Chapter R6

REGION 6 ASSESSMENT SUMMARY—CENTRAL AND SOUTH AMERICA

By C.J. Schenk, D. K. Higley, *and* L.B. Magoon

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Table of Contents

ABSTRACT

Mean undiscovered total oil and gas resources in 26 total and composite petroleum systems in 23 assessed basins in Central and South America are 105 billion barrels of oil (BBO) and 487 trillion cubic feet of gas (TCFG). For undiscovered oil, 83 percent, or about 87 BBO of oil, is estimated to be in Total Petroleum Systems (TPS) in the Guyana-Suriname, Campos, Santos, Falkands Plateau, East Venezuela, Maracaibo, Llanos, and the Putumayo-Oriente-Maranon Basins, with two-thirds of the total resource estimated to be offshore. The remaining 17 percent of the total undiscovered oil is in TPS of the Espirito Santo, Pelotas, Santa Cruz-Tarija, Talara, Tobago Trough, Sergipe-Alagoas, Neuquen, Malvinas, Magallanes, Middle Magdalena, San Jorge, and Progreso Basins, and the Greater Antilles Deformed Belt. For undiscovered non-associated gas, an estimated 61 percent of the resource is in the TPS of seven assessed basins, six of which are predominantly offshore; Foz do Amazonas, Espirito Santo, Santos, Pelotas, Santa Cruz-Tarija (onshore), East Venezuela (in the Columbus Basin of offshore Trinidad and Orinoco offshore), and the Tobago Trough. For undiscovered associated gas resources, 70 percent of the resource is in the TPS of five assessed basins; Guyana-Suriname, Campos, Santos, East Venezuela,and Maracaibo. The exploitation of these oil and gas resources in South America means that the emphasis on future exploration will move offshore to water depths perhaps approaching 4000 m.

INTRODUCTION

Region 6 for the USGS World Petroleum Assessment 2000 encompasses the countries of Central America, the Caribbean area, and South America, from Cuba and Guatemala in the north to Argentina and the Falklands in the south. Mexico is included in Region 5 with Canada and the United States.

Central America, South America, and the Caribbean area were divided into geologic provinces (Schenk and others, 1999), and 26 composite TPS and TPS in 23 of these provinces were assessed for undiscovered petroleum resources (Region 6 map). These ranged from maturely explored TPS in the Maracaibo Basin of Venezuela and in the Neuquen Basin of Argentina to frontier TPS such as in the Guyana-Suriname Basin, the Santos Basin, and the Falklands Plateau. The overall approach in the USGS World Petroleum Assessment 2000 was to (1) attempt to define TPS in these provinces, (2) define assessment units (AU) within TPS, and (3) assess the potential for undiscovered conventional oil and gas in each AU.

A TPS is defined for this study as…"a mappable entity encompassing genetically related petroleum that occurs in seeps, shows, and accumulations (discovered and undiscovered) that have been generated by a pod or by closely related pods of mature source rock, together with the essential mappable geologic elements (source, reservoir, seal, and overburden rocks) that controlled fundamental processes of generation, migration, entrapment, and preservation of petroleum".

The word "total" implies that the petroleum system is defined specifically to include the area of undiscovered petroleum, a modification for this study of the definition of a petroleum system (Magoon and Dow, 1994).

The definition of a TPS is fundamentally dependent upon grouping known petroleum accumulations into genetic families using geochemical information and relating each oil and gas accumulation to its genetic source rock. The differentiation of oils in any basin into genetic families is difficult because of mixing of different oils, geochemical differentiation during migration, and commingled production of oils from several sources in one field, and a general lack of diagnostic geochemical data for many fields. Furthermore, few oils in any basin have been geochemically tied to its parental source rock with any significant degree of certainty. In this study, the TPS is "established" if a source rock is known to be related to a group of oils with certainty, the TPS is "probable" where there is some evidence that the oils are related to a particular source rock, and the TPS is "speculative" if the link between an oil and a source rock is only suspected at this time.

In areas where known petroleum accumulations could not be differentiated into genetic families, a composite TPS was established. A composite TPS is defined as "a mappable entity encompassing all or a portion of two or more TPS. Composite TPS are used when fields within an AU are thought to be charged by more than one source rock". In many provinces, limited geochemical data and commingled production from stratigraphically stacked pods of mature source rock made the definition of one or more unique TPS impossible. In many provinces we defined composite TPS containing petroleum potentially generated from two or more source rocks. Thus, the ability to define an established TPS was not common, given the limited geochemical data available for this study.

An assessment unit (AU) is defined for this study as …"a mappable volume of rock within a TPS that encompasses fields (discovered and undiscovered) which share similar geologic traits and socio-economic factors." TPS or composite TPS can include one or more AU. The AU for each composite TPS or TPS are outlined below. An AU is considered "established" if it contains more than 13 oil and (or) gas fields, "frontier" if the AU contains 1 to 13 oil and (or) gas fields, and "hypothetical" if the AU contains no oil or gas fields greater than some minimum field size established for each AU during the assessment.

Geologic Events, Total Petroleum Systems and Assessment Units

Three major geologic events shaped the development of TPS and composite TPS in Central America, South America, and the Caribbean: (1) the development of the Andean mountain chain, (2) the evolution of the Caribbean plate, and (3) the opening of the Atlantic Ocean. The AU in TPS are grouped into these three geologic categories for purposes of the geologic discussion.

Total Petroleum Systems Associated with Andean Tectonism

The tectonic development of the Andean mountain chain in the Tertiary led to the formation of a fold and thrust belt and a segmented foreland basin that extends the length of the South American continent. Pre-Andean, passive-margin marine source rocks in many of the assessed provinces reached generative maturity for oil or gas because of tectonic loading or burial by thick Tertiary synorogenic clastic sequences. We assessed several provinces with TPS that evolved largely because of Andean tectonism, including TPS in the Magallanes, San Jorge, Neuquen, Santa Cruz-Tarija, Putumayo-Oriente-Maranon, Talara, Progreso, Middle Magdalena, and Llanos Basins (fig. 1). Several of these TPS have been explored extensively, and elements of these TPS have been described in some detail (Biddle and others, 1986; Figari and others, 1998; Fitzgerald and others, 1990; Pindell and Tabbutt, 1995; Pittion and Arbe, 1997; Ramos, 1989; Urien and Zambrano, 1994; Vergani and others, 1995). However, with few exceptions, more geochemical information is required in many of these areas before the TPS can be considered established.

The Magallanes Basin Province (6059) in southern Chile and Argentina (Region 6 map) contains the Lower Inoceramus TPS (605901; probable), named for the only known source rock in this area. Chile produces all of its petroleum from this TPS. The Magallanes Extensional Structures AU (60590101; established) contains about 90 oil and 70 gas fields, mainly in shallow-marine reservoirs of the Upper Jurassic-Lower Cretaceous Springhill Formation. The exploration outlook is estimated to be for small oil and gas fields in shallow marine reservoirs, and possible turbidite reservoirs in the deeper part of the AU. The Andean Fold Belt Structures AU (60590102; frontier) contains three small gas fields, and the potential exists for additional gas fields in this AU. A similar TPS may be present in the Malvinas Basin Province (6060) and South Falklands Basin of the Falklands Plateau Province (6063) based on similarity of geology (Oliverio and Malumian, 1999), but these TPS are speculative at this time.

The San Jorge Basin Province (6058) of Argentina (Region 6 map) contains the D-129 TPS (605801; established), named for lacustrine mudstone source rocks of the Early Cretaceous D-129 Formation. The San Jorge Extensional Structures AU (60580101) and the San Bernardo Fold Belt Structures AU (60580102) are defined in this TPS. The Aguada Bandera TPS (605802; speculative) is defined in the central part of the basin, and contains the hypothetical Basin-Centered Gas AU (60580201, not assessed in this study).

The Neuquen Basin Province (6055) of Argentina (Region 6 map) contains at least three pods of active source rock that have generated petroleum (Urien and Zambrano, 1994). Given the available geochemical data, we were not able to differentiate the products of these sources into genetic families or predict the location of undiscovered accumulations sourced by each of these units. The Neuquen Composite TPS (605501) is defined to include pods of active source rock from the Lower Jurassic Los Molles Formation, the Upper Jurassic-Lower Cretaceous Vaca Muerta Formation, and the Lower Cretaceous Agrio Formation (Urien and Zambrano, 1994). The Neuquen Extensional Structures AU (60550101), Neuquen Foothills Structure AU (60550102), and Dorsal de Neuquen Structure AU (60550103) are placed in this composite TPS.

The Santa-Cruz-Tarija Basin Province (6045; Region 6 map) contains the Los Monos-Machareti TPS (604501; probable), named for source rocks in the Devonian Los Molles Formation. The Sub-Andean Fold and Thrust Belt AU (60450101), Foreland Basins AU (60450102), and Foreland Central Chaco High AU (60450103) are defined in this TPS.

The Putumayo-Oriente-Maranon Basin Province (6041; Region 6 map) contains the Mesozoic-Cenozoic TPS (604101; probable). The Hollin Napo AU (60410101) and the Basin-Centered Gas AU (60410102; not assessed) are defined in this TPS. The Paleozoic TPS (604102; speculative) and the Ene AU (60410201) are also defined in this basin.

The Talara Basin Province (6081) of Peru (Region 6 map) contains the Cretaceous-Tertiary Composite TPS (608101) with many speculative sources, including the Albian Muerto Limestone, the Campanian Redondo Formation, and several Tertiary mudstones, such as the Eocene San Cristobal Formation. No geochemical data are available for any of these possible source rocks. The Cretaceous-Paleogene Basin AU (60810101) is defined in this composite TPS.

The Progreso Basin Province (6083) of northern Peru and southern Ecuador (Region 6 map) contains two speculative TPS: the Neogene TPS (608301) and the Cretaceous-Paleogene TPS (608302). The Neogene TPS (608301; probable) is defined by possible pods of active source rocks of the Oligocene-Early Miocene Heath Formation and Miocene Cardalitos Formation. The Neogene Pull-Apart Basin AU (60830101) is defined in this TPS. The Cretaceous-Paleogene TPS (608302; speculative) may contain source rocks of the Cretaceous Calentura Formation, among other possible source rocks. The Cretaceous-Paleogene Santa Elena Block AU (60830201) is defined in this TPS.

The Middle Magdalena Province (6090) of Colombia (Region 6 map) contains the La Luna-La Paz TPS (609001; established), named for source rocks in the Late Cretaceous La Luna Formation. The Northern AU (60900101), Southern AU (60900102), Eastern AU (60900103), and La Luna and Older AU (60900104) are defined in this TPS.

The Llanos Basin Province (6096) of Colombia (Region 6 map) contains the Gacheta-Mirador TPS (609601; probable). The source rock for the discovered and undiscovered accumulations is most likely the Late Cretaceous Gacheta Formation, an age equivalent of the La Luna Formation. A Tertiary source may also be contributing to the accumulations in the fold and thrust belt, but data are not available to confirm this source at present. The Central AU (60960101) and Peripheral AU (60960102) are defined within this TPS.

Total Petroleum Systems Associated with the Evolution of the Caribbean Plate

The evolution and complex movement of the Caribbean Plate influenced basin development along the margins of the plate. Oblique collision of the Caribbean Plate with the passive margin of northern South America in the Tertiary formed a series of foreland basins across Venezuela in which the deposition of thick synorogenic clastics led to the maturation of the Upper Cretaceous La Luna Formation and its stratigraphic equivalents. We assessed La Luna TPS in the Maracaibo Basin and in part of the East Venezuela Basin. The Maracaibo and East Venezuela Basins are extensively explored for oil and gas, and the La Luna TPS is known in some detail (Di Croce, 1995; Erlich and Barrett, 1992; James, 1990; Leonard, 1983; Lugo and Audemard, 1997; Lugo and Mann, 1995; Parnaud and others, 1995; Talukdar and Marcano, 1994). The TPS in other assessed Caribbean basins, such as the Carupano Basin in the southern end of the Tobago Trough and the Tobago Trough west of Barbados, are far less understood (Robertson and Burke, 1989; Speed and others, 1989, 1991).

The Maracaibo Basin Province (6099; Region 6 map) contains the La Luna-Maracaibo TPS (609901; established), named for the Late Cretaceous La Luna Formation. The La Luna-Maracaibo TPS has had a complex geologic history related to the development of adjacent mountain ranges and the evolution of the foreland basin associated with oblique collision of the Caribbean Plate. The La Luna-Maracaibo TPS in the Maracaibo Basin is divided into two AU, the Main Maracaibo Basin AU (60990101) that covers much of the basin, and the Southwest Maracaibo Basin Fold Belt AU (60990102) along the southwest margin of the basin. The Southwest Maracaibo Basin Fold Belt AU may be partly sourced by the La Luna Formation, and also by coaly sediments of the Paleocene Orocue Formation (Talukdar and Marcano, 1994) and several other potential source rocks (Yurewicz and others, 1998). The hypothetical Basin-Centered Gas AU (60990103) is postulated to exist in the deep, central part of the La Luna-Maracaibo TPS but was not assessed in this study.

The East Venezuela Basin Province (6098) as defined in this study includes the Guarico and Maturin sub-basins and adjacent fold and thrust belts, the Columbus Basin southeast of Trinidad, and the Orinoco Delta and Offshore (Region 6 map). The Guarico and Maturin sub-basins and adjacent fold belts contain the Querecual TPS (609801; established), and is named for a source rock that is stratigraphically equivalent to the Upper Cretaceous La Luna Formation. Four AU are defined in this TPS: East Venezuela Fold and Thrust Belt AU (60980101), Guarico Sub-

Basin AU (60980102), Maturin Sub-Basin AU (60980103), and the Orinoco Heavy Oil and Tar Belt AU (60980104; not assessed in this study). The eastern part of the East Venezuela Basin Province contains an Upper Cretaceous/Tertiary Composite TPS, as there may have been contributions from at least two source rocks to the petroleum accumulations in these areas. Two AU were defined in these areas: Trinidad Basins AU (60980201) and the Orinoco Delta and Offshore AU (60980202).

The southern end of the Tobago Trough Province (6103; Region 6 map) northwest of Tobago is interpreted to contain the Lower Cruse TPS (610301; speculative), in which the source rocks are suggested to be prodelta mudstones of the Miocene Lower Cruse Formation, similar to the TPS in the Columbus Basin of Trinidad. The Carupano Basin Gas AU (61030101) is defined in this TPS.

The Tobago Trough Paleogene TPS (610701; speculative) is defined along the north-south trending inner forearc deformation belt south of the St. Lucia Ridge and west of Barbados in the Lesser Antilles Deformed Belt Province (6107; Region 6 map). The Inner Forearc Deformation Belt AU (61070101) is defined to encompass petroleum in structural traps along the deformation zone (Speed and others, 1989). The age and character of the source rock for this TPS is highly speculative at this time.

The Greater Antilles Deformed Belt Province (6117; Region 6 map) contains the Upper Jurassic-Neocomian Total Petroleum System (established) along the northern margin of the island of Cuba, where the fold and thrust belt fronts the relatively undeformed Bahama carbonate platform (Ball and others, 1985; Echevarria-Rodriquez and others, 1991; Hempton and Barros, 1993). The North Cuba Fold and Thrust Belt AU (61170101) is defined in this TPS.

Total Petroleum Systems Associated with the Opening of the Atlantic Ocean

The opening of the Atlantic Ocean and rifting of South America and Africa in the Jurassic and Lower Cretaceous led to the formation of a series of rift-drift basins along the length of the eastern margin of South America. Many of the source rocks in these basins are genetically related to synrift and transitional-marine sediments, and clastic wedges of the drift phase are interpreted to have been sufficient overburden to mature several of the source rocks. We assessed composite TPS and TPS in the Guyana-Suriname, Foz do Amazonas, Sergipe-Alagoas, Espirito Santo, Campos, Santos, Pelotas, Falklands Plateau (North and South Falklands Basins), and Malvinas Basins. Intensive research efforts are currently focused on the TPS in several of these basins (Cainelli and Mohriak, 1998; Chang and others, 1992; Durham and others, 1999; Estrella and others, 1984; Guardado and others, 1990; Mello and others, 1994; Mohriak and others, 1990, 1997; Richards, 1997).

The Guyana-Suriname Basin Province (6021; Region 6 map) includes the Cenomanian-Turonian TPS (602101; probable), defined on the basis of very limited unpublished geochemistry of shales and oils. The Cenomanian-Turonian TPS is divided into the Late Cretaceous-Tertiary Turbidites AU (60210101), Cretaceous Carbonates AU (60210102), and Nearshore Marine Sandstones AU (60210103). The first two AU are hypothetical, but oil is produced from the large onshore Tambaredjo Field in the third AU. More geochemical information is necessary to firmly establish the Cenomanian-Turonian as the TPS in this basin.

The Foz do Amazonas Basin Province (6022; Region 6 map) includes the Neogene TPS (602201; speculative) associated with 10 km of deltaic and slope sediments deposited off the Amazon shelf since the Miocene (Milliman, 1979). The Amazon Delta and Submarine Fan AU (60220101) is defined in this TPS, and this AU contains one gas field in which the gas may be partly biogenic in origin. The Offshore Gas Hydrates AU (60220102; not assessed in this study) is defined on the presence of a Bottom Simulating Reflector indicating thick gas hydrates, which suggest there may be thermogenic gas generation at depth in this TPS. More work is necessary to adequately define the TPS in this basin. Moreover, Turonian shales may also be a viable source rock in this area (Advocate and others, 1998), but data are not available to further define this speculative TPS.

The Sergipe-Alagoas Basin Province (6029; Region 6 map) includes the Neocomian-Turonian Composite TPS (602901), a possible combination of three source rocks including shales of the Neocomian-Barremian Barra de Ituiba Formation, proto-marine shales of the Aptian Ibura Formation, and possibly black marine shales of the Albian-Turonian interval. With the data available to us we could not separate the petroleum generated from these sources into genetic families. The Western Pre-Aptian Reservoirs AU (60290101) and the Late Cretaceous-Tertiary Deep Water Sandstones AU (60290102) are defined in this composite TPS.

The Espirito Santo Basin Province (6034; Region 6 map) includes the Cretaceous Composite TPS (603401). Several potential source rocks are present in the basin, including synrift shales of the Barremian Cricare Formation, marine shales of the Aptian Mariricu Formation, and possibly marine shales of the Upper Cretaceous Urucutuca Formation. With the limited available data, the petroleum generated or potentially generated from these source intervals could not be separated into genetic families. The Espirito Santo Shelf AU (60340101), the Late Cretaceous-Tertiary Slide Blocks and Turbidites AU (60340102), and the hypothetical Abrolhos Sub-Volcanic Structures AU (60340103) are defined in this composite TPS.

The Campos Basin Province (6035; Region 6 map) contains the Lagoa Feia-Carapebus TPS (603501; established), one of the most studied petroleum systems in South America (Mello and others, 1994). Geochemical analyses of the synrift Lagoa Feia mudstones and reservoired oils demonstrate a strong genetic relationship. Three AU are defined in the Campos Basin. The Late Cretaceous-Tertiary Turbidites AU (60350101) contains several giant oil fields, including Roncador, Marlim, and Albacora. The Cretaceous Carbonates AU (60350102) contains many fields in Macae Formation carbonates, including the first offshore fields discovered in the Campos Basin. The Salt Dome Province Tertiary Sandstones AU (60350103) is hypothetical, and is defined to include petroleum trapped in salt structures in ultra-deep waters of the Campos Basin. However, the presence of adequate Lagoa Feia source rocks in the ultra-deep portion of the basin where we defined the third AU, is questionable. We suggest that another source rock, perhaps a Cenomanian-Turonian source rock, may be necessary to charge potential reservoirs if petroleum from Lagoa Feia source rocks is not present in the distal parts of the Campos Basin.

The Santos Basin Province (6036; Region 6 map) contains the Guaratiba-Guaruja (Cretaceous) Composite TPS, which includes possible source rocks of the Lower Aptian Guaratiba Formation, mudstones of the Albian Guaruja Formation, and possibly Turonian mudstones. Far less geochemical information is available for the Santos Basin compared to the adjacent Campos Basin. We suggest that late synrift and post-rift mudstones are the most important source intervals in this composite TPS. The source rocks are estimated to have reached the generative window for gas over a wide area, suggesting that the composite TPS may be more gas prone than the TPS in the adjacent Campos Basin. The Santos Shelf AU (60360101) and the Salt-Structured Deep-Water Sandstones AU (60360102) are defined in this composite TPS.

The Pelotas Basin Province (6037; Region 6 map) contains the Cenomanian-Turonian-Tertiary Composite TPS (603701; speculative) and is related to the thick wedge of clastic sediments deposited in the Rio Grande cone and other centers of clastic deposition along the Pelotas shelf edge. This composite TPS is partly defined on the presence of thick gas hydrates in the upper part of the sedimentary section, a possible indication that thermogenic gas is being generated at depth in the clastic wedge. This TPS is speculative at this stage. The Pelotas Platform and Basin AU (60370101), which encompasses conventional hydrocarbons that may be present in the sediments of the Rio Grande Cone and adjacent areas along the slope, and the Offshore Gas Hydrates AU (60370102; not assessed in this study), which encompasses the area of gas hydrate occurrence, are defined in this composite TPS.

The Falklands Plateau Province (6060; Region 6 map) is divided into two basins: the North Falklands Basin and the South Falklands Basin. The North Falklands

Basin contains the Neocomian Lacustrine TPS (606001; probable), which is interpreted to be similar to that of the onshore San Jorge Basin of Argentina (Richards, 1997). The hypothetical North Falklands Basin AU (60600101) covers much of the TPS, and includes many types of potential reservoirs and potential structures. The South Falklands Basin may contain a Lower Cretaceous TPS (606002; speculative), similar to the North Falklands and the San Jorge, but the source rock may be more similar to the Lower Inoceramus mudstones of the Magallanes Basin to the west. The South Falklands Basin AU (60600201) covers much of the area of the TPS in the South Falkland Basin.

The Malvinas Basin Province (6063; Region 6 map) contains the Lower Cretaceous Marine TPS (606301; probable), and is similar to the TPS in the adjacent Magallanes Basin. The Malvinas Extensional Structures AU (60630101) covers the area of extensional structures within the TPS.

ASSESSMENT RESULTS

The Region 6 Assessment Results Summary summarizes the assessment of undiscovered conventional oil and gas in 49 assessment units from 26 total and composite TPS in Central America, South America, and the Caribbean. Six AU and one TPS containing unconventional oil or gas were not assessed in this study.

The mean total undiscovered oil, gas, and NGL resources for Region 6 are 105 BBO, 487 TCF, and 20 BBNGL, respectively. Compared with the seven other regions of the world assessed in this study, Central and South America ranks third for undiscovered oil and gas behind only the Middle East Region and the Former Soviet Union Region. This ranking results from an increased emphasis in this assessment on TPS along the Atlantic margin of South America compared with previous assessments (Kingston, 1994; Kronman and others, 1995).

The assessment results are summarized by geologic province in the Region 6 Assessment Results Summary . For most geologic provinces in Region 6, one composite TPS or TPS was responsible for most of the oil and gas in the province, and so the province summaries are used here. The assessment results are also available by assessment unit.

For undiscovered oil, the results show that four offshore TPS are estimated to contain more than 3 BBO undiscovered oil at the mean, including TPS in the Guyana-Suriname Basin (15.2 BBO), the Campos Basin (16.3 BBO), the Santos Basin (23.2 BBO), and the Falklands Plateau (5.8 BBO). These four offshore TPS account for more than half (60.5 BBO, or 57 percent) of the total undiscovered oil resources (105 BBO) of Region 6. Four onshore TPS are estimated to contain more than 3 BBO of undiscovered resource at the mean; East Venezuela (11.9 BBO), Maracaibo (8.2 BBO), Llanos (3.6 BBO), and Putumayo-Oriente-Maranon (3.1

BBO), for a total of 26.8 BBO in these four systems. Together, these eight TPS contain 87.4 BBO, or 83 percent, of the total mean undiscovered oil resource of Central and South America (105 BBO). Several TPS are estimated to contain between 1 and 3 BBO mean undiscovered oil resource, including Espirito Santo (2.9 BBO), Pelotas (2.9 BBO), Santa Cruz-Tarija (2.1 BBO), Talara (1.7 BBO), Lesser Antilles Deformed Belt (1.5 BBO), Sergipe-Alagoas (1.5 BBO), Neuquen (1.3 BBO), and Malvinas (1.0 BBO). The TPS in these eight provinces account for 14.9 BBO, or 15 percent, of the total undiscovered resource in the Region (105 BBO). Five TPS are estimated to have less than 1 bbo undiscovered oil at the mean, including TPS in the Magallanes (0.7 BBO), Middle Magdalena (0.7 BBO), San Jorge (0.5 BBO), North Cuba (0.5 BBO), and Progreso (0.2 BBO). Together, these five TPS account for 2.0 percent of the total undiscovered oil resource in Region 6.

Mean undiscovered gas resources in Region 6 are reported as associated gas (174 TCFG) and non-associated gas (313 TCFG), for a total undiscovered gas resource of 487 TCFG (Region 6 Assessment Results Summary). For undiscovered associated gas (gas in undiscovered oil fields, calculated using a gas/oil ratio), five TPS, including TPS in the Guyana-Suriname (30.3 TCFG), Campos (15 TCFG), Santos (40.7 TCFG), East Venezuela (21.8 TCFG), and Maracaibo (12.5 TCFG), together contain 120 TCFG, or 70 percent of the total undiscovered associated gas in Region 6. The remaining 54 TCFG (associated gas) is found in TPS in the other 16 assessed basins.

For non-associated gas, the TPS of seven provinces, including the Foz do Amazonas (29.8 TCFG), Espirito Santo (27.6 TCFG), Santos (39.8 TCFG), Pelotas (16.3 TCFG), Santa Cruz-Tarija (25.5 TCFG), East Venezuela (71.7 TCFG), and Tobago Trough (20.1 TCFG), contain 74 percent (231 of 313 TCFG) of the non-associated gas (gas in undiscovered gas fields) in Region 6. Of these seven provinces, five are offshore. East Venezuela, one of the two onshore provinces, is estimated to contain 23 percent of all undiscovered non-associated gas in Region 6. More than half of this undiscovered gas is offshore in the Columbus Basin and in the Orinoco Offshore in the East Venezuela Basin.

One result of the Monte Carlo methodology used for calculating undiscovered resources for this study is an estimate of the "largest mean undiscovered field size" (oil or gas) in each AU. Fifteen AU are estimated to contain undiscovered giant oil fields (mean size >0.5 BBO), including the Late Cretaceous-Tertiary Turbidites AU in the Guyana-Suriname Basin (2.6 BBO), Santo Shelf AU in the Santos Basin (2.0 BBO), Salt Dome Province Tertiary Sandstones AU in the Campos Basin (1.9 BBO), Salt-Structured Deep Water Sandstones AU in the Santos Basin (1.6 BBO), Late Cretaceous-Tertiary Turbidites AU in the Campos Basin (1.6 BBO), East Venezuela Fold and Thrust Belt AU (1.4 BBO), Orinoco Delta and

Offshore AU (1.0 BBO), Inner Forearc Deformation Belt AU of the Tobago Trough (1.0 BBO), Main Maracaibo Basin AU (1.0 BBO), South Falklands Basin AU (0.96 BBO), North Falklands Basin AU (0.95 BBO), Pelotas Platform and Basin AU (0.82 BBO), Late Cretaceous-Tertiary Slide Blocks and Turbidites AU of the Espirito Santo Basin (0.7 BBO), and the Cretaceous Carbonates AU of the Guyana-Suriname Basin (0.7 BBO). Of these fifteen AU, twelve are entirely offshore, and eleven of the fifteen AU are either hypothetical or frontier with respect to known petroleum discoveries.

Ten AU are estimated to contain undiscovered giant gas fields (mean size >3 TCFG), including the Santos Shelf AU (6.5 TCFG), Inner Forearc Deformation Belt AU of the Tobago Trough (5.6 TCFG), Late Cretaceous-Tertiary Slide Blocks and Turbidites AU of the Espirito Santo Basin (5.1 TCFG), Pelotas Platform and Basin AU (4.2 TCFG), Orinoco Delta and Offshore AU (4.0 TCFG), Abrolhos Sub-Volcanic Structures AU of the Espirito Santo Basin (3.4 TCFG), Carupano Basin Gas AU (3.3 TCFG), Amazon Delta and Fan AU (3.2 TCFG), Late Cretaceous-Tertiary Turbidites AU of the Guyana-Suriname Basin (3.1 TCFG), and the East Venezuela Fold and Thrust Belt AU (3.0 TCFG). Of these ten AU, nine are entirely offshore, and eight of the ten AU are either hypothetical or frontier with respect to known petroleum accumulations.

SIGNIFICANCE OF ASSESSMENT RESULTS

Central and South America, with an estimated 105 BB mean undiscovered oil resource and 487 TCF mean undiscovered total gas resource, will continue to be an important oil- and gas-producing region for the next several decades. The relative magnitude of the undiscovered oil resource is less than that of only the Middle East and the Former Soviet Union in total undiscovered oil resources.

Future exploration of the undiscovered oil resource in Central and South America will increasingly move offshore, as onshore basins in South America are more maturely explored than offshore basins. In this study, more than half of the undiscovered oil resource is estimated to be in offshore TPS, where water depths can reach 4000m. In addition to the offshore basins having most of the total undiscovered oil resource, we estimate that of the 15 AU that contain undiscovered giant oil fields, twelve are offshore. For gas, we estimate that of the ten AU that contain giant gas fields, nine are offshore. The future of major oil exploration is certain to be offshore in South America.

Natural gas utilization is increasing dramatically in South America (Gaffney, 1999). Significant infrastructure for transportation and utilization of natural gas for electric power generation and other activities is under construction or planned, and the future appears bright for natural gas utilization in the so-called Southern Cone countries (Brazil, Argentina, Chile, Peru, and Bolivia) and in Venezuela and Colombia. Our assessment suggests that, like oil, the distribution of a significant portion of the associated gas and non-associated gas is to be found in only seven of the 23 assessed basins. For associated gas, 70 percent of the total undiscovered gas is estimated to be in TPS in Guyana-Suriname, Campos, Santos, East Venezuela, and Maracaibo Basin provinces, and, with the exception of Guyana-Suriname Basin, the infrastructure for gas gathering and transportation is developed or partly developed at this time. For nonassociated gas, the emphasis shifts offshore to include the Foz do Amazonas, Espirito Santo, Santos, Pelotas Basin provinces, part of East Venezuela Basin Province, and the Tobago Trough; the Santa Cruz-Tarija Basin Province is the onshore exception. At present, the nonassociated gas of the Santa Cruz-Tarija Basin Province is being transported to Brazil by pipeline, but most of the other areas, especially offshore areas, await the development of infrastructure. The exception is the Columbus Basin of Trinidad (considered to be part of East Venezuela Basin Province in this study), where the gas production and transportation infrastructure is highly developed. The Columbus Basin of offshore Trinidad (Trinidad Basins AU) and the Orinoco Delta and Offshore Area AU contain about 60 percent of the undiscovered non-associated gas resources of the East Venezuela Basin. The development of the offshore non-associated gas resource represents a significant aspect of energy development in South America.

We assessed composite TPS and TPS in 23 basins in the Central and South America region. Many other basins, with established production or no production to date, could be assessed in this region. The future assessment of these basins will shed further light on the distribution of offshore oil and gas resources and onshore gas resources in particular.

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