Attachment 11
The Washington Coal Region (Pacific and Central)

The Pacific Coal Region (Figure A11-1) is approximately 6,500 square miles and lies along the western and eastern flanks of the Cascade Range from Canada into northern Oregon. The coals along the western flank lie within the Puget downwarp. Bellingham, Seattle, Tacoma, and Olympia in the State of Washington, and Portland, Oregon lie in or adjacent to the sub-basins. Choate et al. (1980) estimated coalbed methane resources for four target sub-basins (Figure A11- 1) representing 1,800 square miles of the 6,500 square mile Pacific Coal Region to be 0.3 trillion to 24 trillion cubic feet (Tcf). The Central Coal Region (Figure A11-2) is primarily the Columbia Plateau, between the Cascade Range to the west and the Rocky Mountains in Idaho, to the east. The Region extends from the Okanogan Highlands in the north to the Blue Mountains to the south, and encompasses approximately 63,320 square miles. Pappajohn and Mitchell (1991) estimated the coalbed methane potential of the Central Coal Region to be more than 18 billion cubic feet (Bcf) per square mile. According to the available literature, there were no producing fields in either the Pacific Coal Region or the Central Coal Region in Washington as of 2000 (GTI, 2001).

11.1 Basin Geology

A series of discontinuous coal fields lie along the western flank of the Cascade Range (Figure A11-3). The Roslyn and Taneum-Manastash fields are located on the eastern flank of the Cascade Range (Figure A11-3). The coal-bearing sediments were formed in a swampy fluvial-deltaic coastal plain depositional environment in the Paleocene to late Eocene Eras. In the Columbia Plateau Region, the Cretaceous to Eocene coal-bearing rocks are buried beneath a thick sequence of extrusive basalts.

The coal-bearing deposits of the Pacific and the Central Coal Regions are Cretaceous to Eocene Age and formed within fluvial and deltaic depositional environments prior to the uplift of the Cascade Mountain Range. The coalbeds of the Pacific and Central Basins are thought to result from peat accumulations in poorly drained swamps of the lower deltas while the thinner coalbeds probably formed in the better drained upper deltas (Buckovic, 1979 as cited in Choate et al., 1980). During the Oligocene, Cascade volcanic activity buried the deltaic sediments and compression caused some deformation of the sediments. During the Miocene, extensive volumes of basalt poured out in central Washington and covered the coal-bearing fluvial deposits. During the late Pliocene, the Coast Range and the Cascades continued to be uplifted, separating the Pacific Coal Region from the Central Coal Region, and causing extensive tectonic deformation, folding and faulting, of the coal-bearing sediments.

Deformation of the coal-bearing rocks increases toward the Cascade front. Fracturing may enhance porosity and permeability of the coalbeds, allowing greater methane storage and production (Pappajohn and Mitchell, 1991). On the other hand, however, fracturing may also increase the porosity and permeability of confining beds, allowing methane to escape up the stratigraphic section over time and dissipate in the atmosphere. Continuing deformation, primarily faulting, may be a limiting factor controlling methane production in the Pacific Coal Region as well.

11.1.1 Pacific Coal Region Geology

In the Pacific Coal Region, deformation has increased geologic complexity making it difficult to follow or correlate coalbeds, especially across faults. Geothermal heating along the western flank of the Cascades created a thermally altered zone of increased coal rank ranging into the bituminous and anthracite ranks. The maturation to bituminous rank increases potential methane yields (Walsh and Lingley, 1991; Pappajohn and Mitchell, 1991).

The major coal-bearing areas are in, from north to south, Whatcom, Skagit, King, Pierce, Kittitas, Thurston, Lewis, and Cowlitz Counties in Washington (Figure A11-3). The discussion of regional geology presented here illustrates the geologic conditions in the Green River district in King County, the Wilkerson-Carbonado coalfield in Pierce County, and the Centralia-Chehalis district in northern Lewis and southern Thurston Counties, and does not attempt to provide a detailed description of every coalfield. For more detailed information on the Bellingham area, Whatcom County, the reader is referred to Beikman et al. (1961), for Whatcom and Skagit Counties to Jenkins (1923 and 1924), and for the Roslyn coal area to Walker (1980). Other areas not discussed but important within the Pacific Region are the Toledo-Castle Rock District, and the Roslyn-Cle Elum and Teneum-Manastash fields. The stratigraphy for three sub-basins (Green River, Wilkerson-Carbonado, and Centralia-Chehalis) of the Pacific Coal Region is presented in Figure A11-4. The general setting and geology of each sub-basin is unique and complex.

The coal deposits of King County are located southeast of Seattle (Figure A11-3). The Green River district is the largest and most extensively mined coal-bearing area in King County. The King County coals occur in the Puget Group of Eocene Age (Figure A11-4). Evans (1912) divided the Puget Group into 3 coal zones, which, from oldest to youngest, are the Bayne, Franklin, and Kummer. Deformation has been moderate and most of the coalbeds dip less than 35 degrees. In parts of the Green River district the deformation has been more intense, and dips of 50 degrees or more are common. The King County coals range in rank from subbituminous to high-volatile bituminous. Within the Green River District, the Puget Group is estimated to be at least 6,500 feet thick and contains at least 15 coalbeds up to 40 feet thick (Beikman et al., 1961). The principal coalbeds are located in the Franklin and Kummer zones in the Puget Group (Vine, 1969). Coal has been mined in the Green River District since about 1883, and it has produced more than 25 million tons of coal. Currently there is no coal production in the district.

The Wilkerson-Carbonado coalfield is located in Pierce County, southeast of Seattle (Figure A11- 3). The Pierce County coals occur in the Eocene Carbonado Formation (Beikman et al., 1961). The Carbonado consists of more than 5,000 feet of interbedded, layered lenses of sandstone, siltstone, mudstone, and shale with carbonaceous shale and coal (Figure A11-4). At least 10 coalbeds have been identified in the area. Coalbeds range in thickness from 1 to 5 feet with the maximum thickness of 15 feet. The coals range in rank from high-volatile bituminous to low-volatile bituminous. The Wilkerson-Carbonado coals have the highest rank of any major coal-bearing area in Washington State. Throughout the field, deformation has been intense. Dips of 60 degrees or more are common, and fault displacements range from a few feet to more than 1,500 feet. Although these areas have recently been targets of coalbed methane exploration, there is currently no production.

The coal deposits of Lewis and Thurston Counties occur in the Skookumchuck Formation (Figure A11-3) of late Eocene Age (Snavely et al., 1958). The Centralia-Chehalis district is located in northern Lewis and southern Thurston Counties (Figure A11-3). Deformation of the Skookumchuck is moderate resulting in tightly folded anticlines and broad open synclines. The coal deposits have been cut by a series of high angle reverse faults roughly paralleling the fold axes. The faults dip to the northeast, with the southwest block downthrown, and have displacements ranging from 200 to 500 feet. The coal rank ranges from lignite to anthracite. The central part of the Centralia-Chehalis district contains as many as 14 subbituminous coalbeds ranging from a few inches to over 40 feet in thickness. The district contains more than half of the calculated coal reserves of the State. The TransAlta Centralia Mining Company continues to operate a major strip mine centered about 5 miles northeast of Centralia, where it is anticipated that 9,400 acres will be stripped over 35 years. Within the Centralia mine, the Big Dirty bed is more than 40 feet thick. To the west of Centralia, the Vader coal area contains several lignite beds with thickness up to 20 feet, which may correlate in part with the coals in the Centralia-Chehalis area.

In Whatcom and Skagit counties (Figure A11-3), the Chuckanut Formation contains as many as 15 coalbeds, ranging from 1 to 15 feet thick and ranking from lignite to anthracite, but generally bituminous. The rank of the coal increases eastward towards the crest of the Cascades Range.

The rank of Pacific Region coals varies greatly from place to place, ranging from lignite to anthracite, but generally rank increases toward the crest of the Cascade Range. The coal rank is used to identify bituminous coal-target areas where gas yields may be greatest. While the structural geology is very complex, the thermally-altered metamorphic zone is rather predictable. Both of these factors will play a major role in the design of any exploration and development plans for coalbed methane in the Pacific Coal Region.

The complex stratigraphy and structural deformation of the lenticular coals in the Pacific Coal Region are major obstacles to the exploration and development of coalbed methane fields. Predicting the location of coalbeds is a complex and difficult process because the geology in the area has been modified by intense deformation. Additionally, the faulting that commonly occurs along the axes of anticlines may form conduits for the escape of methane through overlying confining beds. Steeply dipping beds of coal have presented difficulties in controlling drill bit directions and in development and stimulation for coalbed methane production.

Choate et al. (1980) estimated coalbed methane resources for four target sub-basins (Figure A11-1), representing 1,800 square miles of the 6,500 square mile Pacific Coal Region, to be 0.3 trillion to 24 Tcf. Methane had been encountered in 67 oil and gas exploration wells drilled in this region by 1984. Methane gas was found at depths of less than 500 feet in 25 wells, less than 1,000 feet in 38 wells, and less than 2,000 feet in 50 wells. In western Whatcom County, methane has been found in unconsolidated glacial drift capped by impervious clay beds. East of Ferndale, methane gas reportedly has been produced commercially from unconsolidated deposits at depths ranging from 166 to 193 feet at flow rates ranging from 750,000 to 5,000,000 cubic feet per day (Choate et al., 1980).

11.1.2 Central Coal Region Geology

The Central Coal Region refers to the coal-bearing formations east of the Cascade Range. The Columbia River Basalt Group, primarily the Grande Ronde Basalt, Wanapum Basalt, and Saddle Mountains Basalt bury the Cretaceous to Eocene coal-bearing formations of the Central Coal Region. In this region, methane is entrained in groundwater from confined aquifers in the basalts. Interbedded with the flood basalts are epiclastic and volcaniclastic sediments. The less fractured zones of basalt appear to act as aquitards (Johnson et al., 1993). Johnson et al. (1993) have concluded that the greatest volume of methane is derived from upward migration from the underlying Eocene coals. They also suggest that faults through the underlying sediments and basalts provide conduits for the migration of gas-bearing groundwater into the confined zones.

The Yakima fold belt lies between the confluence of the Snake and Columbia Rivers and the Cascade Range, and is a series of broad asymmetric anticlines and synclines whose axes generally trend west northwest to east southeast (Figure A11-5). The anticlinal ridges are typically cut by thrust faults that are inclined and steepen with depth (Reidel et al., 1989). While the anticlines may form structural traps for methane in the source coalbeds, the thrust faults in the anticlines may form conduits for the upward migration of methane through overlying confining beds. The fold structures are very flat and broad and do not result in the steeply dipping strata that are characteristic of the Pacific Coal Region west of the Cascades.

11.2 Basin Hydrology and USDW Identification

Surficial deposits of Pleistocene glacial outwash locally form aquifers capable of sustaining public drinking water supplies in the Pacific and Central Washington Regions. In the Central Coal Region, aquifers in the basalts are extensively developed for irrigation. Public water supplies in Pierce County (Olympia area) and King County (Seattle area) of the Puget Sound Region (Pacific Coal Basin) are obtained from the glacial drift aquifer (Dion, 1984) that overlies Eocene sediments, which may contain coal and methane. Water quality information from four gas test wells indicates the presence of 1,330 to 1,660 milligrams per liter (mg/L) total dissolved solids (TDS) in water within the coalbeds of Pierce County (Dion, 1984). This meets the water quality requirements of an underground source of drinking water (USDW). The Washington Department of Ecology and the EPA deemed this water to be of sufficient quality to permit its discharge to surface waters of the Carbon River (Pappajohn and Mitchell, 1991).

The Columbia River Basalt Group is identified as a major regional multi-aquifer province (Lindholm and Vaccaro, 1988; Dion, 1984). The aquifer is used extensively for irrigation, but may also be used as a source of drinking water. Wells in the Basalts commonly yield 150 to 3,000 gallons per minute. TDSs in the water produced generally range from 250 to 500 mg/L (Dion, 1984).

The occurrence of methane in groundwater is one factor leading to the assessment of the coalbed methane production potential in Washington. Methane in groundwater occurs in the basalts, but only in confined aquifers (porous or fractured zones near the top or bottom of a basalt layer), and is thought to have migrated upward from underlying coalbeds. Water supply wells and irrigation wells in the Columbia River Basalts and water wells in numerous different lithologies in the Pacific Coal Region have been recognized as containing methane. Data demonstrating the co-location of a coal seam and a USDW were found for Pierce County, where methane gas test well results report TDS levels far lower than the 10,000 mg/L USDW water quality threshold (Dion, 1984).

11.3 Coalbed Methane Production Activity

Complex stratigraphy and structural deformation creates major obstacles to the development of gas from the Pacific Coal Region. The coals are known from active and inactive mines to be gassy, folded, faulted, and commonly steeply inclined. The difficulties and dangers involved with underground coal mining led to closure of the mines once the shallow deposits were exhausted. However, their characteristics have been well documented by the mining operations. Many of these same structural characteristics have impeded the development of coalbed methane gas. The available literature indicates that no significant production had been achieved by 1996 (GRI, 1999). According to the available literature, there were no producing fields in either the Pacific Coal Region or the Central Coal Region in Washington as of 2000 (GTI, 2001). However, in northwest Oregon, the Mist gas field was developed in the 1990s.

11.3.1 Pacific Coal Region Production Activity

Between 1986 and 1993, 19 coalbed methane wells were drilled in the northern Pacific Coal Region (Quarterly Review, 1993). Three tests were conducted near the town of Black Diamond in the Green River coal area of King County. One of the wells was hydraulically fractured and the others completed by open-hole cavitation. Steep dips of the strata led to wellbore deviation during drilling and to caving following the fracturing operations. One well produced 32,000 to 62,000 cubic feet per day of coalbed methane gas with no water in an open-hole test. Another was hydraulically fractured with 12/20 mesh sand and nitrogen foam in two zones at depths of 2,228 to 2,442 feet and 2,505 to 2,638 feet, but no test results were released. Caving was so prominent that it interfered with wellbore cleanup following the hydraulic fracturing operations. According to available publications, optimal fracturing and completion methods for use in the structurally difficult Pacific Coal Region are yet to be applied and proven.

11.3.2 Central Coal Region Production Activity

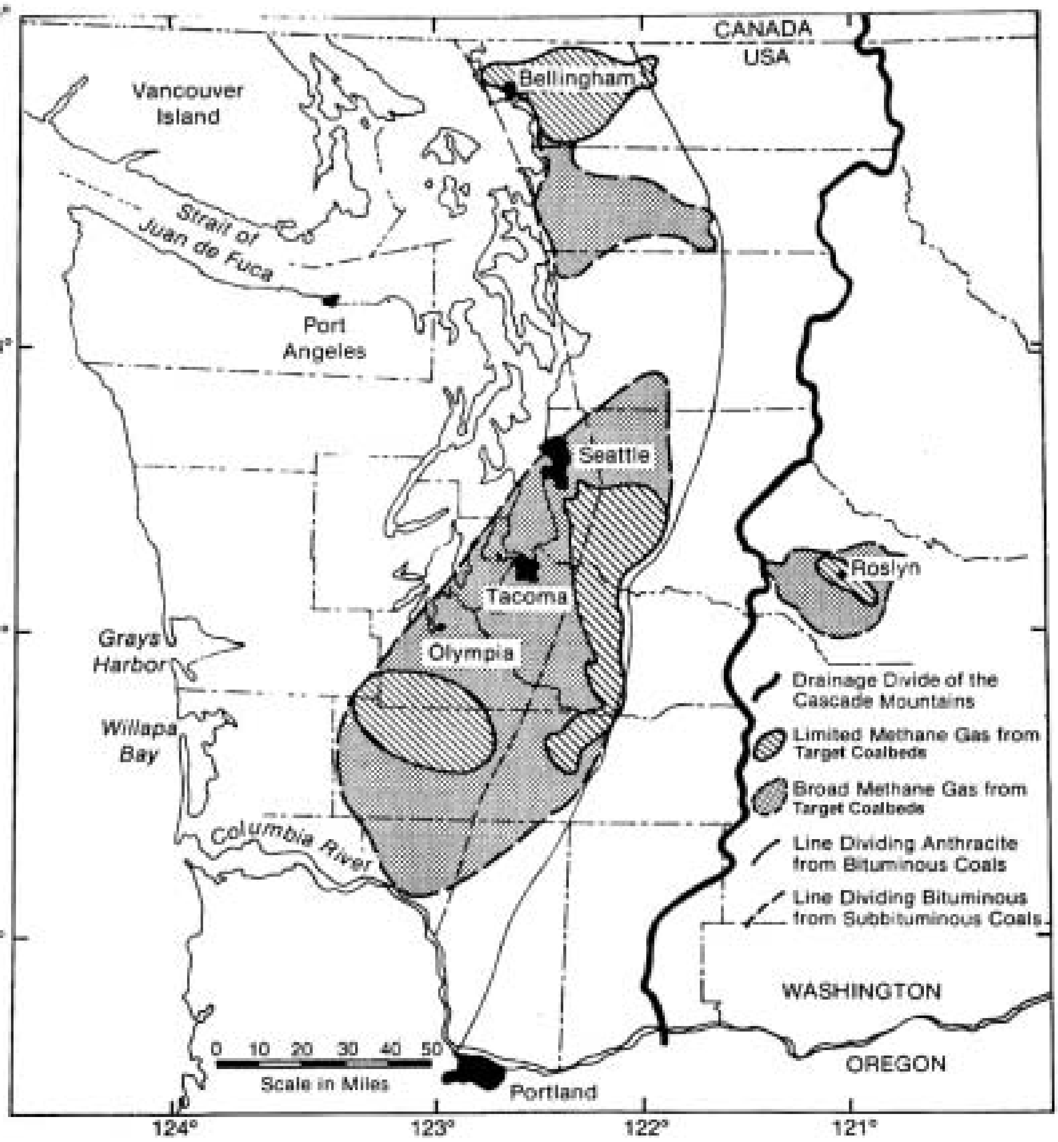
The one commercial gas field (Rattlesnake Hills) in the Central Coal Region was shut down in 1941. Production from the Cretaceous to Eocene coalbeds that lie below the basalts may have large potential. Pappajohn and Mitchell (1991) estimated the coalbed methane potential of the Central Coal Region to be more than 18 Bcf per square mile. It is unlikely that the whole 63,320 square miles of the region could yield that rate because the coals are only known to occur below the basalts in the western part of the basin. Much is not known about the potential coalbed methane production from these obscured deposits, and development depends on successful exploration.

Although the coals of the Central Coal Region may not be as greatly deformed and unpredictable as those in the Pacific Coal Region, they are overlain by the Columbia River Basalt Group, in which individual basalt flows up to 300 feet thick can cover thousands of square miles. The Rattlesnake Hills gas field operated between 1913 and 1941 in the western part of this region and indicates greater potential for development.

11.4 Summary

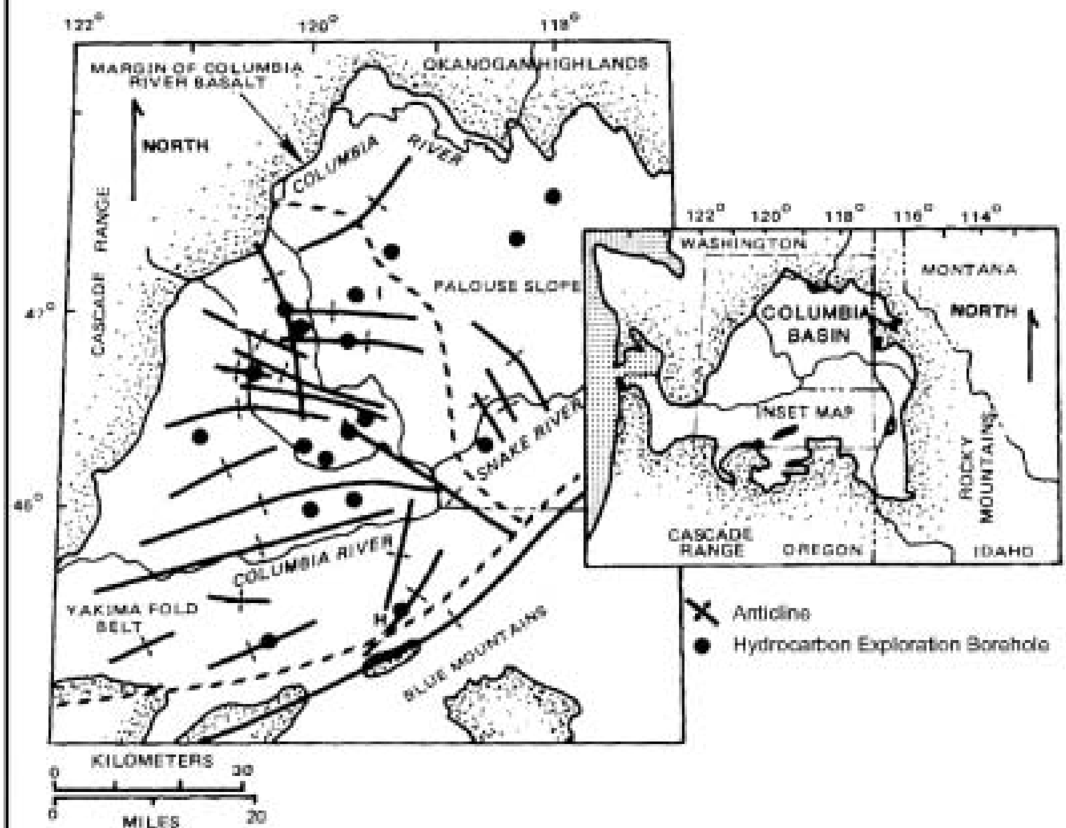
The geologic structure of the coal-bearing rocks is difficult to interpret in the Pacific and Central Coal Regions, and methane may be technically difficult to produce in these regions. A connection exists between the Washington coalbeds and a USDW. However, there were no producing coalbed methane wells in the Pacific and Central Coal Regions in Washington as of 2000 (GTI, 2001). In some areas, the Pacific and Central Regions' coals exist within a potential USDW. In other areas of the basin, there is evidence that the coalbeds are below a USDW. Hydraulic fracturing has been documented in this region. Data demonstrating the co-location of a coal seam and a USDW were found for Pierce County, where methane gas test well results report TDS levels of 1,330 to 1,660 mg/L, far less than the USDW classification limit of 10,000 mg/L (Dion, 1984).

In this region, methane occurs in groundwater flowing through fractured zones in basalts, although less fractured zone of the basalts appear to act as hydraulic confining layers. Johnson, et al. (1993) concluded that the greatest volume of this methane has migrated upward from underlying coalbeds. Water supply wells and irrigation wells in the Columbia River Basalts and water wells in numerous different lithologies in the Pacific Coal Region have been recognized as containing methane. Development of coalbed methane in the Washington Coal Region may have some impact on highly productive basalt aquifers that meet the requirements of a USDW and are already in use as large sources of irrigation water for agriculture.



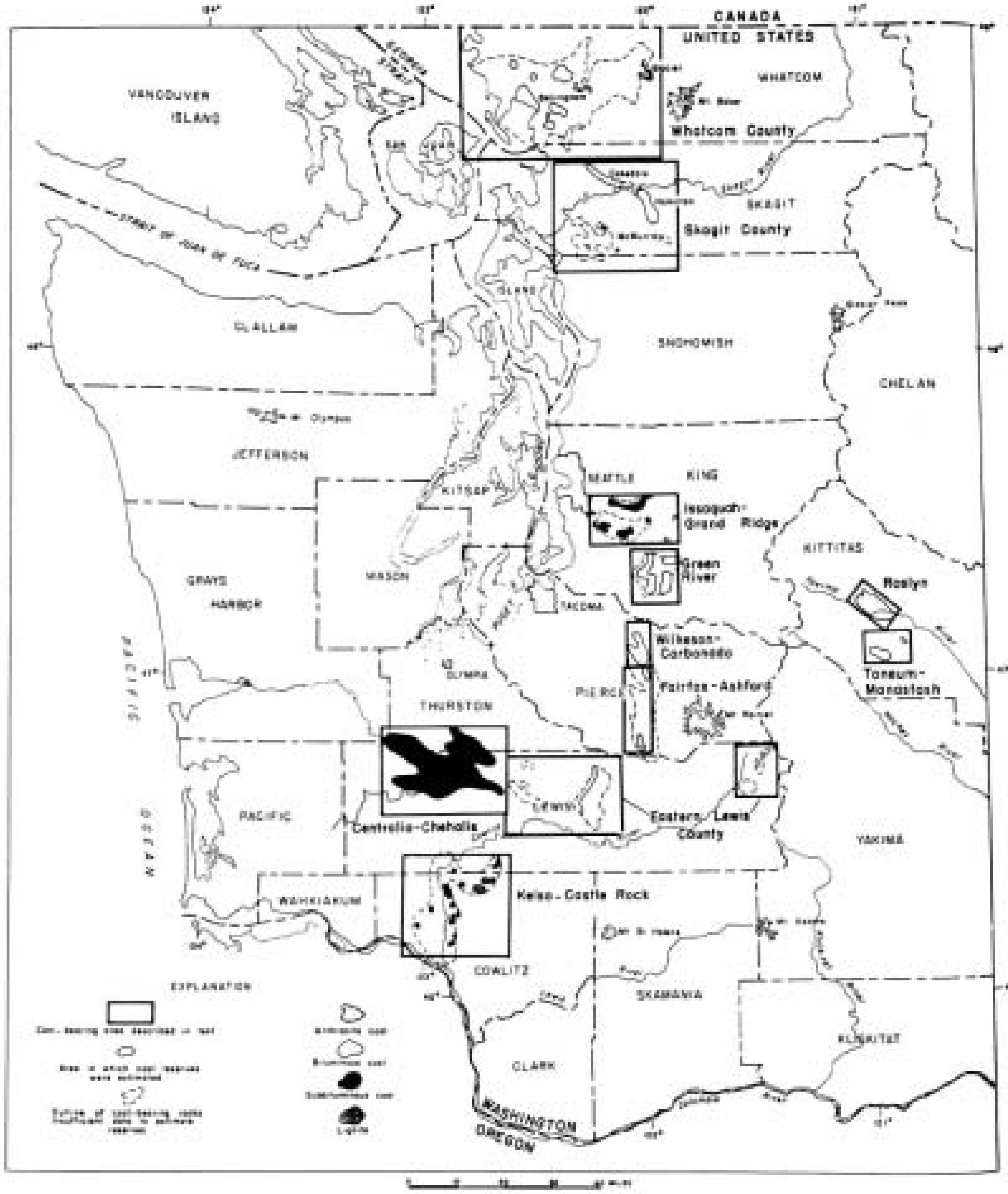
The Pacific Coal Region Showing Targeted Subbasins
Used for Coalbed Methane Estimates (Choate et al., 1980)

Figure A11-1



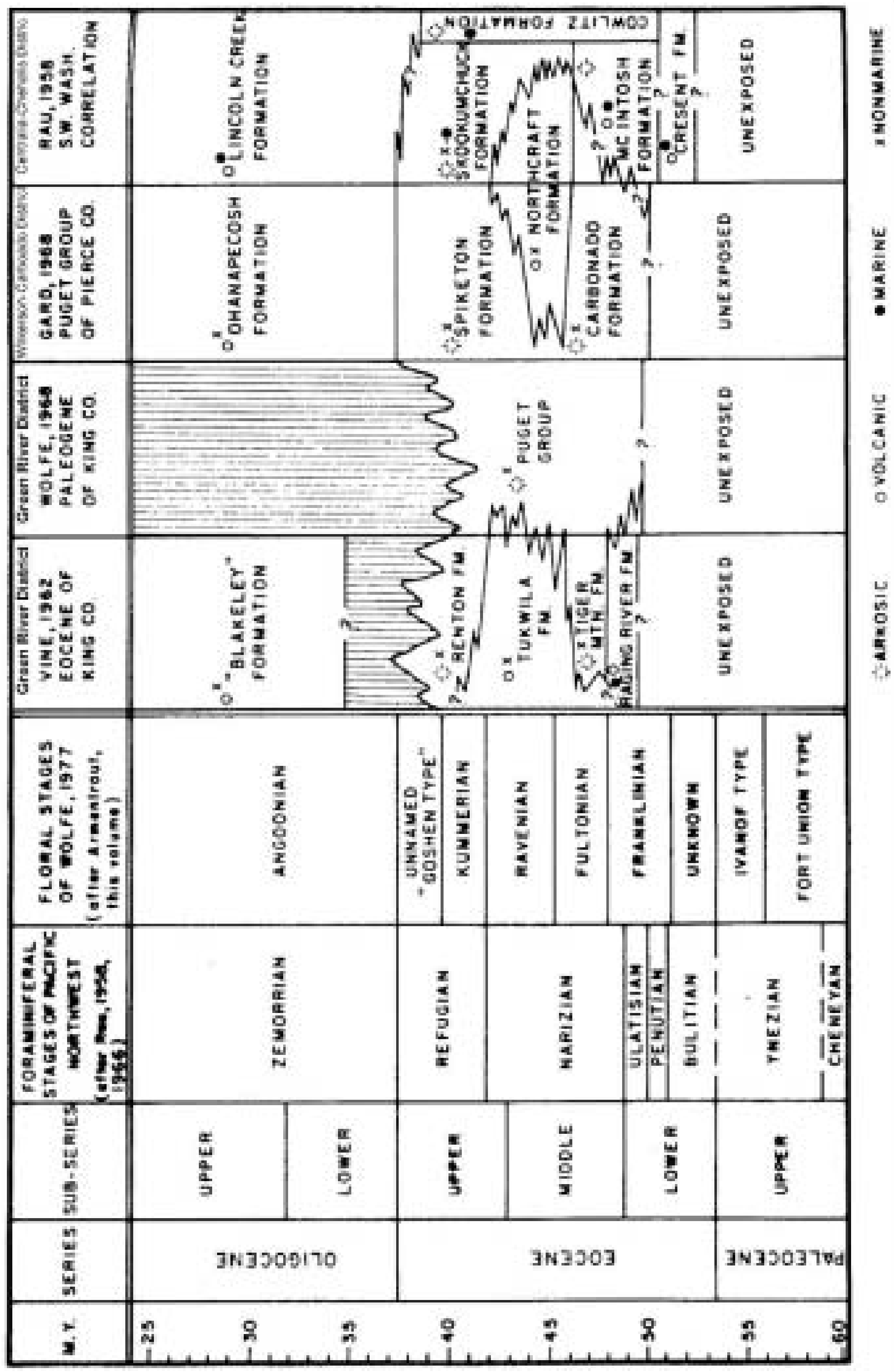
The Central Coal Region (Johnson et al., 1993)

Figure A11-2



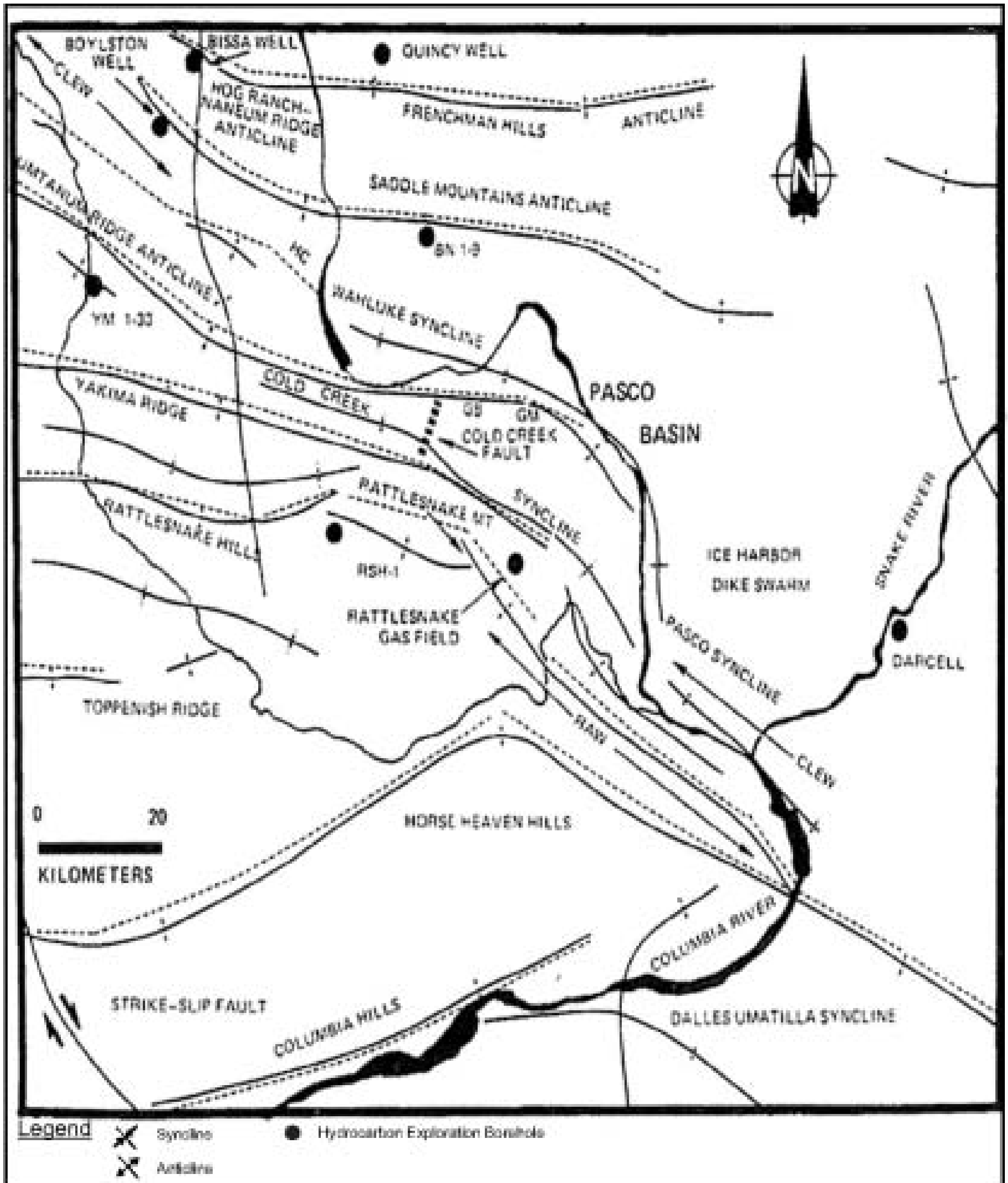
Major Coal-Bearing Areas in Western Washington (Choate et al., 1980)

Figure A11-3



Stratigraphy for Three Coal Districts of the Pacific Coal Region (Choate et al., 1980)

Figure A11-4



Structural Map of the Central Columbia Basin and Yakima Fold Belt
(Johnson et al., 1993)

Figure A11-5

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