

PETROLEUM GEOLOGY AND RESOURCE ESTIMATES OF THE PACIFIC OCS REGION

LOCATION

The Pacific OCS Region extends from the United States-Canada maritime boundary to the United States-Mexico maritime boundary and comprises submerged Federal lands (i.e., beyond the 3-mile line) offshore Washington, Oregon, and California (see front cover). The Region encompasses an area of complex geology along a tectonically active crustal margin. Intermittent periods of Cenozoic sedimentary deposition, volcanism, folding, and faulting within this region have created a number of environments favorable for the generation, accumulation, and entrapment of hydrocarbons. Numerous geologic basins and areas exist along the continental shelf and slope within the Region (fig. 10). Some of these are geological extensions of onshore basins and have proven hydrocarbon accumulations; several other areas are sparsely explored but are expected to have considerable petroleum potential.

GEOLOGIC SETTING

The geologic history of the Pacific coastal margin has been dominated by the interaction of oceanic and continental crustal plates. The modern tectonic framework includes juxtaposed oceanic and continental crust along three primary tectonic boundaries: (1) subduction of oceanic crust beneath continental crust along the Cascadia subduction zone, (2) right-lateral strike-slip movement of oceanic crust along the east-west-trending Mendocino fracture zone, and (3) right-lateral strike-slip movement of continental crust along the north-west-trending San Andreas fault zone. The Mendocino fracture zone separates the Region into two distinct tectonic realms: (1) a northern area where Cenozoic geologic history has been consistently dominated by convergent tectonics along the Cascadia subduction zone and (2) a southern area where early Cenozoic geologic history has been dominated by convergent tectonics along an ancient subduction zone and where middle to late Cenozoic geologic history has been dominated by wrench tectonics along the San Andreas and subsidiary faults.

Regional stratigraphic relationships also differ between these tectonic realms. Based on limited drilling information, the Cenozoic stratigraphic section north of the Mendocino fracture zone appears to consist of interbedded sedimentary,

volcanic, and volcanoclastic strata that were deposited in shelf and slope environments within a forearc setting. South of the fracture zone, the Cenozoic stratigraphic section is divisible into three major stratigraphic sequences: (1) Cretaceous to lower Miocene clastic (pre-Monterey) strata deposited as transgressive-regressive marine sequences in shelf and slope environments within a forearc setting, (2) middle to upper Miocene siliceous and calcareous (Monterey Formation) strata deposited in primarily slope environments, and (3) upper Miocene and younger clastic (post-Monterey) strata deposited in shelf and slope environments. All or part of this tripartite stratigraphic framework is generally recognized in basins of varying geologic settings, although the thickness and compositional character of strata vary from one basin to another.

The Region is separated into two distinct petroleum geologic realms as a result of the tectonic and stratigraphic histories—gas and oil. Within the tectonically convergent area north of the Mendocino fracture zone, predominantly gas resources are expected to reside in clastic reservoir rocks. Basins south of this zone have been formed or structurally modified primarily by lateral and rotational crustal movements along the San Andreas and related faults; many of these basins contain thick sequences of “Monterey” strata, which are important petroleum source and reservoir rocks, and clastic reservoir rocks in which predominantly oil resources are expected to reside.

EXPLORATION AND DISCOVERY STATUS

Petroleum exploration in the Pacific OCS Region has been underway for more than 40 years. Numerous exploratory wells and coreholes have been drilled; most of these are located offshore southern California where several oil and gas fields have been discovered (Sorensen and others, 1995; 1996). The Region is traversed by nearly 200,000 miles of seismic-reflection profiles; the density of these data ranges from sparse in frontier areas (e.g., Washington-Oregon area) to extremely dense in mature producing areas (e.g., Santa Barbara-Ventura basin). The most important petroleum reservoirs discovered as of this assessment are fractured siliceous rocks of the Monterey Formation; additional petroleum accumulations exist in clastic reservoirs underlying and overlying the Monterey.

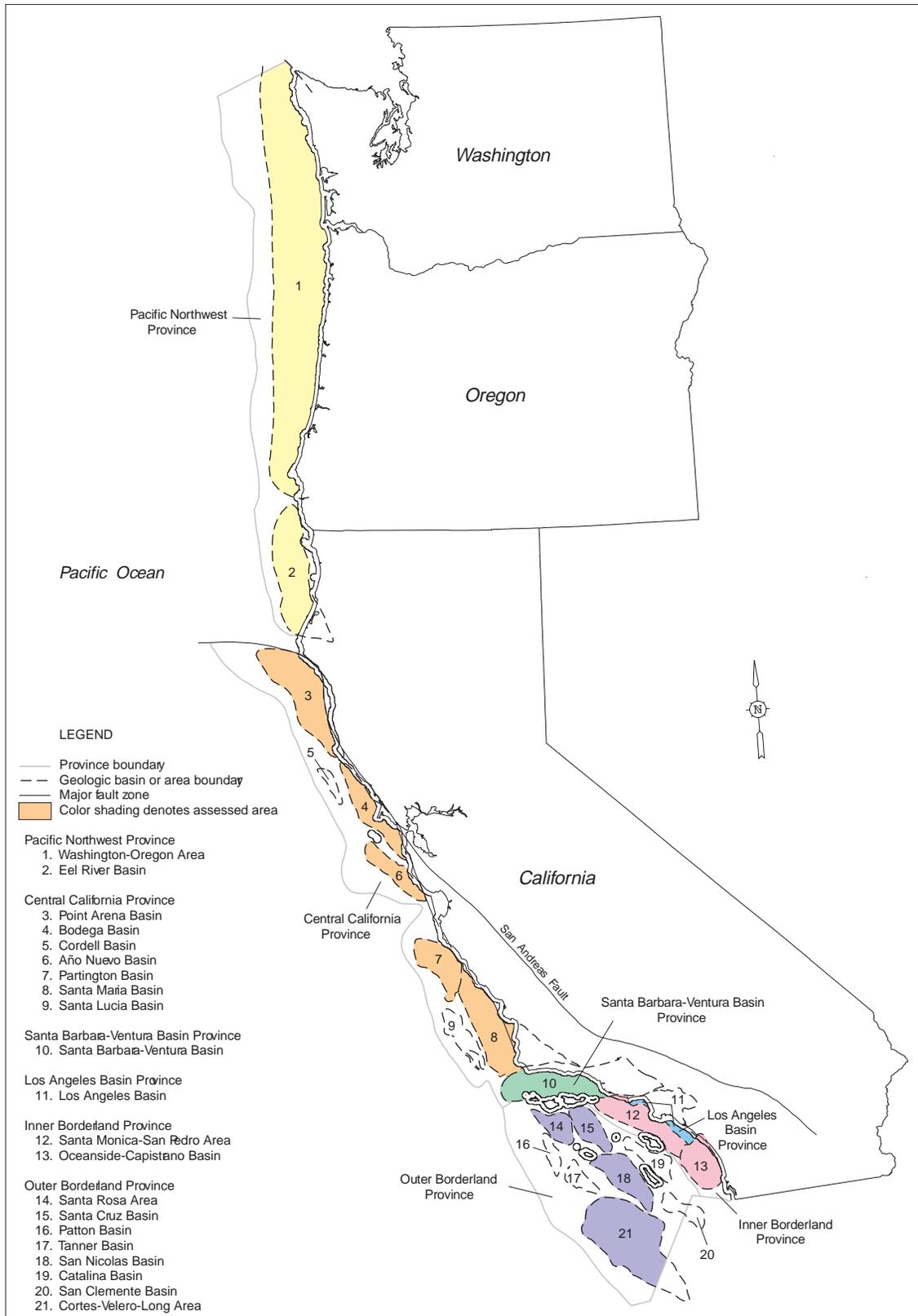


Figure 10. Map of the Pacific OCS Region showing assessment provinces, geologic basins and areas, and assessed areas. Colors correspond to the provinces shown on the front cover and discussed in the text.

Table 1. Location, name, and classifications of petroleum geologic plays defined for this assessment of the Pacific OCS Region. Continued on next page.

Assessment Area	Play	Exploration & Discovery Status ¹	Hydrocarbon Type ²	Reservoir Rock Type ³
Pacific Northwest Province				
Washington-Oregon Area	Growth Fault	Conceptual	Mixed	Neogene Clastic
	Neogene Fan Sandstone	Frontier	Mixed	Neogene Clastic
	Neogene Shelf Sandstone	Conceptual	Mixed	Neogene Clastic
	Paleogene Sandstone	Frontier	Mixed	Paleogene-Cretaceous Clastic
	Melange ⁴	Frontier	Oil	Melange
Eel River Basin	Neogene Fan Sandstone	Established	Mixed	Neogene Clastic
	Neogene Shelf Sandstone	Frontier	Mixed	Neogene Clastic
	Paleogene Sandstone	Frontier	Mixed	Paleogene-Cretaceous Clastic
	Melange ⁴	Conceptual	Oil	Melange
Central California Province				
Point Arena Basin	Neogene Sandstone	Frontier	Oil	Neogene Clastic
	Monterey Fractured	Frontier	Oil	Neogene Fractured Siliceous
	Pre-Monterey Sandstone	Frontier	Oil	Paleogene-Cretaceous Clastic
Bodega Basin	Neogene Sandstone	Frontier	Oil	Neogene Clastic
	Monterey Fractured	Frontier	Oil	Neogene Fractured Siliceous
	Pre-Monterey Sandstone	Frontier	Oil	Paleogene-Cretaceous Clastic
Año Nuevo Basin	Neogene Sandstone	Frontier	Oil	Neogene Clastic
	Monterey Fractured	Frontier	Oil	Neogene Fractured Siliceous
	Pre-Monterey Sandstone	Frontier	Oil	Paleogene-Cretaceous Clastic
Santa Maria-Partington Basin	Basal Sisquoc Sandstone	Frontier	Oil	Neogene Clastic
	Monterey Fractured	Established	Oil	Neogene Fractured Siliceous
	Paleogene Sandstone	Conceptual	Oil	Paleogene-Cretaceous Clastic
	Breccia	Conceptual	Oil	Neogene Clastic
Santa Barbara-Ventura Basin Province				
Santa Barbara-Ventura Basin	Pico-Repetto Sandstone	Established	Mixed	Neogene Clastic
	Monterey Fractured	Established	Oil	Neogene Fractured Siliceous
	Rincon-Monterey-Topanga Sandstone	Established	Oil	Neogene Clastic
	Sespe-Alegria-Vaqueros Sandstone	Established	Mixed	Paleogene-Cretaceous Clastic
	Gaviota-Sacate-Matilija Sandstone	Established	Mixed	Paleogene-Cretaceous Clastic
	Cretaceous-Paleocene Sandstone ⁴	Established	Mixed	Paleogene-Cretaceous Clastic
Los Angeles Basin Province				
Los Angeles Basin	Puente Fan Sandstone	Established	Oil	Neogene Clastic
	San Onofre Breccia	Frontier	Oil	Neogene Clastic
Inner Borderland Province				
Santa Monica-San Pedro Area	Pliocene Clastic ⁴	Conceptual	Oil	Neogene Clastic
	Upper Miocene Sandstone	Frontier	Oil	Neogene Clastic
	Modelo	Conceptual	Oil	Neogene Clastic
	Dume Thrust Fault	Frontier	Oil	Neogene Clastic
	San Onofre Breccia	Conceptual	Oil	Neogene Clastic
Oceanside-Capistrano Basin	Upper Miocene Sandstone	Conceptual	Oil	Neogene Clastic
	Monterey Fractured	Conceptual	Oil	Neogene Fractured Siliceous
	Lower Miocene Sandstone	Conceptual	Oil	Neogene Clastic
	Paleogene-Cretaceous Sandstone	Established	Oil	Paleogene-Cretaceous Clastic

Table 1. Location, name, and classifications of petroleum geologic plays defined for this assessment of the Pacific OCS Region. Continued from previous page.

Assessment Area	Play	Exploration & Discovery Status ¹	Hydrocarbon Type ²	Reservoir Rock Type ³
Outer Borderland Province				
Santa Cruz Basin	Monterey Fractured	Conceptual	Oil	Neogene Fractured Siliceous
	Lower Miocene Sandstone	Conceptual	Oil	Neogene Clastic
Santa Rosa Area	Monterey Fractured	Conceptual	Oil	Neogene Fractured Siliceous
	Lower Miocene Sandstone	Conceptual	Oil	Neogene Clastic
Santa Cruz-Santa Rosa Area	Paleogene-Cretaceous Sandstone	Conceptual	Oil	Paleogene-Cretaceous Clastic
San Nicolas Basin	Upper Miocene Sandstone	Conceptual	Oil	Neogene Clastic
	Monterey Fractured	Conceptual	Oil	Neogene Fractured Siliceous
	Lower Miocene Sandstone	Conceptual	Oil	Neogene Clastic
Cortes-Velero-Long Area	Paleogene-Cretaceous Sandstone	Conceptual	Oil	Paleogene-Cretaceous Clastic
	Lower Miocene Sandstone	Conceptual	Oil	Neogene Clastic
	Paleogene-Cretaceous Sandstone	Conceptual	Oil	Paleogene-Cretaceous Clastic

¹ Plays are classified according to their exploration and discovery status as follows:

Established plays are those in which hydrocarbon accumulations have been discovered.

Frontier plays are those in which hydrocarbon accumulations have not been discovered, but in which hydrocarbons have been detected (e.g., shows, bright spots).

Conceptual plays are those in which hydrocarbons have not been detected, but for which data suggest that hydrocarbon accumulations may exist.

² Plays are classified according to their expected predominant hydrocarbon type as follows:

An *oil play* contains predominantly crude oil and associated gas.

A *gas play* contains predominantly nonassociated gas and may contain condensate.

A *mixed play* contains crude oil, associated gas, and nonassociated gas, and may contain condensate.

³ Plays are classified according to the age and lithology (rock type) of their reservoir rocks as follows:

Plays having *Neogene clastic reservoir rocks* include reservoir rocks that consist of Miocene and/or Pliocene sandstone, siltstone, shale, and/or breccia.

Plays having *Neogene fractured siliceous reservoir rocks* include reservoir rocks that consist of Miocene fractured chert, siliceous shale, porcelanite, dolomite, and/or limestone.

Plays having *Paleogene-Cretaceous clastic reservoir rocks* include reservoir rocks that consist of Cretaceous through Oligocene sandstone, siltstone, and/or shale.

Plays having *Melange reservoir rocks* include reservoir rocks that consist of sandstone within Cretaceous through Miocene melange.

⁴ Not formally assessed.

ASSESSMENT PROVINCES, ASSESSMENT AREAS, AND PLAYS

The petroleum geologic framework of the region provided the basis for the delineation of assessment provinces, assessment areas, and petroleum geologic plays. For this assessment, the Pacific OCS Region is subdivided into six assessment provinces: Pacific Northwest, Central California, Santa Barbara-Ventura basin, Los Angeles basin, Inner Borderland, and Outer Borderland (see front cover). Each province comprises one or more assessment areas (i.e., geologic basins or areas), within which petroleum geologic plays have been defined (fig. 10). Fifty individual plays within the Region have been defined and described, and 46 of these have been formally assessed (table 1). Some areas and plays

that lack sufficient petroleum geologic data or for which data suggest that petroleum potential is negligible have not been assessed. Additionally, several late Tertiary submarine fans exist within the Region; these areas of deep-sea sedimentation lack sufficient data and also have not been assessed.

The subareas defined for this assessment are similar, but not identical, to those defined for previous assessments. Notable differences are the consolidation of the Washington-Oregon area and Eel River basin as the Pacific Northwest province, and the inclusion of the Santa Maria and Partington basins in the Central California province. Other changes to the names and boundaries of some subareas have been made for ease of reference and assessment.

Table 2. Estimates of undiscovered conventionally recoverable oil and gas resources in the Pacific OCS Region as of January 1, 1995, by province. All estimates are risked values. The low, mean, and high estimates correspond to the 95th-percentile, mean, and 5th-percentile values of a probability distribution, respectively. Percentile values are not additive; some total mean values may not equal the sum of the component values due to independent rounding.

Province	Oil (Bbbl)			Gas (Tcf)			BOE (Bbbl)		
	Low	Mean	High	Low	Mean	High	Low	Mean	High
Pacific Northwest	0.19	0.41	0.75	2.34	3.91	6.03	0.61	1.11	1.79
Central California	4.17	4.95	5.82	4.21	5.23	6.39	4.94	5.88	6.93
Santa Barbara-Ventura Basin	1.74	1.85	1.95	3.84	4.61	5.48	2.43	2.67	2.92
Los Angeles Basin	0.19	0.31	0.49	0.17	0.32	0.53	0.22	0.37	0.58
Inner Borderland ¹	0.87	1.79	3.18	0.79	2.07	4.19	1.04	2.16	3.85
Outer Borderland	0.63	1.40	2.56	0.98	2.79	5.89	0.82	1.89	3.56
<i>Total Pacific OCS Region¹</i>	<i>8.99</i>	<i>10.71</i>	<i>12.62</i>	<i>15.21</i>	<i>18.94</i>	<i>23.19</i>	<i>11.82</i>	<i>14.08</i>	<i>16.60</i>

¹ Includes a small area and volume of resources in the State offshore and onshore area adjacent to the Federal offshore area.

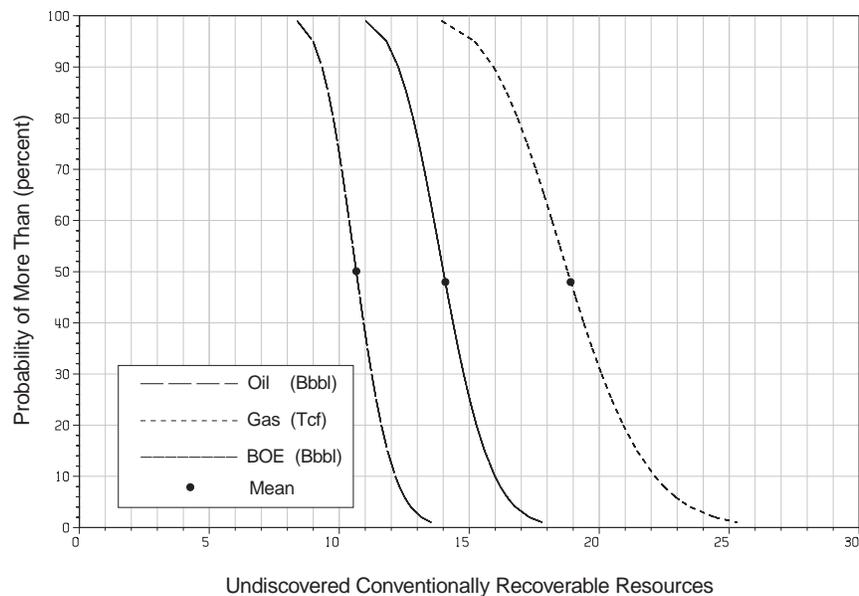


Figure 11. Cumulative probability plot of estimated undiscovered conventionally recoverable resources of the Pacific OCS Region.

RESOURCE ESTIMATES

Undiscovered Conventionally Recoverable Resources

Estimates of the total volume of undiscovered conventionally recoverable resources in the Region have been developed by statistically aggregating the constituent province estimates. As a result of this assessment, the total volume of undiscovered conventionally recoverable oil and gas resources in the Pacific OCS Region is estimated to be 10.71 Bbbl of oil and 18.94 Tcf of gas (mean estimates). The low,

mean, and high estimates of resources in the Region are listed in table 2 and illustrated in figure 11. A discussion of the contribution of undiscovered conventionally recoverable resources in the Pacific OCS Region to the undiscovered resources in the United States OCS is presented in appendix E.

Undiscovered Economically Recoverable Resources

Estimates of the total volume of undiscovered conventionally recoverable resources in the Region that may be economically recoverable under various

Table 3. Estimates of undiscovered economically recoverable oil and gas resources in the Pacific OCS Region as of January 1, 1995 for three economic scenarios, by province. All estimates are risked mean values. The \$18-per-barrel scenario is based on prices of \$18 per bbl of oil and \$2.11 per Mcf of gas; the \$25-per-barrel scenario is based on prices of \$25 per bbl of oil and \$2.94 per Mcf of gas; the \$50-per-barrel scenario is based on prices of \$50 per barrel of oil and \$5.87 per Mcf of gas. Some total values may not equal the sum of the component values due to independent rounding.

Province	\$18-per-barrel Scenario			\$25-per-barrel Scenario			\$50-per-barrel Scenario		
	Oil (Bbbl)	Gas (Tcf)	BOE (Bbbl)	Oil (Bbbl)	Gas (Tcf)	BOE (Bbbl)	Oil (Bbbl)	Gas (Tcf)	BOE (Bbbl)
Pacific Northwest	0.10	0.93	0.27	0.14	1.32	0.38	0.22	2.13	0.60
Central California	2.59	2.77	3.08	3.17	3.38	3.77	3.98	4.22	4.73
Santa Barbara-Ventura Basin	1.17	2.91	1.68	1.37	3.43	1.98	1.64	4.11	2.38
Los Angeles Basin	0.21	0.21	0.25	0.24	0.25	0.29	0.28	0.29	0.33
Inner Borderland ¹	1.19	1.37	1.43	1.39	1.60	1.67	1.61	1.85	1.94
Outer Borderland	0.06	0.10	0.08	0.30	0.52	0.40	0.94	1.83	1.27
<i>Total Pacific OCS Region¹</i>	<i>5.31</i>	<i>8.30</i>	<i>6.79</i>	<i>6.61</i>	<i>10.49</i>	<i>8.48</i>	<i>8.67</i>	<i>14.42</i>	<i>11.24</i>

¹ Includes a small area and volume of resources in the State offshore and onshore area adjacent to the Federal offshore area.

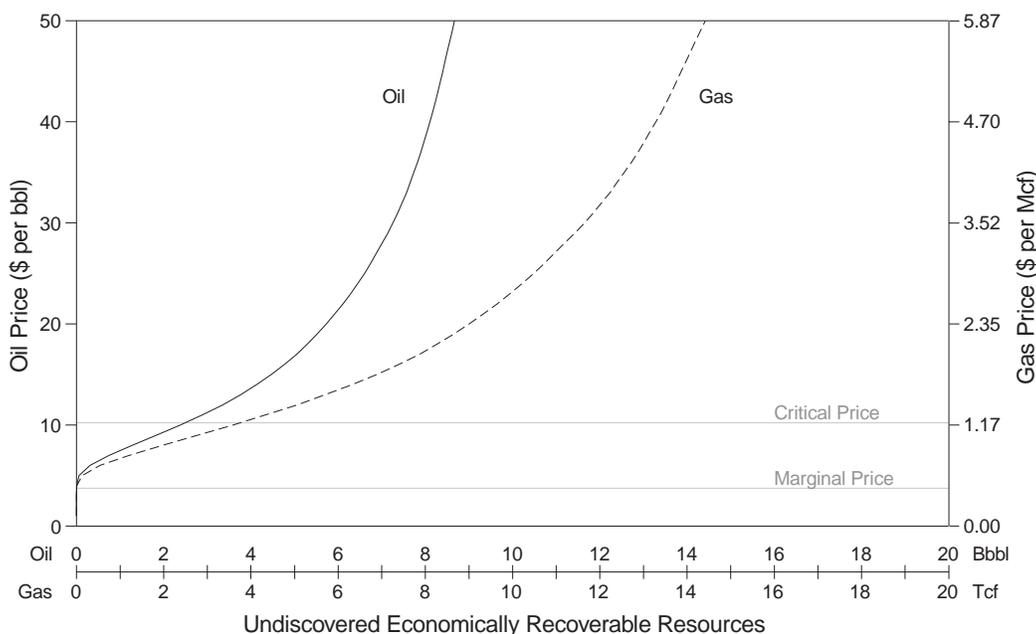


Figure 12. Price-supply plot of estimated undiscovered economically recoverable resources of the Pacific OCS Region.

economic scenarios have been developed by statistically aggregating the constituent province estimates. As a result of this assessment, 5.31 Bbbl of oil and 8.30 Tcf of gas are estimated to be economically recoverable from the Pacific OCS Region under economic conditions existing as of this assessment (i.e., the \$18-per-barrel economic scenario) (table 3).

Larger volumes of resources are expected to be economically recoverable under increasingly favorable economic conditions (fig. 12). A discussion of the contribution of undiscovered economically recoverable resources in the Pacific OCS Region to the undiscovered resources in the United States OCS is presented in appendix E.

Table 4. Estimates of the total endowment of oil and gas resources in the Pacific OCS Region, by province. Estimates of discovered resources (including cumulative production and remaining reserves) and undiscovered resources are as of January 1, 1995. Estimates of undiscovered conventionally recoverable resources are risked mean values. Some total values may not equal the sum of the component values due to independent rounding.

Province	Discovered Resources (Reserves)						Undiscovered Conventionally Recoverable Resources			Total Resource Endowment		
	Cumulative Production			Remaining Reserves			Oil (Bbbl)	Gas (Tcf)	BOE (Bbbl)	Oil (Bbbl)	Gas (Tcf)	BOE (Bbbl)
	Oil (Bbbl)	Gas (Tcf)	BOE (Bbbl)	Oil (Bbbl)	Gas (Tcf)	BOE (Bbbl)						
Pacific Northwest	0	0	0	0	0	0	0.41	3.91	1.11	0.41	3.91	1.11
Central California	0.12	0.04	0.13	0.67	0.66	0.78	4.95	5.23	5.88	5.74	5.93	6.79
Santa Barbara-Ventura Basin	0.49	0.67	0.61	0.65	1.72	0.96	1.85	4.61	2.67	2.99	7.01	4.24
Los Angeles Basin	0.07	0.02	0.07	0.06	0.01	0.06	0.31	0.32	0.37	0.44	0.36	0.50
Inner Borderland ¹	<0.01	<0.01	<0.01	negligible			1.79	2.07	2.16	1.79	2.07	2.16
Outer Borderland	0	0	0	0	0	0	1.40	2.79	1.89	1.40	2.79	1.89
<i>Total Pacific OCS Region¹</i>	<i>0.68</i>	<i>0.74</i>	<i>0.81</i>	<i>1.38</i>	<i>2.39</i>	<i>1.80</i>	<i>10.71</i>	<i>18.94</i>	<i>14.08</i>	<i>12.77</i>	<i>22.07</i>	<i>16.69</i>

¹ Includes a small area and volume of resources in the State offshore and onshore area adjacent to the Federal offshore area.

Total Resource Endowment

As of this assessment, cumulative production from the Region was 678 MMbbl of oil and 738 Bcf of gas; remaining reserves were estimated to be 1.38 Bbbl of oil and 2.39 Tcf of gas (Sorensen and others, 1995). These discovered resources and the aforementioned undiscovered conventionally recoverable resources collectively compose the Region's estimated total resource endowment of 12.77 Bbbl of oil and 22.07 Tcf of gas (table 4).

ORGANIZATION AND CONTENT OF THIS SECTION

The following parts of this section present detailed information regarding the petroleum geology and resource estimates of provinces, assessment areas, and plays in the Region. The information is organized in a hierarchical order of a province, its constituent assessment areas, and their constituent plays. Although there are apparent differences in the degree of detail of the information presented, there is general consistency among the organizational formats of the respective discussions.

Province discussions include descriptive information regarding the location, geologic setting, and resource estimates of each province. Illustrations include a map showing the location of the province and its constituent assessment areas, a cumulative probability plot of the estimated undiscovered conventionally recoverable resources, and a price-supply plot of the undiscovered economically recoverable resources. Tabular lists of estimates of

undiscovered conventionally recoverable resources, undiscovered economically recoverable resources, and total resource endowment (where resources have been discovered) by assessment area are also presented.

Assessment area discussions include descriptive information regarding the location, geologic setting, exploration, and resource estimates of the area. Illustrations include a map showing the location of the area and its constituent plays, a stratigraphic column showing the stratigraphic units, hydrocarbon attributes, and plays, a field-size rank plot and cumulative probability plot of estimated undiscovered conventionally recoverable resources, and a price-supply plot of the undiscovered economically recoverable resources. Tabular lists of estimates of undiscovered conventionally recoverable resources, undiscovered economically recoverable resources, and total resource endowment (where resources have been discovered) by play are also presented.

Play discussions include descriptive information regarding the location, petroleum geologic characteristics (source rocks, reservoir rocks, and traps), exploration, and resource estimates of the play, as well as a pool-size rank plot of estimated undiscovered conventionally recoverable resources.

Every effort has been made to completely and accurately cite the work of others in these discussions. Additional references providing relevant information not cited in the text are listed at the end of some discussions.