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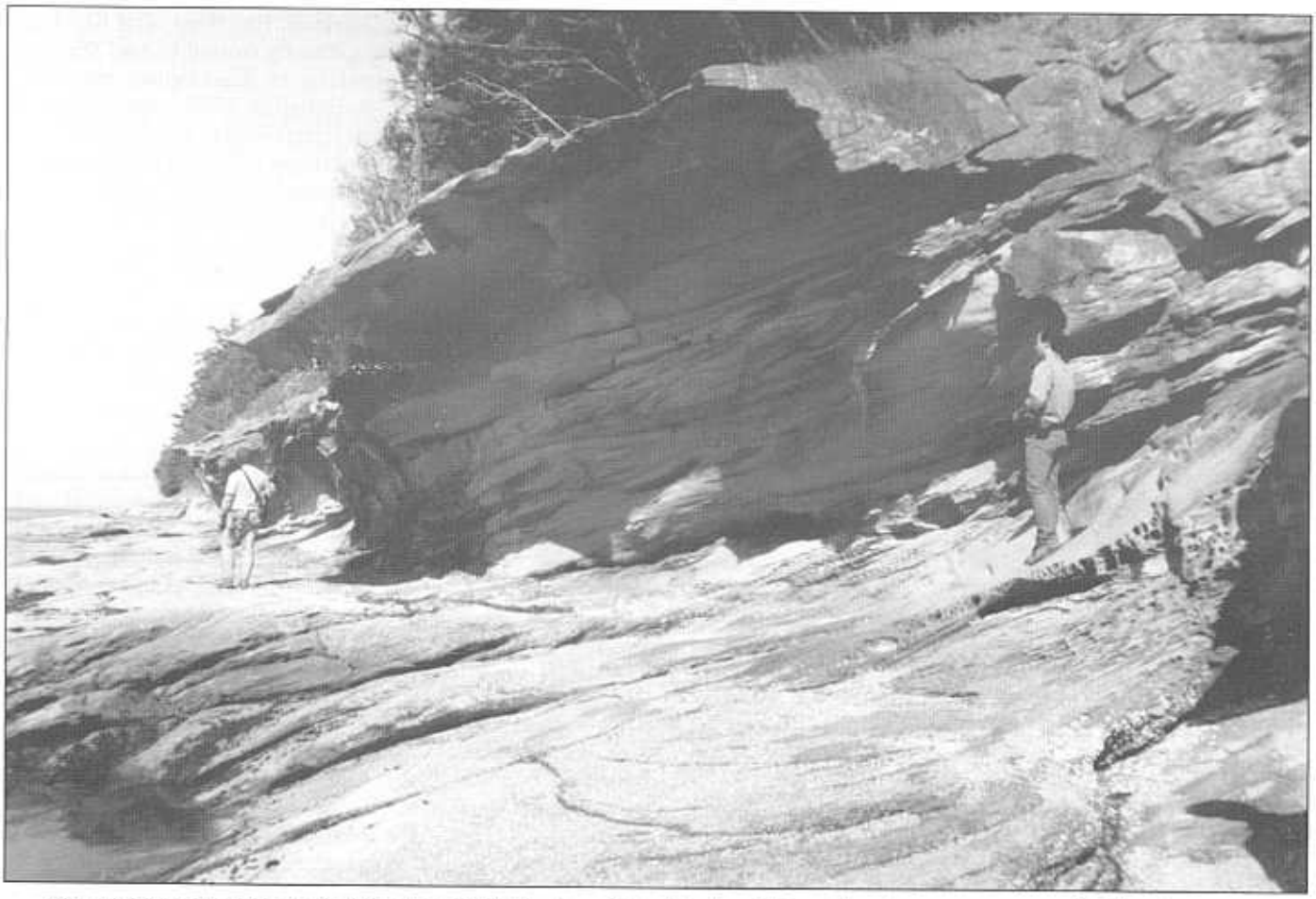

Cross-bedded sandstone of the Governors Point Member of the Chuckanut Formation at an outcrop west of Bellingham. S. Y. Johnson (USGS) interprets these as braided river deposits; their source was a rapidly eroding highland on and near Lummi Island. See related article, p.12. Photo by T. J. Walsh.

IN THIS ISSUE

Petroleum Geology of the Bellingham Basin, Washington, and Evaluation of the AHEL and Partners Birch Bay No. 1 Well

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A preliminary evaluation of well logs, drill and core samples, gas samples from seeps, and geophysical data from the Bellingham basin in 1986 by American Hunter Exploration Ltd. (AHEL) revealed the significant hydrocarbon potential of this frontier basin. In 1986 and 1987, a seismic and gravity program was completed to further delineate structural highs (Fig. 1). The Birch Bay No. 1 well was drilled by AHEL and partners in 1988 to test a large anticlinal structure in the western part of the basin (Fig. 1). The total depth of this well was 9,125 ft, and it penetrated nonmarine Tertiary Huntingdon and Chuckanut Formation sedimentary rocks. The well was drilled both to test the structure for commercial hydrocarbons and to provide pertinent data for basin evaluation.

Fourteen cores were cut, and 14 drillstem tests were performed to evaluate the structure for hydrocarbons and reservoir quality. In addition, multiple sets of cutting samples were collected to determine the source rock potential and the biostratigraphic age of the rocks. Figure 2 is a north-south seismic section across the Birch Bay structure. Regional correlation of a middle Eocene seismic reflector suggests a structural closure of approximately 8 mi^2. The Birch Bay No. 1 well, located near the crest of the anticline, tested water that contained solution gas from numerous sandstones. The salinity of the water increased from 800 ppm chlorides at 800 ft to 23,000 ppm at 3,500 ft. Three sandstone intervals had good mud gas responses and tested gas to surface at low rates. Both post-Eocene faulting and the near-surface subcropping of Oligocene sedimentary rocks may have permitted the deep flushing of meteoric water and the breaching of the structural trap. Reinterpretation of the seismic data shows that the well may not be in the optimum structural location on this faulted anticline. If the Mist field in Oregon is used as an analogue for exploration, numerous gas pools of less than 8 billion ft^3 of recoverable gas reserves may be present in small faulted blocks in the Birch Bay structure.

Reservoir rock penetrated in the well consists of medium- to coarse-grained arkosic sandstones and bimodal or polymodal conglomerates. The sandstones coarsen downward, a character typical of fluvial meander channels. Several conglomerate/sand channel deposits have the blocky electric-log profile of braided streams. Porosity decreases with depth from 26 percent at 1,000 ft to less than 10 percent below 6,000 ft. This decrease is caused by feldspar degradation, an increase in silica cement, and compaction. Permeability-feet (Kh) calculations from core analyses indicate permeable reservoir rock down to at least 4,500 ft. However, flow capacity (in situ Kh) calculations suggest that laboratory permeability measurements may be optimistic. Laboratory analyses could be affected by clay dehydration and (or) removal of net overburden pressure. Despite the more pessimistic in situ Kh calculations, good quality (>100 md/ft) reservoir rock ca-

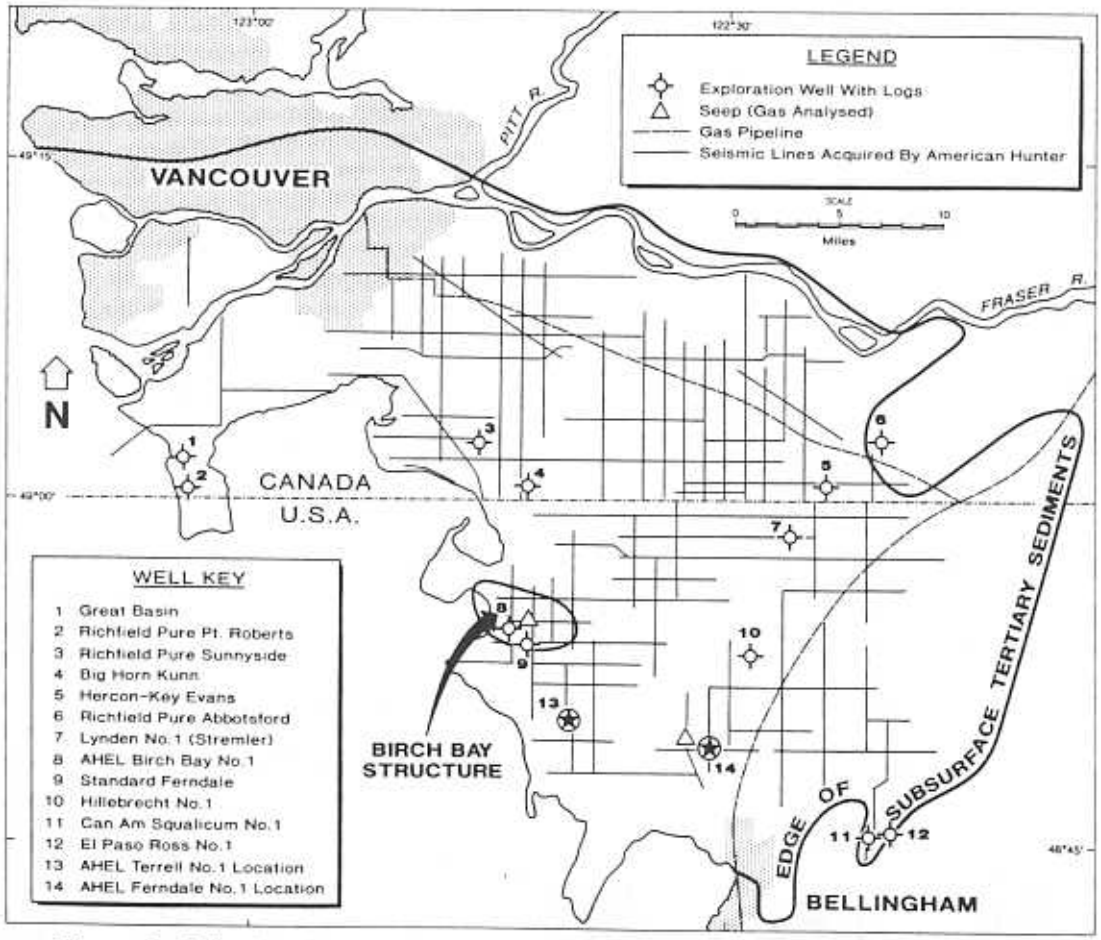

Figure 1. Bellingham Basin Project area. AHEL and partners have licensed two new drilling locations, Terrell No. 1 and Ferndale No. 1; these wells will test the Chuckanut Formation in two subsurface structures.

pable of storing and producing hydrocarbons is present in the well above 4,500 ft.

An unconformity may be present at 6,000 ft where shale changes color from gray-brown above this depth to bluish gray, orange, and maroon. Below 6,000 ft the sands are impermeable and fractured, and they have a high lithic content. A saltwater flow at 7,925 ft and good gas shows from cemented impermeable sands below 6,000 ft attest to the presence of fractures. A 200-ft-thick diorite sill was penetrated at 7,000 ft. Its age has yet to be determined.

Palynological analyses by J. Lentin of L. I. B. Consultants Ltd. indicate lower Oligocene deposits at 130 ft, upper Eocene at 600 ft, middle Eocene at 1,800 ft, and lower Eocene at 3,600 ft. Samples between 3,600 ft and 6,500 ft contained undiagnostic material. Below 6,500 ft, samples were barren of spores or pollen. On the basis of the stratigraphic sequence proposed by Johnson (1982), this would place the Padden Member of the Chuckanut Formation between 600 ft and 3,600 ft, the Bellingham Bay Member from 3,600 ft to the proposed unconformity at 6,000 ft, and possibly Paleocene or Cretaceous sedimentary rocks below 6,000 ft.

Source rock evaluation shows that coals and shales down to a depth of 6,000 ft have high concentrations of Type IIB kerogen (liquid hydrocarbon prone); numerous rocks in this interval contain more than 6 percent total organic carbon (TOC). Rocks below 6,000 ft contain Type III kerogen (humic) and have low TOC values. Pyrolysis data show that "early-mature" maturation conditions prevail below 6,000 ft, and vitrinite reflectance data indicate that early mature conditions occur below 4,200 ft. Thus the kerogen-rich Type IIB rocks are immature, and the kerogen-poor Type III rocks are within the oil window on the structure. From this it can be concluded that in order to generate significant quantities of hydrocarbons, the kerogen-rich Type IIB rocks must be buried significantly deeper or located closer to a high heat-flow regime.

Gas seeps from old well casings (Fig. 1) have been sampled and analyzed by American Hunter. Isotope analyses

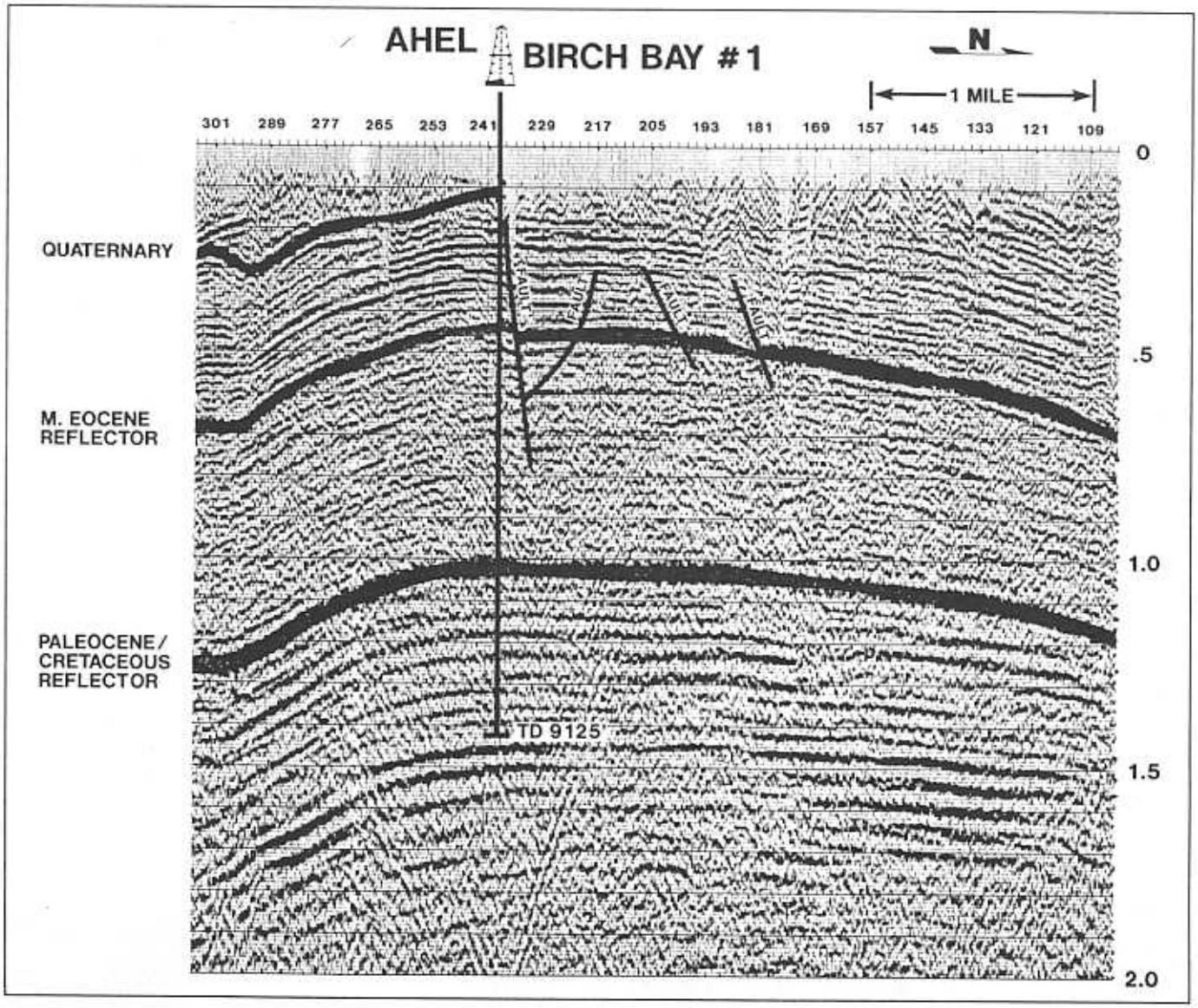

Figure 2. Seismic section across the Birch Bay structure. The middle Eocene reflector was mapped regionally across the basin. The Birch Bay anticline has 5,000 acres of structurally closed area mapped on the Eocene reflector. Vertical scale is two-way time in seconds.

indicate a thermal origin with some biogenic mixing for the gases. This substantiates that hydrocarbons have been generated at depth and that there is a potential for commercial accumulations of gas in the basin.

In summary, the Bellingham basin has all the characteristics that contribute to commercial hydrocarbon accumulations. The Chuckanut Formation contains rich source rocks that should be mature east or southwest of the Birch Bay No. 1 well. Thick, porous, and permeable channel sandstone reservoirs are common in the Chuckanut Formation. Furthermore, large fault-related structures, adequate shale seals, and numerous thermogenic gas shows are present in the basin. The basin's potential could be confirmed by drilling more wells.

Reference Cited

Johnson, S. Y., 1982, Stratigraphy, sedimentology, and tectonic setting of the Eocene Chuckanut Formation, northwest Washington: University of Washington Doctor of Philosophy thesis, 221 p., 4 pl.

Northwest Pipeline Corporation Expands into the '90s

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The Federal Energy Regulatory Commission's (FERC) program, commonly referred to as "open access", completely changed the character of the natural gas industry. Beginning in the mid-1980s with the issuance of Orders 436 and 500, the FERC directed interstate pipeline companies to provide natural gas service to all parties on a nondiscriminatory basis. Access to such transportation services combined with market-based wellhead pricing allowed gas to become competitive with alternative fuels and more cost effective for all end-users. The subsequent impact on Pacific Northwest natural gas markets in industrial, commercial, and residential applications has been dramatic. The volume of gas transported annually through Northwest Pipeline Corporation's (Northwest) system has grown from 432 trillion Btu (TBtu) in 1985 to 555 TBtu in 1990, an increase of 28 percent.

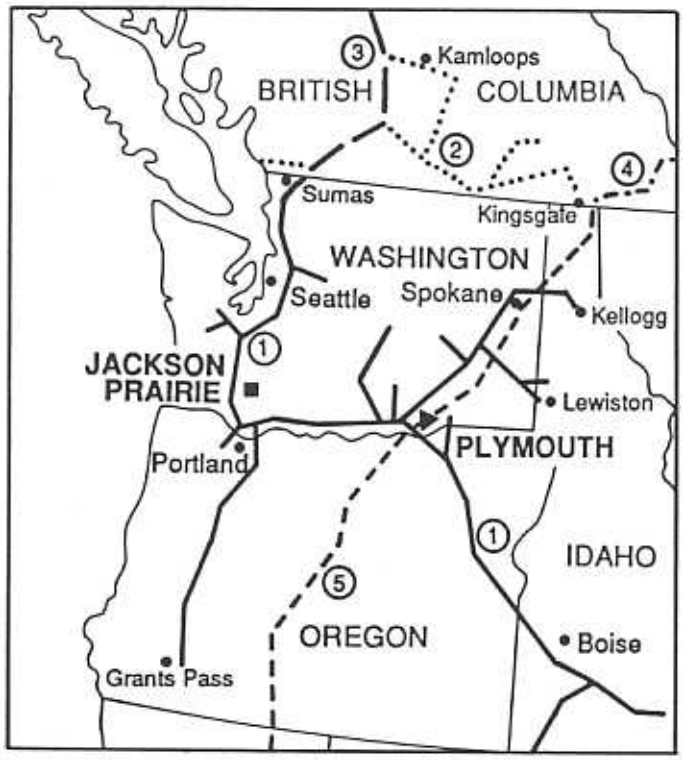

Figure 1. Natural gas transmission lines and storage facilities in Washington and adjacent areas. 1, Northwest Pipeline Corp.; 2, B.C. Gas Inc.; 3, Westcoast Energy, Inc.; 4, Alberta Natural Gas Co., Ltd.; 5, Pacific Gas Transmission Co.

This increase in demand has been driven by several factors that include competitive pricing, demand for electricity, population and industrial growth in the region, and air-quality concerns. This growth spurred natural-gas producers, marketers, local distribution companies, and end-users to request additional firm (or guaranteed on a 365-days-per-year basis) transportation capacity on Northwest to serve their expanding markets. By early 1990, Northwest's firm transportation capacity queue had grown to include 47 shippers requesting more than 3 TBtu per day of additional firm capacity.

In response to those requests, Northwest filed an application with the FERC on December 31, 1990, requesting authority to construct and operate facilities capable of delivering an additional 534,007 million Btu per day (MMBtu/d). The application was amended on October 7, 1991, to reduce the volume to its current 433,415 MMBtu/d. This would effectively increase the system's capacity by approximately 20 percent. The FERC's final order authorizing construction is expected in the first quarter of 1992. Upon receipt of that order, construction would begin in the second quarter of 1992, with commencement of service in the first quarter of 1993.

The expansion project includes the installation of approximately 42 miles of pipeline and 42,000 horsepower of compression at various places throughout the state of Washington. These additions will bolster the existing system that

Mainline Capacities	1990 Performance
Design day: 2.0 Bcf/day	Total deliveries: 555 TBtu
Record delivery: 2.4 Bcf/day	Average daily delivery: 1.5 TBtu
System receipts (in MMcf/day):	Service activity:
Canadian - 790	92% transmission; 8% sales
Domestic - 580	Sources of gas:
Jackson Prairie - 450	51% domestic
Plymouth LNG - 300	49% Canadian