Grande Ronde Basalt (middle Miocene)--Aphanitic to fine-grained, aphyric basaltic andesite flows and associated flow breccia; upper three or four flows have well developed colonnades, lower flows have well developed entablatures; upper flows have high-Mg Grande Ronde chemistry, and lower flows have low-Mg Grande Ronde chemistry (Wells, 1981)

Tigr

Intrusive Grande Ronde Basalt (middle Miocene)--Invasive sills, dikes, and irregular bodies of massive to crudely columnar and platy jointed, medium-grained aphyric basaltic andesite with associated peperites; previously mapped as Depoe Bay Basalt (Snavely and others, 1973)

Tco

Columbia River Basalt Group, undivided (Miocene)--Fine-grained, aphyric to sparsely phyric basalt and basaltic andesite flows and associated flow breccia

Tico

Intrusive Columbia River basalt, undivided (Miocene)--Invasive sills and dikes and associated peperites of Columbia River basalt

Tiqm

Ordway Creek stock (upper Eocene)--Hypidiomorphic granular, granophyric, and porphyritic quartz monzonite and granodiorite; contains inclusions of Grays River volcanic rocks; zircon fission track age is about 41 m.y. (R. E. Wells, USGS, oral commun., 1986)

Tgv

Grays River volcanic rocks (upper Eocene)--Subaerial basalt flows, flow breccia, aquagene tuff, pillow basalt, and interbedded siltstone and sandstone; flows are commonly porphyritic, containing phenocrysts of calcic plagioclase, augite, and olivine; flows are columnar and platy jointed, with weathered [flow] tops and oxidized basal [flow] breccia; aquagene tuff composed mostly of angular clasts of amygdaloidal basalt and locally interbedded with amygdaloidal pillow basalt (Wolfe and McKee, 1972); foraminifers from siltstones interbedded with and immediately underlying the Grays River volcanic rocks are referable to the Narizian Stage; siltstones overlying the unit contain foraminifers of Narizian or Refugian age; these rocks have previously been mapped as Goble Volcanics but are mostly older than and are chemically distinct from Goble (Phillips and Kaler, 1985); chemical differences between the two units are summarized in Table 1 and Figure 1, 2 and 3; includes volcanic rocks of Unit B (?) (Wolfe and McKee, 1968)

Tbt

Basaltic tuff (middle and upper Eocene)--Basalt lapilli tuff, basalt breccia, amygdaloidal pillow basalt, and basaltic sandstone and conglomerate; tuff composed of palagonitized glass shards cemented by calcite, chlorite, and zeolites; interbedded with the lower part of the McIntosh Formation and the upper part of the Crescent Formation (Wells, 1981); includes the Pe Ell Volcanic Member of the Cowlitz Formation (Henriksen,1956), as well as older basaltic tuff

Tib

Basaltic and gabbroic intrusive rocks (middle and upper? Eocene)--Massive to blocky jointed and columnar jointed, fine- to very coarse grained gabbroic sill complex intruding the upper part of the Crescent Formation and the lower part of the McIntosh Formation in northeastern part of map; also includes numerous basaltic to gabbroic dikes and sills in the Grays River and Naselle River valleys

Tcr

Crescent Formation (lower? and middle Eocene)--"Pillowed, columnar-jointed, and massive basalt, fine- to medium-grained, nonvesicular to amygdaloidal, aphyric to plagioclase-pyroxene-olivine-phyric; typically shows submarine alteration of glassy pillow rims and interstitial glass to waxy green smectite clays; clay minerals, zeolite, calcite, and quartz fill vesicles and abundant slickensided fractures" (Wells, in press); K-Ar ages of the Crescent Formation in this area average approximately 48 m.y. (Duncan, 1982), and foraminifers are referable to the Penutian? and Ulatisian Stages (Wells, 1981)

REFERENCES CITED

Addicott, W. O., 1976, Neogene molluscan stages of Oregon and Washington. In Fritsche, A. E., editor, 1976, Symposium on the Neogene of the Pacific coast: Society of Economic Paleontologists and Mineralogists, Pacific Section, San Francisco, California, p. 95-195.

Addicott, W. O., 1981, Significance of pectinids in Tertiary biochronology of the Pacific Northwest. In Armentrout, J. M., editor, 1981, Pacific Northwest Cenozoic biostratigraphy: Geological Society of America Special Paper 184, p. 17-37.

Alger, M. P., 1985, Geology. In Olmstead, D. L., 1985, Mist gas field--Exploration and development, 1979-1984: Oregon Department of Geology and Mineral Industries Oil and Gas Investigation 10, p. 6-9.

Armentrout, J. M., 1975, Molluscan biostratigraphy of the Lincoln Creek Formation, southwest Washington. In Weaver, D. W.; Hornaday, G. R.; Tipton, Ann, editors, 1975, Paleogene symposium and selected technical papers--Conference on future energy horizons of the Pacific coast: America Association of Petroleum Geologists Pacific Section Annual Meeting, p. 14-48.

Armentrout, J. M., 1981, Correlation and ages of Cenozoic chronostratigraphic units in Oregon and Washington. In Armentrout, J. M., editor, 1981, Pacific Northwest Cenozoic biostratigraphy: Geological Society of America Special Paper 184, p. 137-148.

Armentrout, J. M.; Hull, D. A.; Beaulieu, J. D.; Rau. W. W., 1983, Correlation of Cenozoic stratigraphic units of western Oregon and Washington: Oregon Department of Geology and Mineral Industries Oil and Gas Investigation 7, 90 p., 1 pl.

Armentrout, J. M.; Suek, D. H., 1985, Hydrocarbon exploration in western Oregon and Washington: American Association of Petroleum Geologists Bulletin, v. 69, no. 4, p. 627-643.

Arnold, Ralph; Hannibal, Harold, 1913, The marine Tertiary stratigraphy of the north Pacific coast of America: Proceedings of the American Philosophical Society, v. 52, p. 559-605.

Brown and Ruth Laboratories, Inc., 1982, Regional Petroleum Geochemistry of Washington and Oregon: Houston, Texas, 118 p.

Collier, A. J., 1913, Coal resources of Cowlitz River valley, Cowlitz and Lewis and Clark Counties, Washington. In Campbell, M. R., editor, 1913, Contributions to Economic Geology (Short papers and preliminary reports), 1911: U.S. Geological Survey Bulletin 531, p. 323-330.

Cope, E. D., 1880, On certain Tertiary strata of the Great Basin [Remarks]: Proceedings of the American Philosophical Society, v. 19, p. 60-62.

Cooper, D. M., 1981, Sedimentation, stratigraphy, and facies variation of the lower to middle Miocene Astoria Formation in Oregon: Oregon State University Doctor of Philosophy thesis, 524 p.

Coryell, G. F., 1978, Stratigraphy, sedimentation, and petrology of the Tertiary rocks in the Bear Creek-Wickiup Mountain-Big Creek area, Clatsop County Oregon: Oregon State University Master of Science thesis, 178 p., map scale 1:15,840.

Cressy, F. B., Jr., 1974, Stratigraphy and sedimentation of the Neahkahnie Mountain-Angora Peak area, Tillamook and Clatsop Counties, Oregon: Oregon State University Master of Science thesis, 148 p., map scale 1:15,480.

Culver, H. E., 1919, The coal fields of southwestern Washington: Washington Geological Survey Bulletin 19, 155 p.

Dall, W. H.; Harris, G. B., 1892, Correlation papers--Neocene: U.S. Geological Survey Bulletin 84, 349 p.

Diller, J. S., 1905, Coal in Washington near Portland, Oregon. In Emmons, S. F.; Hayes, C. W., 1905, Contributions to Economic Geology, 1904: U.S. Geological Survey Bulletin 260, p. 411-412.

Duncan, R. A., 1982, A captured island chain in the Coast Range of Oregon and Washington: Journal of Geophysical Research, v. 87, no. B13, p. 10,827-10,837.

Etherington, T. J., 1931, Stratigraphy and fauna of the Astoria Miocene of southwest Washington: University of California Publications, Bulletin of the Department of Geological Sciences, v. 20, no. 5, p. 31-142.

Henriksen, D. A., 1956, Eocene stratigraphy of the lower Cowlitz River-eastern Willapa Hills area, southwestern Washington: Washington Division of Mines and Geology Bulletin 43, 122 p., 2 pl.

Howe, H. V., 1926, Astoria, mid-Tertiary type of Pacific coast: Pan-American Geologist, v. 45, no. 4, p. 295-306.

Kadri, M. M., 1982, Structure and influence of the Tillamook uplift on the stratigraphy of the Mist area, Oregon: Portland State University Master of Science thesis, 105 p.

Kadri, M. M.; Kelty, K. B.; Ordway, Elizabeth; Timmons, D. M.;

Van Atta, R. O., 1981, Preliminary geologic map of Townships 4, 5, 6, and 7 N., Ranges 4 and 5 W., northwest Oregon. In Kelty, K. B., 1981, Stratigraphy, lithofacies, and environments of deposition in the Scappoose Formation in central Columbia County, Oregon: Portland State University Master of Science thesis, 81 p.

Kelty, K. B., 1981, Stratigraphy, lithofacies, and environment of deposition of the Scappoose Formation in central Columbia County, Oregon: Portland State University Master of Science thesis, 81 p.

Kleinpell, R. M.; Hornaday, G.; Warren, A. D.; Tipton, A, 1980, The Miocene Stratigraphy of California Revisited: American Association of Petroleum Geologists, 416 p., 42 pl.

Landes, Henry; Ruddy, C. A., 1903, Coal deposits of Washington: Washington Geological Survey Annual Report 1902, pt. 2, p. 167-177.

Livingston, V. E., Jr., 1966, Geology and mineral resources of the Kelso-Cathlamet area, Cowlitz and Wahkiakum Counties, Washington: Washington Division of Mines and Geology Bulletin 54, 110 p., 2 pl.

Mallory, V. S., 1959, Lower Tertiary biostratigraphy of the California Coast Range: American Association of Petroleum Geologists, 416 p., 42 pl.

McDougall, K. A., 1980, Paleoecological evaluation of late Eocene biostratigraphic zonations of the Pacific Coast of North America: Journal of Paleontology, v. 54, no. 4, supplement (Paleontological Monograph 2), 75 p.

McFarland, C. R., 1983, Oil and gas exploration in Washington, 1900-1982: Washington Division of Geology and Earth Resources Information Circular 75, 119 p.

Meany, E. S., 1923, Origin of Washington Geographic Names: University of Washington Press, 357 p.

Murphy, T. H., 1981, Geology of the Nicolai Mountain-Gnat Creek area, Clatsop County, northwest Oregon: Oregon State University Master of Science thesis, 355 p.

Nelson, M. P., 1978, Tertiary stratigraphy and sedimentation in the Young's River-Lewis and Clark River area, Clatsop County, Oregon: Oregon State University Master of Science thesis, 242 p.

Newton, V. C., Jr., 1976, Geologic map of the upper Nehalem River basin, Oregon: In Newton, V. C., Jr.; Van Atta, R. O., 1976, Prospects for natural gas production and underground storage of pipeline gas in the upper Nehalem River basin, Columbia-Clatsop Counties, Oregon: Oregon Department of Geology and Mineral Industries Oil and Gas Investigations 5, 56 p.

Newton, V. C., Jr.; Van Atta, R. O., 1976, Prospects for natural gas production and underground storage of pipe-line gas in the upper Nehalem River basin, Columbia-Clatsop Counties, Oregon: Oregon Department of Geology and Mineral Industries Oil and Gas Investigations 5, 56 p.

Niem, A. R.; Niem, W. A., 1985, Geologic map of the Astoria basin, Clatsop and northernmost Tillamook Counties, northwest Oregon: Oregon Department of Geology and Mineral Industries Oil and Gas Investigations 14, 2 pl., scale 1:100,000.

Niem, A. R.; Van Atta, R. O., 1973, Cenozoic stratigraphy of northwestern Oregon and adjacent southwestern Washington. In Beaulieu, J. D., Field Trip Committee Chairman, Geologic field trips in northern Oregon and southern Washington: Oregon Department of Geology and Mineral Industries Bulletin 77, p. 75-132.

Olbinski, J. S., 1983, Geology of the Buster Creek-Nehalem Valley area, Clatsop County, Oregon: Oregon State University Master of Science thesis, 204 p., map scale 1:32,000.

Olmstead, D. L., 1985, Mist gas field--Exploration and development, 1979-1984: Oregon Department of Geology and Mineral Industries Oil and Gas Investigation 10, 36 p.

Pease, M. H., Jr.; Hoover, Linn, 1957, Geology of the Doty-Minot Peak area, Washington: U.S. Geological Survey Oil and Gas Investigations OM-88, 1 sheet, scale 1:62,500.

Phillips, W. M.; Kaler, K. L., 1985, Chemical variation in upper Eocene volcanic rocks, southwestern Washington [abstract]: Geological Society of America Abstracts with Programs, v. 17, no. 6, p. 400.

Phillips, W. M., compiler, 1987, Geologic map of the Mount St. Helens quadrangle, Washington and Oregon: Washington Division of Geology and Earth Resources Open File Report 87-4, 59 p., 1 pl., scale 1:100,000

Phillips, W. M., compiler, 1987, Geologic map of the Vancouver quadrangle, Washington and Oregon: Washington Division of Geology and Earth Resources Open File Report 87-10, 27 p., 1 pl., scale 1:100,000

Rau, W. W., 1948, Foraminifera from the Miocene Astoria Formation in southwestern Washington: Journal of Paleontology, v. 22, no. 6, p. 774-782.

Rau, W. W.., 1958, Stratigraphy and foraminiferal zonation in some of the Tertiary rocks of southwestern Washington: U.S. Geological Survey Oil and Gas Investigations Chart OC-57, 2 sheets.

Rau, W. W., 1966, Stratigraphy and Foraminifera of the Satsop River area, southern Olympic Peninsula, Washington: Washington Division of Mines and Geology Bulletin 53, 66 p., 8 pl.

Rau, W. W., 1967, Geology of the Wynoochee Valley quadrangle, Grays Harbor County, Washington: Washington Division of Mines and Geology Bulletin 56, 51 p., 1 pl.

Rau, W. W., 1981, Pacific Northwest Tertiary benthic foraminiferal biostratigraphic framework--An overview: Geologic Society of America Special Paper 184, p. 67-84.

Rau, W. W., 1986, Geologic map of the Humptulips quadrangle and adjacent areas, Grays Harbor County, Washington: Washington Division of Geology and Earth Resources Geologic Map GM-33, 1 sheet, scale 1:62,500.

Rau, W. W.; Grocock, G. R., 1974, Piercement structure outcrops along the Washington coast: Washington Division of Geology and Earth Resources Information Circular 51, 7 p.

Roberts, A. E., 1958, Geology and coal resources of the Toledo-Castle Rock district, Cowlitz and Lewis Counties, Washington: U.S. Geological Survey Bulletin 1062, 71 p.

Snavely, P. D., Jr.; Brown, R. D., Jr.; Roberts, A. E.,; Rau, W. W., 1958, Geology and coal resources of the Centralia-Chehalis district, Washington, with a section on microscopical character of Centralia-Chehalis coal, by J. M. Schopf: U.S. Geological Survey Bulletin 1053, 159 p., 13 pl.

Snavely, P. D., Jr.; MacLeod, N. S.; Wagner, H. C., 1973, Miocene tholeiitic basalts of coastal Oregon and Washington and their relations to coeval basalts of the Columbia Plateau: Geological Society of America Bulletin, v. 84, no. 1, p. 387-424.

Snavely, P. D., Jr.; Rau, W. W.; Hoover, Linn, Jr.; Roberts, A. E., 1951a, McIntosh Formation, Centralia-Chehalis coal district, Washington: American Association of Petroleum Geologists Bulletin, v. 35, no. 5, p. 1052-1061.

Snavely, P. D.; Roberts, A. E.; Hoover, Linn, Jr.; Pease, M. H., Jr., 1951b, Geology of the eastern part of the Centralia-Chehalis coal district, Lewis and Thurston Counties, Washington: U.S. Geological Survey Coal Investigations Map C-8, 2 sheets, scale 1:31,680.

Twenhofel, W. H., 1946, Mineralogical and physical composition of the sands of the Oregon coast from Coos Bay to the mouth of the Columbia River: Oregon Department of Geology and Mineral Industries Bulletin 30, 46 p.

Van Atta, R. O.; Kelty, K. B., 1985, Scappoose Formation, Columbia County, Oregon--New evidence of age and relation to Columbia River Basalt Group: American Association of Petroleum Geologists Bulletin, v. 69, no. 5, p 688-698

Wagner, H. C., 1967a, Preliminary geologic map of the Raymond quadrangle, Pacific County, Washington: U.S. Geological Survey Open-File Report 67-265, 1 sheet, scale 1:62,500.

Wagner, H. C., 1967b, Preliminary geologic map of the South Bend quadrangle, Pacific County, Washington: U.S. Geological Survey Open-File Report 67-266, 1 sheet, scale 1:62,500.

Wagner, H. C.; Batatian, L. D.; Lambert, T. M.; Tomson, J. H., 1986, Preliminary geologic framework studies showing bathymetry, location of geophysical tracklines and exploratory wells, sea floor geology and deeper geologic structures, magnetic contours, and inferred thickness of Tertiary rocks on the continental shelf and upper continental slope off southwestern Washington between latitudes 46 degrees N. and 48 degrees 30 minutes N. and from the Washington coast to 125 degrees 20 minutes W.: Washington Division of Geology and Earth Resources Open-File Report 86-1, 10 p., 6 pl.

Walsh, T. J.; Korosec, M. A.; Phillips, W. M.; Logan, R. L.; Schasse, H. W., in press, Geologic map of Washington--Southwest quadrant: Washington Division of Geology and Earth Resources Geologic Map 34, scale 1:250,000.

Walsh, T. J.; Phillips, W. M., 1983, Rank of Eocene coals in western and central Washington--A reflection of Cascade plutonism?: Washington Division of Geology and Earth Resources Open-File Report 83-16, 21 p.

Warren, W. C.; Norbisrath, H., 1946, Stratigraphy of the upper Nehalem River basin, northwestern Oregon: American Association of Petroleum Geologists Bulletin, v. 30, no. 2, p. 213-237.

Warren, W. C.; Norbisrath, H; Grivetti, R. M., 1945, Geology of northwestern Oregon west of Willamette River and north of latitude 45°15': U.S. Geological Survey Oil and Gas Investigations Preliminary Map 42, scale 1:145,728.

Weaver, C. E., 1912, A preliminary report on the Tertiary paleontology of western Washington: Washington Geological Survey Bulletin 15, 80 p.

Weaver, C. E., 1916, The Tertiary formations of western Washington: Washington Geological Survey Bulletin 13, 327 p.

Weaver, C. E., 1937, Tertiary stratigraphy of western Washington and northwestern Oregon: University of Washington Publications in Geology, v. 4, 266 p.

Weaver, C. E., and others, 1944, Correlation of the marine Cenozoic formations of western North America: Geological Society of America Bulletin, v. 55, p. 569-598.

Weaver, C. E., 1945, Geology of Oregon and Washington and its relation to occurrence of oil and gas: American Association of Petroleum Geologists Bulletin, v. 29, no. 10, p. 1377-1415.

Wells, R. E., 1979, Geologic map of the Cape Disappointment-Naselle River area, Pacific County, Washington: U.S. Geological Survey Open-File Report 79-389, 1 sheet, scale 1:48,000.

Wells, R. E., 1981, Geologic map of the eastern Willapa Hills, Cowlitz, Lewis, Pacific, and Wahkiakum Counties, Washington: U.S. Geological Survey Open-File Report 81-674, 1 sheet, scale 1:62,500.

Wells, R. E., in press, Geologic map of the Cape Disappointment-Naselle River area, Pacific and Wahkiakum Counties, Washington: U.S. Geological Survey Miscellaneous Investigations Series Map I-1832, scale 1:62,500.

Wells, R. E.; Niem, A. R.; MacLeod, N. S.; Snavely, P. D., Jr.; Niem, W. A., 1983, Preliminary geologic map of the west half of the Vancouver (Wa.-Ore.) $1^{o} \times 2^{o}$ quadrangle, Oregon: U.S. Geological Survey Open-File Report 83-591, 1 sheet, scale 1:250,000.

Wolfe, E. W.; McKee, E. H., 1968, Geology of the Grays River quadrangle, Wahkiakum and Pacific Counties, Washington; Washington Division of Mines and Geology Geologic Map GM-4, 6 p., 1 pl., scale 1:62,500.

Wolfe, E. W.; McKee, E. H., 1972, Sedimentary and igneous rocks of the Grays River quadrangle, Washington: U.S. Geological Survey Bulletin 1335, 70 p.

Wolfe, J. A., 1981, A chronologic framework for Cenozoic megafossil floras of northwestern North America and its relation to marine geochronology: Geological Society of America Special Paper 184, p. 39-47.

Wurden, F. H.; Ford, D. M., 1976, Jackson Prairie gas storage project, Chehalis, Washington. In Newton, V. C., Jr.; Van Atta,

R. O., 1976, Prospects for natural gas production and underground storage of pipeline gas in the upper Nehalem River basin, Columbia-Clatsop Counties, Oregon: Oregon Department of Geology and Mineral Industries Oil and Gas Investigations 5, 56 p.