Hydrocarbon Resources of Argentina

By Dr. Marcelo R. Yrigoyen, Trend Argentina S.A., Buenos Aires, Argentina

Abstract: The total sedimentary basinal area of Argentina is about 1.4 million square kilometers onshore and 400,000 square kilometers offshore down to 200 meter depth ● Six of the mostly onshore pericratonic basins have been productive for both oil and natural gas, and all of them belong to the sub-Andean domain ● Their current daily production amounts to 482,600 BOPD (of which only 27,900 BOPD come from the offshore) and 2,230 million CFGD ● Present proven plus probable reserves are 2.83 billion barrels of oil and 27.8 trillion cubic feet of gas ● Cumulative production to December 31, 1990 is 5.0 billion barrels of oil and 13.7 trillion cubic feet of gas, of which 93% corresponds to associated gas ● The most important basins from the standpoint of current oil production are: San Jorge (yielding 37.8% of Argentina's total production); Neuquén (33.7%); Cuyo (14.4%); Magallanes (10.5%), and Tarija (2%) ● Yacimientos Petrolíferos Fiscales S.A. (YPF), the Argentine state agency, is the largest operator in the country with about 60% of the total crude oil produced ● The remainder is produced by private Argentine and international companies ● However, this relation is expected to change in the near future due to a strong deregulation and privatization policy implemented by the government in the Argentine oil industry ● By the end of 1990, 36,691 wells had been drilled in the country, of which 22,926 were oil producers and 1,694 were gas producers ● The exploratory drilling effort amounted to 4,777 wildcats or 13% of the total, the balance being mostly development wells.

1 INTRODUCTION

Located at the southern end of Latin America (Figure 1), Argentina's surface area is 2,791,810 square kilometers onland and 1,235,214 square kilometers offshore including the oceanic islands and the Antarctic sector. Population is 32.3 million inhabitants (May 1991). Energy requirements during 1990 were in the order of 57 million cubic meters of oil equivalent, of which 39% came from oil, 38% from natural gas, 12% from hydroelectricity, 4% from nuclear energy, and 7% from coal and wood.

Argentina's geological configuration shows about 20 major sedimentary basins onland with a surface area about 1,400,000 square kilometers and 9 basins in the South Atlantic shelf with a surface area of 400,000 square kilometers down to 200 meters water depth. In other words, 23% of the total area covered by sedimentary basins is located offshore and 77% onshore. As of 1990, six basins have produced commercial vólumes of oil and natural gas.

The presence of commercial hydrocarbons in Argentina has been known since the 18th century. Preliminary studies of some shallow oil seeps were carried out in 1865 when the first oil concessions were granted, but it was not until 1881 that hydrocarbon deposits discovered in the Tarija and Oran sedimentary basins in northern Argentina (Figure 2) were first scientifically investigated. The first exploratory well in search for oil in Argentina, drilled by a private businessman from Mendoza in 1880, was in the vicinity of Cacheuta natural oil seepages in the northern Cuyo basin. The area was later developed and became in those days an "important commercial oil field" where 30 productive wells were drilled before the end of the 19th century. This early exploration, development drilling, and exploitation of oil resources in Argentina was started by a group of private investors who realized the value of hydrocarbons and their significance in the future economic development of the country.

ARGENTINA

SURFACE

.CONTINENTAL	2,791.810 Km²
.OFF-SHORE & ANTARTIC	1,235.214 Km²

POPULATION

32.3 MILLION INHABITANTS

1990 ENERGY DEMAND

57 MILLION m^3 OIL EQUIVALENT:
- 39 % Oil
- 38 % Natural Gas
- 12 % Hydroenergy
- 4 % Nucleoenergy
- 7 % Coal/Wood

SEDIMENTARY BASINS

.ON-LAND	1,400,000 Km²
.OFF-SHORE	400,000 Km²

• OIL & GAS PRODUCTIVE BASIN

Figure 1

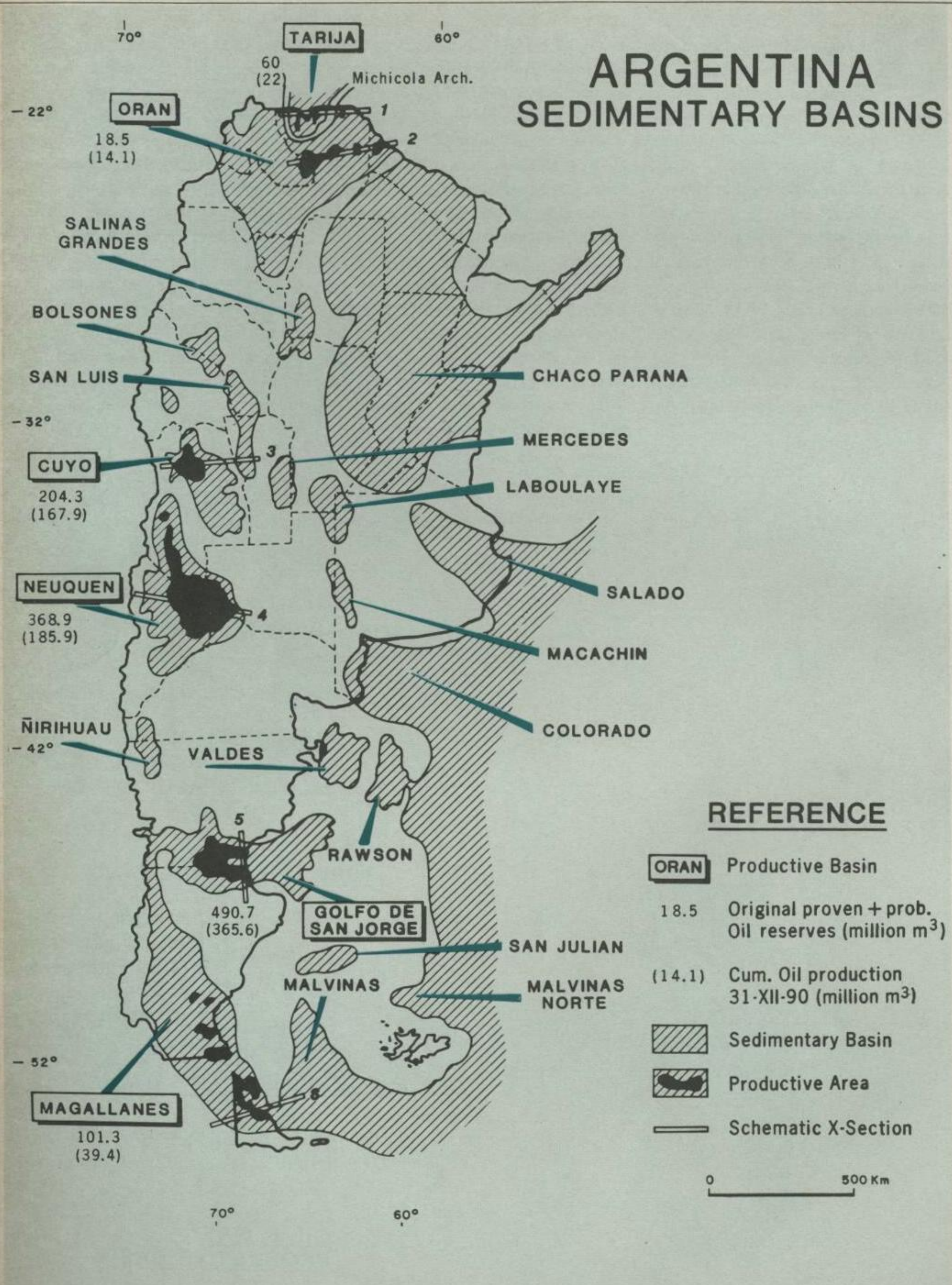
ARGENTINA
SEDIMENTARY BASINS
70°
60°
TARIJA
60
(22)
Michicola Arch.
ORAN
18.5
(14.1)
SALINAS GRANDES
BOLSONES
SAN LUIS
CHACO PARANA
MERCEDES
CUYO
204.3
(167.9)
LABOULAYE
SALADO
NEUQUEN
368.9
(185.9)
MACACHIN
COLORADO
ÑIRIHUAU
VALDES
RAWSON
490.7
(365.6)
GOLFO DE SAN JORGE
SAN JULIAN
MALVINAS
MALVINAS NORTE
MAGALLANES
101.3
(39.4)
– 22°
– 32°
– 42°
– 52°
1
2
3
4
5
6
REFERENCE
ORAN Productive Basin
18.5 Original proven + prob. Oil reserves (million m3)
(14.1) Cum. Oil production 31-XII-90 (million m3)
Sedimentary Basin
Productive Area
Schematic X-Section
0
500 Km

Figure 2

2 OIL PRODUCING BASINS IN ARGENTINA

Figure 2 shows the distribution of the main Argentina sedimentary basins, including the areas where hydrocarbons are being produced at present. The six basins that have been productive up to now are: Tarija, Oran, Cuyo, Neuquén, San Jorge (also called Golfo de San Jorge basin) and Magallanes (or Austral), the latter with both onshore and offshore hydrocarbon productions. The first two basins are independent tecto-sedimentary units which, because they are contiguous and in some way overlapped, are generally referred to as a single basin, the "Northwest basin". The Argentine oil basins have been recently described in several reports, including those of Turic et al (1981), Cáceres and Montangero (1985) and Lesta, Digregorio and Mozetic (1985). A geologic summary of these and other basins in Argentina is given in Table 1, and information on reservoirs, production and reserves is presented in Table 2. These tables (partially updating of M.R. Yrigoyen (1985), 1982) give the reader a general idea of basin size, geometry and basin characteristics. Supplementary information is also provided in the following discussion of each individual productive basin. In addition, typical transverse sections of the basins are shown in Figures 3 to 8.

Tarija Basin

The Tarija basin is a segment of a large pericratonic basin that extends from central Bolivia to northern Argentina. Like many other basins of the sub-Andean region of South America, the Tarija basin may be subdivided into two areas: (1) a structurally complex area along the Andean front in the west, which is characterized by persistent, longitudinal, overthrust asymmetrical anticlines that have eroded to a distinctive topography of parallel ridges and valleys, and (2) a platform area in the east, which is characterized by more gently folded rocks, in a large part hidden by the Chaco plains to the east. This basin has a Precambrian metamorphic basement covered by several thousand meters of Cambrian, Ordovician, Silurian and Devonian marine sediments. These early basinal deposits are unconformably overlain by thick non-marine deposits (partly of fluvioglacial origin) of Carboniferous age, by marine and non-ma-

Table 1 : Producing Basins of Argentina: Description of Basin Geology
Planilla 1: Descripción Geológica de las Cuencas Productivas de Argentina

Geologic Basin Description	Tarija	Oran	Cuyo	Neuquén	San Jorge	Magallanes
Basinal Area (x 1000 km²)	76	142	40	120	88	120
Sedimentary Volume (x 1000 km³)	286	350	112	290	222	320
Average Sedimentary Thickness (m)	3,800	2,600	2,500	2,600	2,500	2,500
Max. Depth to Economic Basement (m)	4,200	5,700	6,000	6,500	6,000	9,500
Basin Classification	Pericr. asymetr. foreland	Pericrat. interm. fault through	Pericrat. interm. fault through	Pericr. foreland embayment	Intra/pericrat. fault throuth	Pericr. foreland asym. through
Basin Shape	Elongated	Elongated	Elongated	Triangular	Oval	Elongated
Azimuth of Depositional Axis	S-N	SW-NE	S-N	S-N	W-E	SSE-NNW
Sedimentary Fill	Pal+Tr+K+T	K+T	Tr+K+T	(Tr) J+K+T	JL+K+T	K+T
Basinal Basement	Paleozoic	Paleozoic	Pre.+Paleoz.	Pal+Triassic	Pal./J.volc	Pal./J.volc.
Main Source Rock	Mid. Devonian	Late Cretac.	Late Triassic	Late Jurassic	Early Cretac.	Early Cretac.
Main Reservoir Units & Lithology	Tupambi SS/ Sta. Rosa SS	Yacoraite SS & Lms/Palmar Largo volcanics	Barrancas SS Victor-Potrer. SS	Several Lms & SS Units	Chubut SS	Springhill SS
Age of Reservoir	Carboniferous/ Early Devon.	Late Cretac.	Early Cretac./ Late Triassic	Cretac. to Jurass.	Late Cret./Pal.	Early Cretac.

rine sediments of Triassic age and finally by a thick sequence of Tertiary red-beds. The main source rock of hydrocarbons appears to be the widespread black shales of the Los Monos Formation of middle Devonian age. The reservoir rocks consist of several sandstone units within the Silurian and Devonian to a Pennsylvanian sedimentary sequence. The most prolific units have been the early Devonian Santa Rosa Formation and the Mississippian Tupambi sands.

The present tectonic configuration of the Tarija basin (Figure 3) is the result of the superposition of several phases of deformation, presumably controlled by ancient tectonic alignments delineated during the early Paleozoic. The main periods of deformation that affected the area occurred in the late Paleozoic and during the Andean orogeny in the late Mesozoic and Cenozoic. Compressional movements from the west during the Andean orogeny caused imbricate overthrusting in some areas, as shown in Figure 3.

Year 1990 production of the Argentine Tarija basin was 475,500 m³ of oil and 2,136 million m³ of natural gas. Remaining proven reserves as of December 31, 1990 are 21.3 million m³ of oil and 143,563 million m³ of gas.

Additional synoptic geologic information and production/reserve data are presented in Tables 1 and 2, respectively.

Oran Basin

The Oran basin, located east of the Andes in northeasternmost Argentina, is another structural remnant of a much larger Cretaceous-Tertiary basin. In the west it was probably open to the Pacific for a short period before the Andean uplift. One arm of the basin appears to have also extended to the north-northwest and connected with the Altiplano region of Bolivia and southern Perú. Andean uplift during the middle to late Tertiary destroyed most of the western part of the basin and left a long northeast trending trough that extends across northern Argentina into the plains of western Paraguay (Figure 4). A second smaller trough, known as the Metan sub-basin, extends southward along the sub-Andean mountain front. The Michicola arch, near the Bolivian border, forms the northern boundary of the Oran basin. The western margin of the basin ends abruptly against the eastern side of the Andes.

The basin floor, which is a block-faulted

Table 2: Producing Basins of Argentina: Description of Basin Geology
Planilla 2: Datos de Producción y Reservas de las Cuencas Productivas de Argentina

Production and Reserve Data	Tarija	Oran	Cuyo	Neuquén	San Jorge	Magallanes	Total Country
Average Depth to Reservoirs (m.b KB)	1800/4500	2000/4000	2000/3000	700/3200	500/3600	1600/2500	-
Average Oil Gravity (°API)	54/40	44	29.4	29.5/33.2	23.5	40.8	-
Number or Wells Drilled (approximate)	1,025	180	2,700	8,560	21,950	2,260	36,691.0
Oil Recovery per Well (x 1000 m³)	135	80		26	22	60	-
Oil Recovery per hectare (m³/ha)	3,320	4,700	4,500	2,750	1,100	2,250	
Average Daily Production per well (m³/day)	50	80	12	10.2	5.1	22.2	7.5
Number of Giant Fields (+80 million m³)			1 oil	1 gas, 1 oil+cond.	2 oil		5.0
Original Proven Oil Reserves (million m³)	43.4	18.4	196.7	286.1	427.5	72.5	1,044.6
Cumulative Oil Production (million m³) 31-XII-90	22.1	14.1	167.9	185.9	365.6	39.4	795.0
Remaining Proven Oil Reserves (million m³) 31-XII-90	21.3	4.3	28.8	100.2	61.9	33.1	249.6
Probable Oil Reserves (million m³) 30-XII-90	16.5	0.1	7.6	83.8	63.2	28.8	200.0
Original Proven + Probably Oil Reserves (million m³) 31-XII-90	59.9	18.5	204.3	368.9	490.7	101.3	1,243.6
1990 Oil Production (x 1000 m³)	475.5	520.1	4,434.6	9,048.6	10,055	3,470	28,004
1990 Average Daily Oil Production (m³/day)	1,303	1,425	12,149	24,791	27,548	9,507	76,723
Original Proven Gas Reserves (million m³)	209,965	5,226	8,171	461,976	102,334	180,377	968,049.0
Cumulative Gas Production(million m³)	66,402	4361	7,349	140,492	89,695	80,694	388,993.0
Remaining Proven Gas Reserves(million m³) 31-XII-90	143,563	865	822	321,484	12,639	99,683	579,036.0
Probable Gas Reserves (million m³) 31-XII-90	44,937	1,000		88,240	3,256	71,588	209,021.0
Original Proven + Probable Gas Reserves (million m³)	254,937	6,226	8,171	550,216	105,590	251,965	1,177,105.0
1990 Gross Gas Production (million m³)	2,136	55	245	12,643	2,900	5,871	23,850.0
1990 Average Daily Gas Production (x 1000 m³)	5,852	151	671	34,638	7,945	16,085	65,342.0

peneplane surface of Precambrian to early Devonian metasediments, forms an extensive graben with a northeast trending axis. The graben began to fill with nonmarine clastic sediments during the early to middle Cretaceous. In Maastrichtian-Paleocene times the carbonate/sand/shale sequence of the Yacoraite Formation was deposited during an extensive shallow-marine transgression. This sequence is mainly the source and also the main producer of hydrocarbons in the Oran basin. During the Eocene-Oligocene widespread red-beds were deposited, and from Miocene to present the erosional products of the uplifting Andes formed huge synorogenic and postorogenic clastic deposits that spread eastward over large areas of South America. These clastic deposits are more than 5 km thick in the Oran basin. As the proto-Andean mountain rose the clastic deposits, which were coarser near the mountain front, became progressively finer eastward across the Chaco plains.

The difference between the western and eastern parts of the Oran basin is mainly one of tectonic style. Prominent longitudinal structural trends resulting from compression and thrusting in the west give way to gentle folding in the east. The Lomas de Olmedo structural trend (Figure 4) separates the eastern and western parts of the basin. To the east of this isolated structure new oil production was discovered in 1984. In that area hydrocarbons are mainly reservoired in andesitic effusive bodies of an uppermost Cretaceous age.

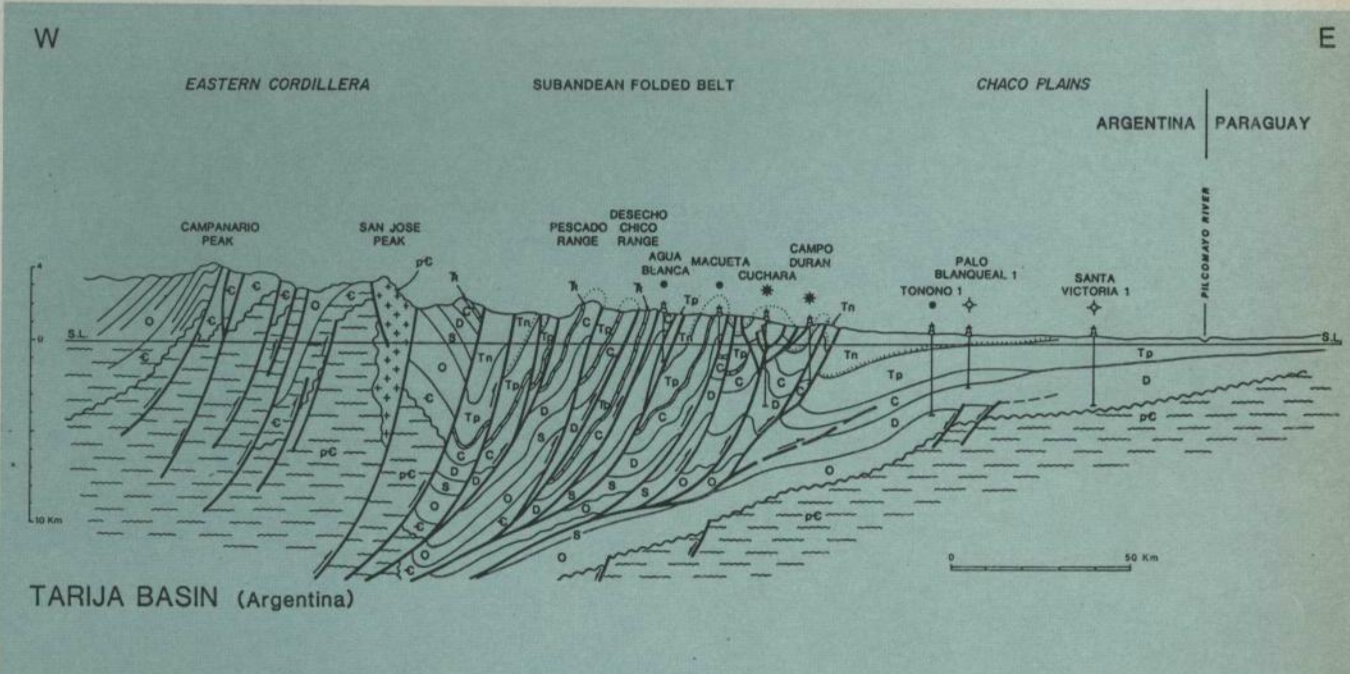

Figure 3

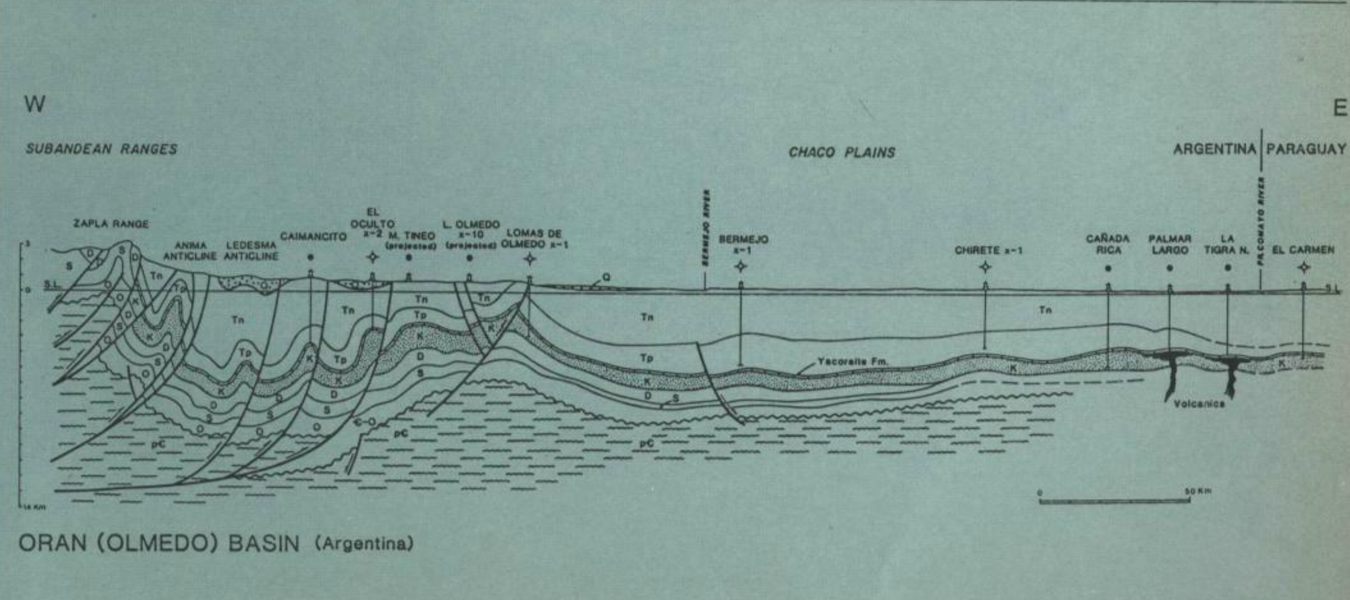

Figure 4

Year 1990 production of the Oran basin was 520,100 m^3 of oil and 55 million m^3 of natural gas. Remaining proven reserves as of December 31, 1990 are 4.3 million m^3 of oil and 865 million m^3 of gas.

Additional synoptic geologic information and production/reserve data are shown in Tables 1 and 2, respectively.

Cuyo Basin

The most productive part of the Cuyo basin, which covers an area of 40,000 km^2, lies at the eastern foothills of the Andes (Figure 2). Cuyo is a typical pericratonic landlocked intermontane basin of a transtensional taphrogenic style. It includes several fault-bounded subbasins filled with a non-marine sedimentary sequence as much as 12,000 m thick, mainly of Triassic and Tertiary ages, which overlies a complex basement of Precambrian and early Paleozoic metasedimentary rocks and Permo-Triassic volcanic rocks. The Jurassic (?) and the Cretaceous are poorly represented, but Neocomian clastic sediments and basalts constitute the principal reservoirs and caprocks, respectively, in the main productive area (Figure 5).

The basin fill, chiefly of middle-late Triassic age, consists of alluvial-fan and fluvial-plain deposits containing tuffaceous material in the upper part. An intermediate unit of lacustrine shale, the Cacheuta Formation, is generally accepted as being the main source of the oil produced from the Cuyo basin. The up-

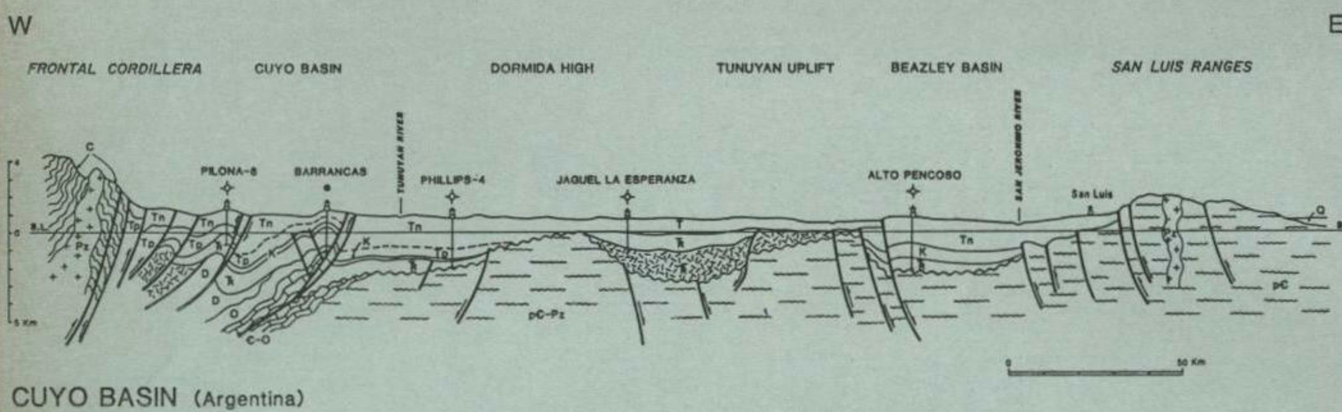

Figure 5

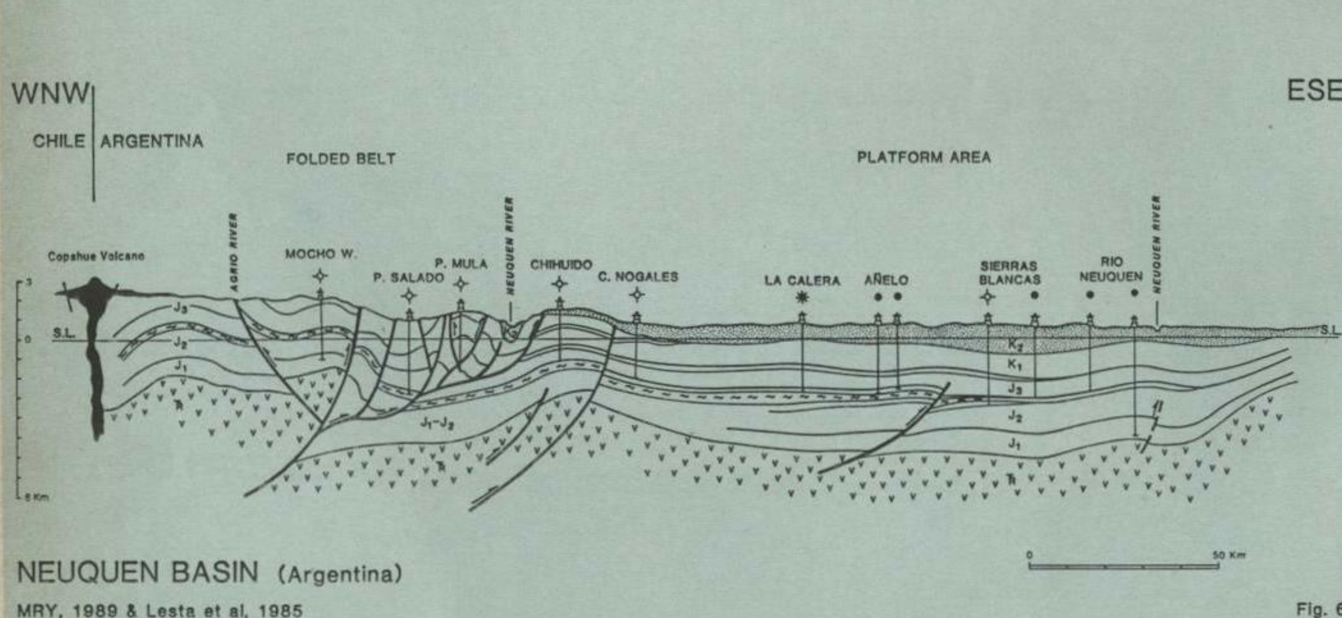

Figure 6

permost Triassic Río Blanco Formation is overlain with slight unconformity by non-marine and volcanic deposits of Neocomian age. Late Cretaceous to early Tertiary movements started a new erosional and depositional cycle leading to accumulation of thick Tertiary terrestrial deposits. This Cenozoic sequence begins with the oil-productive Papagayos Formation at the base, overlain by several thousand meters of middle to late Tertiary red beds.

The folds and faults in the Cuyo basin were formed largely during the Tertiary-Quaternary, but some structures were formed during the Mesozoic. Structural traps are the most important oil producing features in the Cuyo basin (Figure 5) but several oil pools are also in stratigraphic traps. In the western, productive, part of the basin the structures are faulted, asymmetrical closed anticlines along two (or three) almost parallel trends. The asymmetrical folds and thrust faults, which generally strike north, decrease in intensity from west to east, giving way to fault-controlled broad, flat, intermontane valleys. Oil reservoir sands lie within the Triassic and basal Tertiary sequences, but the Early Cretaceous Barrancas Formation is by far the main producing unit in the Punta de Bardas-Vacas Muertas giant oil field.

Year 1990 production of the Cuyo basin was 4,434,600 m^3 of oil and 245 million m^3 of natural gas. Remaining proven reserves as of December 31, 1990 are 28.8 million m^3 of oil and 822 million m^3 of gas.

Additional synoptic geologic information and production/reserve data are shown in Tables 1 and 2, respectively.

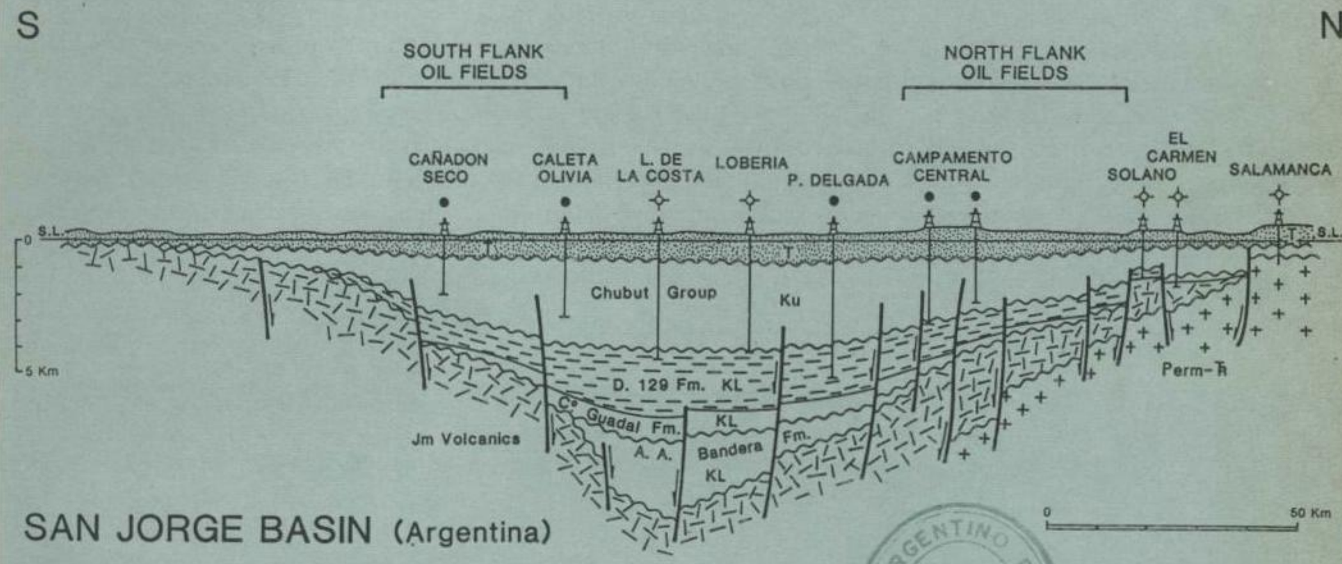

Figure 7

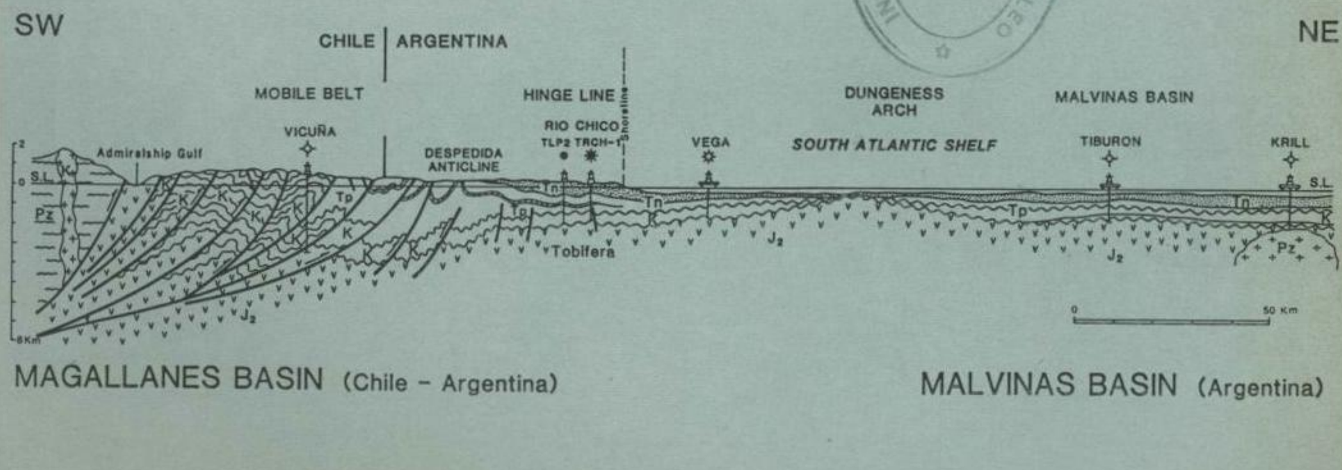

Figure 8

Neuquén Basin

The Andean segment of the Neuquén basin is in the backarc sub-Andean domain, but the so-called "Neuquén embayment" basin segment shows an aulocogenic pericratonic character that extends into the eastern foreland. As a whole, the Neuquén basin is a predominantly Jurassic-Cretaceous depositional basin. It is roughly triangular (Figure 2), and its western margin terminates against the north-trending Tertiary structures of the Andean Front. From a tectonic standpoint, the Neuquén basin lies on the continental interplate at the margin of the Andean belt.

Neuquén basin sedimentation began as Early Jurassic to Kimmeridgian fill in a rift system that opened in the Late Triassic. This fill consists of marine and nonmarine clastic sediments and subordinate carbonates and evaporites. During the Late Jurassic and Early Cretaceous the basin evolution shifted into an early downwarping stage, and a thick series of carbonates, shales, and sandstones was deposited. In the Late Cretaceous, after the Subhercynian orogeny, a thick postorogenic unit of red beds was deposited in an extended area during a late downwarping phase. These sedimentary rocks are overlain by a discontinuous sequence of Cenozoic rocks, coeval with the Andean deformation to the west (Figure 6).

The Neuquén basin is the second most prolific hydrocarbon producer of Argentina. Nearly all potential reservoirs have been productive somewhere in the basin, but the Jurassic Lotena-Punta Rosada and Tordillo-Sierras Blancas sands and the Late Jurassic-Early Cretaceous Quintuco-Loma Montosa carbonates are the major commercial reservoir rocks. Los Molles and Vaca Muerta black shales, which are widespread in the basin, are rich oil and gas source rocks. Block faulting, wrenching, and drape folding during the Jurassic, and in subsequent Andean orogenic deformation, formed the many structural traps which, together with stratigraphic traps, controlled commercial accumulations in the Neuquén basin. In some cases both structural and stratigraphic factors form the combined geometry for important pools, like in the giant Loma de la Lata field, for both oil and gas reserves.

Year 1990 production of the Neuquén basin was 9,048,600 m^3 of oil and 12.6 billion m^3 of natural gas. Remaining proven reserves as of December 31, 1990 are 100.2 million m^3 of oil and 321.5 billion m^3 of gas.

Additional synoptic geologic information and production/reserve data are shown in Tables 1 and 2, respectively.

San Jorge Basin

Although of medium size (roughly 88,000 km^2), the San Jorge basin is the most important hydrocarbon producing basin of Argentina. Its sedimentary fill accumulated during several episodes. Northwest trending extensional graben systems were formed and filled during a Triassic and Early Jurassic volcanic epi-

Table 3: Oil and Gas statistics in Argentina, 1990
Planilla 3: Estadística de Petróleo y Gas en Argentina, año 1990

OIL		
Total demand	22,937,736 m^3/year	62,843 m^3/day
Local production	28,004,036 m^3/year	76,723 m^3/day
Importation (Crude & Prod.)	61,600 m^3/year	169 m^3/day
Exportation	5,127,900 m^3/year	14,049 m^3/day
PROVEN OIL RESERVES (Dec. 31, 1990)	249.6 million m^3/(=1,570 million Bbl) (=9 years)	
NATURAL GAS		
Total production	23,850 million m^3/year	65.34 million m^3/day
Delivered to trunk-lines	17,738 million m^3/year	48.59 million m^3/day
Importation from Bolivia	2,193 million m^3/year	6.00 million m^3/day
Flared/vented	2,632 million m^3/year	7.21 million m^3/day
PROVEN GAS RESERVES (Dec. 31, 1990)	579,056 million m^3 (=20.4 TCF) (=25 years)	

DRILLING

Wells drilled during 1990:	Wildcats	108 wells	Total Wells 904	711 oil producers
	Outpost	111 wells		33 gas producers
	Development	685 wells		160 dry & abandoned

1990	on oil & oil/gas production	12,347 wells
	on gas production	472 wells

sode (Lonco Trapial and Bahía Laura Groups). The basin continued to subside and fill during Late Jurassic-earliest Cretaceous rifting coincident with the opening of the Atlantic Ocean, and during the following Cretaceous downwarp phase. Finally, a latest Cretaceous-early Tertiary tensional deformation gave rise to the structural alignments now prevalent in the basin. Many structural traps along normal faults were formed at this time.

A middle Tertiary compressional event produced the narrow north trending San Bernardo fold belt, which exhibits reverse movements on older, normal graben-bounding faults, and local low-angle thrust faults. A prominent early to middle Tertiary unconformity resulted from uplift and erosion of Cretaceous sediments around the basin margins and the accumulation of continental tuffaceous and shallow-marine sediments within the basin during the Cenozoic.

The Early Cretaceous lacustrine dark shales of the "D-129" Formation (Figure 7) are the most favourable source rocks yet identified. Most hydrocarbon production has come from middle to upper Cretaceous sands above this source rock, and from Paleocene sands along the north and south flanks of the basin and their distal extensions. This pattern suggests that hydrocarbon trapping may have been related to vertical migration along reactivated graben faults. Volcanic tuffs, tuffaceous sands, and other evidence of igneous activity are present throughout the basin fill, and reservoir quality is generally low because of the high tuffaceous content of the sand lenses. Sills, dikes, and other intrusive bodies are widespread in the basin.

In both north and south flanks of the San Jorge basin there are two clusters of somewhat inter-related fields that could be integrated as two giant oil fields, with an estimated ultimate recovery of more than 130 million m^3 each.

Year 1990 production of the San Jorge basin was 10 million m^3 of oil and 2,900 million m^3 of natural gas. Remaining proven reserves as of December 31, 1990 are 61.9 million m^3 of oil and 12,639 million m^3 of gas.

Additional synoptic geologic information and production/reserve data are shown in Tables 1 and 2, respectively.

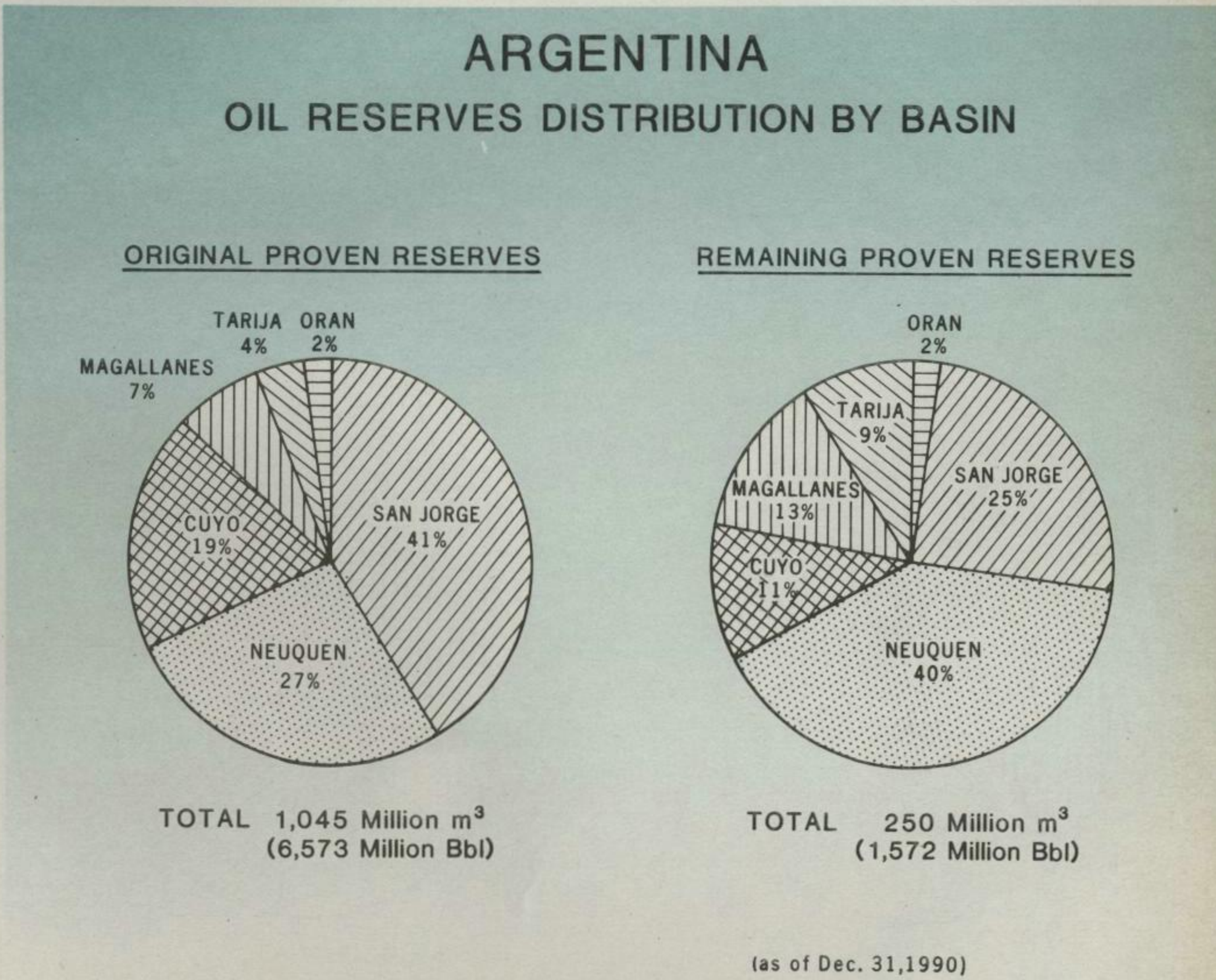

Figure 9

Magallanes Basin

The Magallanes basin is located in the southernmost tip of South America (Figure 2). It is bounded on the west by the Patagonian batholith and the Southern Andes deformed belt. In the north and east, it is bounded by the Dungeness arch, a large long-lived basement high. In the northwest, a shallow embayment apparently connects the Magallanes basin to the western side of the San Jorge basin. In the southeast, another embayment, around the southern tip of the Dungeness arch, connects the Magallanes basin with the offshore Malvinas basin, the latter with good prospective interest but no commercial production so far.

The Magallanes basin lies on the southernmost part of the South American Plate, where it has been subjected to complicated compressional and transcurrent deformation along the convergent margin between the South American and Scotia plates. To the west, the southern extension of the Chile Trench forms a plate boundary between the Antarctic (and other microplates) and the South American Plate. South of the Chile Rise, this boundary is the site of strike-slip motion and slow subduction, whereas to the north of the Chile rise, subduction of the Nazca Plate beneath South America is considerably faster. In the past, interaction along the western margin of South America has controlled much of the deformation and deposition seen today in the Magallanes basin.

The Magallanes basin underwent a two-phase development history. The basin first formed by rifting during the Middle Jurassic to Early Cretaceous, providing a substratum of normal fault blocks. After this phase of rifting a foredeep basin formed in front of advancing Andean thrust sheets. This phase of basin development was long-lived and diachronus. It began during the Late Cretaceous and continued well into the Tertiary. Of the two phases of basin development, the first was caused by thinning and thermal cooling of the lithosphere, whereas the second was caused by flexural loading. All commercial pools of the Magallanes basin are located in the platform area near the Atlantic coast and in the area immediately offshore (Figure 8). Major hydrocarbon accumulations are in the Late Jurassic-Early Cretaceous Springhill transgressive basal sand, although some

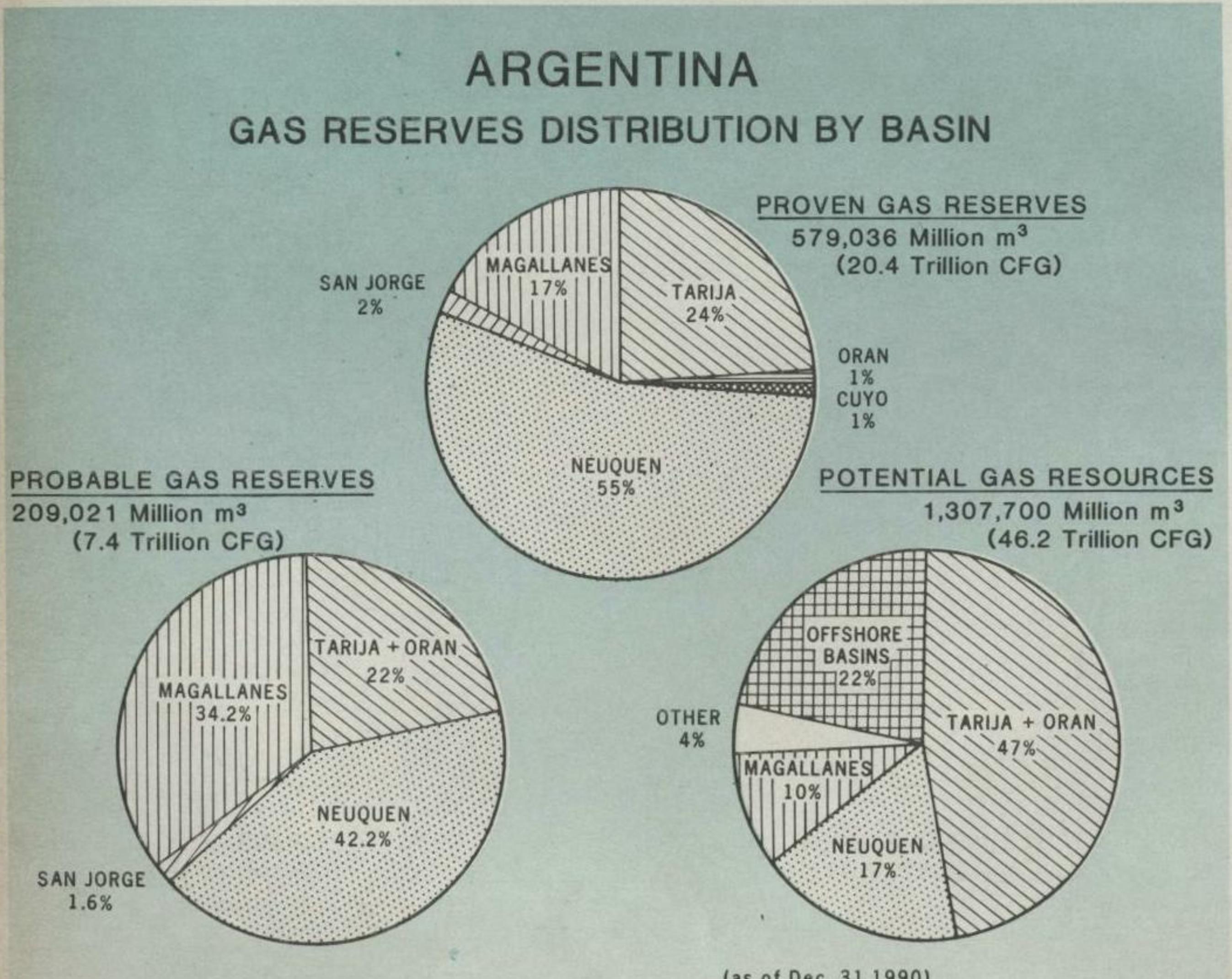

Figure 10

production has come from the weathered and fractured top of the Middle to Late Jurassic volcanic basement. The main source rock is the Early Cretaceous black shale that conformably overlies the Springhill sands. The most common traps are positive topographic features on the eroded surface of the volcanic basement, as well as elongated anticlines flanked by faults. Stratigraphic control in some fields is indicated by the presence of barriers and local pinching-out of the Springhill sand on top of the so-called "bald-highs".

Year 1990 production of the Magallanes basin was 3.47 million m^3 of oil and 5,871 million m^3 of natural gas. Remaining proven reserves as of December 31, 1990 are 33.1 million m^3 of oil and 99,683 million m^3 of gas. Up to now, all the offshore hydrocarbon production of Argentina is restricted to the Atlantic shelf extension of the Magallanes basin with a present output of 28,000 BOPD.

Additional synoptic geologic information and production/reserve data are shown in Tables 1 and 2, respectively.

3 PRODUCTION AND RESERVES OF OIL & NATURAL GAS

Argentina's total oil requirements in 1990 were about 23 million m^3, or 62,843 m^3/day, distributed as shown on Table 3.

Total oil produced locally (28,004,036 m^3) during the same year exceeded demand for the period and allowed exportation of 5.1 million m^3 of crude and products to neighbouring countries. Imports consisted of small amounts (61,600 m^3) of special crude oil and products.

At the end of 1990 country's proven oil reserves totalled 249.6 million m^3. In other words, proven reserves were adequate to meet the country's needs for about 9 years at the 1990 production rate.

The natural gas reserves of Argentina are larger and are sufficient for a longer period than oil. Gas production in 1990 was 23,850 million m^3 (65.34 million m^3/day) of which 74% was delivered to trunk lines. Of the remainder, 16% was reinjected and used in field and transport operations and 10% unspent (flared or vented due to lack of gas lines in isolated areas or because of undesirable contaminants such as sulphur or carbon dioxide).

Argentina's proven gas reserves of natural gas amount to 579,056 million m^3 (around 20.4 trillion cubic feet) or enough to meet the present demand for 25 years.

It should be noted that in 92% of the fields, natural gas in Argentina is associated with liquid hydrocarbons.

This domestic oil and natural gas pro-

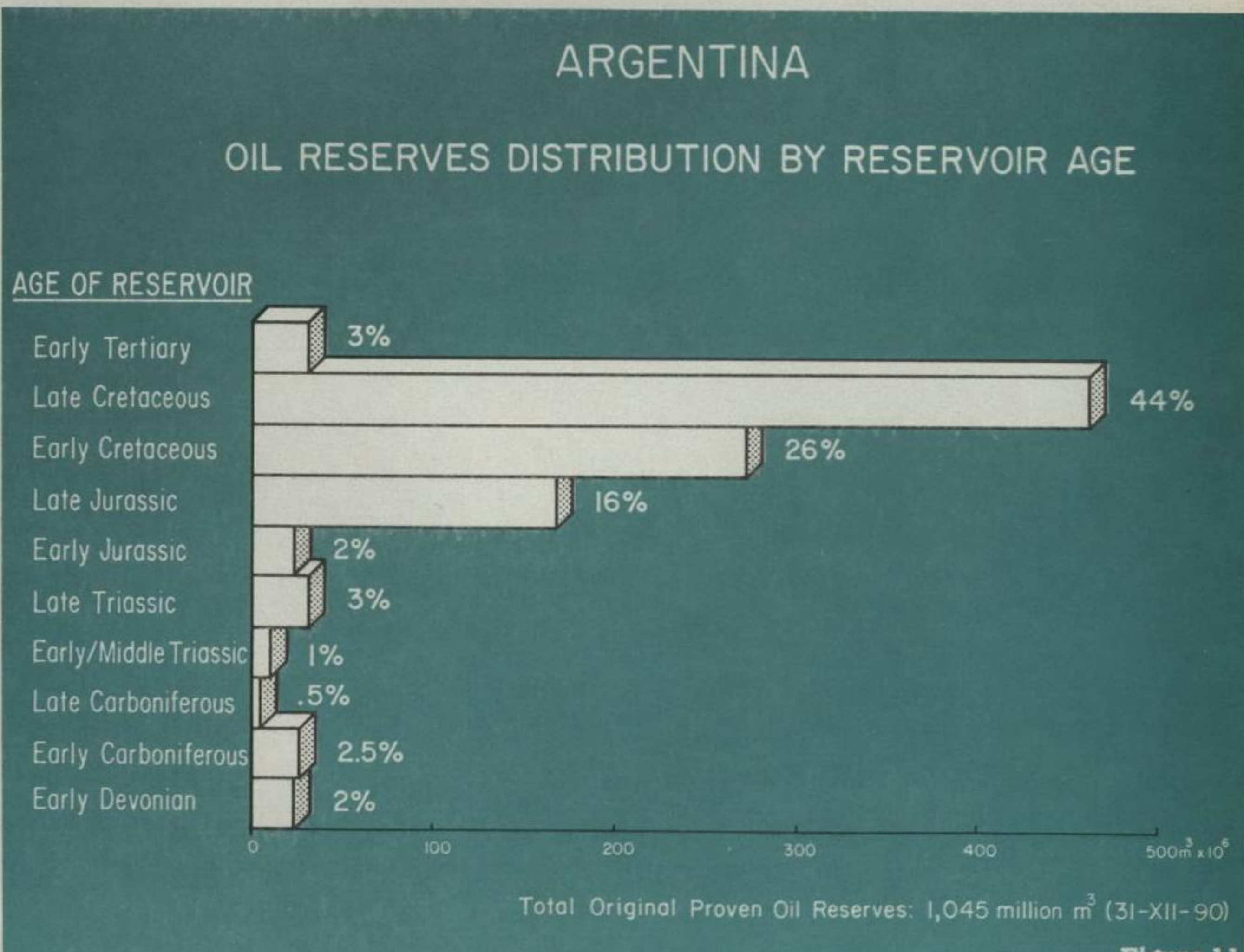

Figure 11

duction requires a significant drilling effort. Total drilling in the country in 1990 amounted to 904 wells, 108 of which were new field wildcats, 111 outpost wells and 685 development wells. As a result of this activity, 711 new oil wells and 33 gas wells were put on production whereas 160 wells were dry and abandoned. At the end of 1990, there were 12,347 producing oil wells and 472 gas wells on stream.

Statistics show that present depletion of oil reserves in Argentina is almost twice that of natural gas reserves. In other words, the smaller resource is being exploited at a rate faster than the large resource. Several measures have been implemented to revert this situation. On the one hand, several exploration programs are being carried out and, on the other hand, intensification of development drilling and production has already started in marginal and central fields recently awarded to private companies. Of the total known sedimentary basins, covering more than 1,800,000 km², only 28% has been studied in some detail. Thus, more than a million km² remain to be explored in search for commercial hydrocarbons. Average exploration effort todate is equivalent to barely one exploratory well every 375 km², an indication of the large amount of exploration drilling yet to be done in Argentina. Extensive areas of onland basins and significant portions of offshore basins require immediate exploration if depletion rates are to be changed.

4 DISTRIBUTION OF OIL & GAS RESERVES

The distribution of oil and gas reserves within the six sedimentary basins is shown in Figures 9 and 10. Figure 9 shows the percentage distribution of the 1045 million m³ of original proven oil reserves and the 1990 proven reserves (250 million m³). As can be seen, the San Jorge and Neuquén basins have tree-fourths of the oil discovered in Argentina. The remaining reserves, in order of magnitude, are in the Cuyo, Magallanes, Tarija, and Oran basins. The largest volumes of gas reserves (Figure 10), mostly associated, are in the Neuquén basin, followed by the Magallanes, Tarija, and Oran basins. In respect to yet-to-be-discovered potential gas reserves, great significance is given to the basins in the northwestern part of the country and the offshore basins being developed in the South Atlantic.

The distribution of proven oil reserves according to the age of the reservoirs is shown in Figure 11. As can be seen, 70% of the total proven oil reserves are in

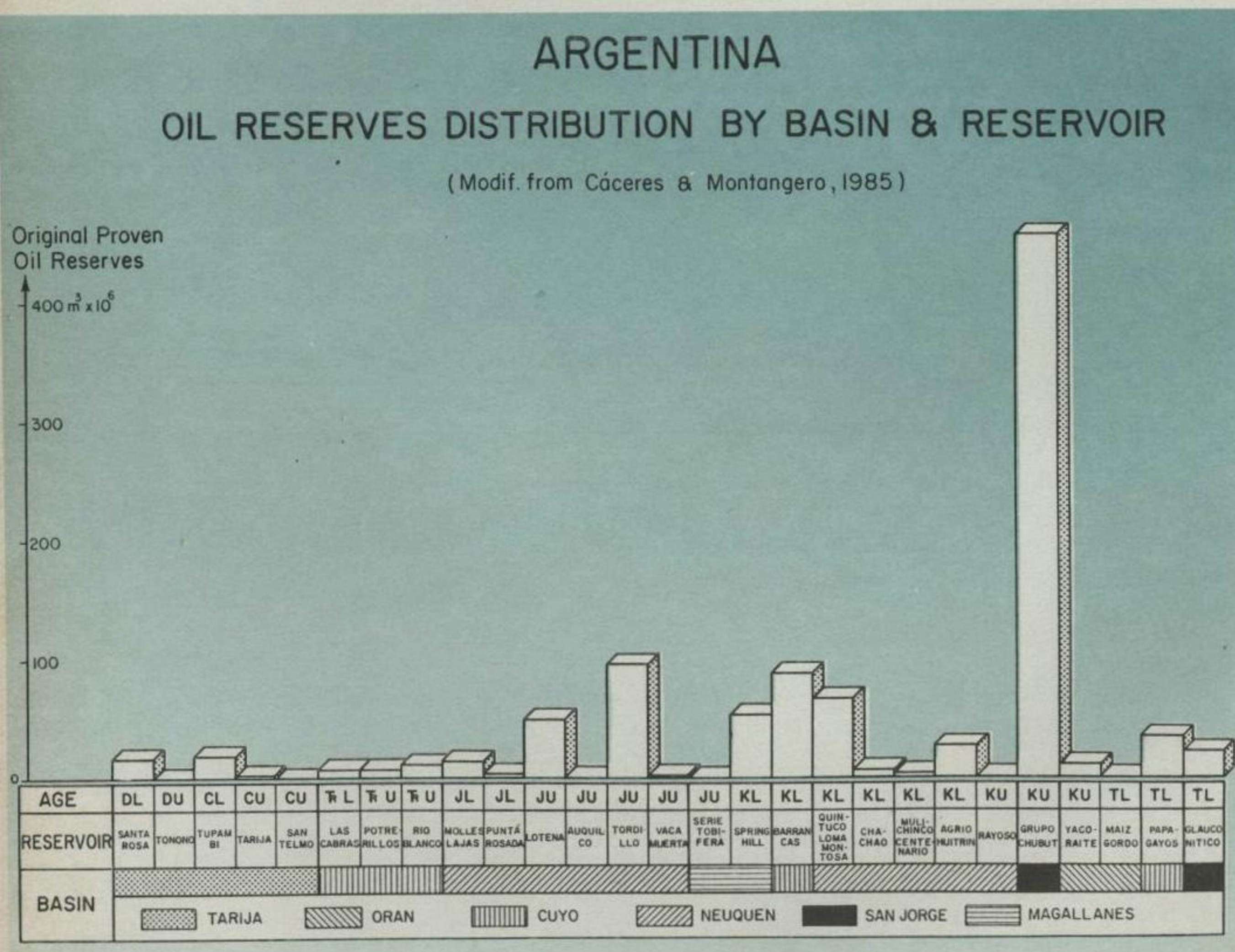

Figure 12

Cretaceous reservoirs, especially within Late Cretaceous sediments. Jurassic reservoirs rank second. The remaining proven reserves are in Triassic, Jurassic, Tertiary, and Paleozoic sediments.

Figure 12 shows the proven oil reserves in each reservoir formation within its respective basin. The very large reserves within the Chubut Group (Late Cretaceous) in the San Jorge basin are evident, as are the somewhat smaller reserves within Early Cretaceous rocks of the Neuquén basin. Reserves are found in Paleozoic reservoirs only in the Tarija basin, whereas reserves are in Triassic, also Cretaceous and Tertiary reservoirs, in the Cuyo basin. Proven reserves of the Magallanes basin are almost entirely in early Cretaceous (and late Jurassic) sandstones of the Springhill Formation, and to a much lesser degree in volcanic rocks of early to middle Jurassic age, informally known as "Serie Tobífera". In the Oran basin, the largest reservoir is in Late Cretaceous fractured limestones of the Yacoraite Formation. Smaller reserves are in sandstones of the overlying early Tertiary Santa Bárbara Group.

In several fields, significant hydrocarbon production is being obtained from igneous reservoirs, both extrusive and intrusive rocks. For example, fields recently discovered in the western part of the Oran basin produce from late Cretaceous weathered volcanics. In the Neuquén basin, commercial production was obtained from the top of a sequence of weathered volcanic flows of the Choiyoi Group (Triassic) and from andesitic dikes and sills (early Tertiary) with good fracture porosity. The intrusions are particularly prevalent in the northern segment of the basin that extends south of Mendoza province.

5 SIZE & NUMBER OF OIL FIELDS

The distribution of Argentine oil reserves according to the size and number of fields is shown by a tridimensional chart (Figure 13). The vertical axis shows fields of different size, according to their proven reserves, ranging from a minimum of less than 100,000 m³ to a maximum of more than 16 million m³. The other two orthogonal axes show the number of fields in each category. Original proven oil reserves amounting to 1045 million m³ (Figure 13) are distributed in 284 oil fields of different size. More than half of these reserves (540 million m³) are in 15 major fields having more than 100 million barrels, whereas 37% (394 million m³) is found in 52 fields of the next two lower categories which range from 4 to 16 million m³ (from 25 to 100 million barrels). The

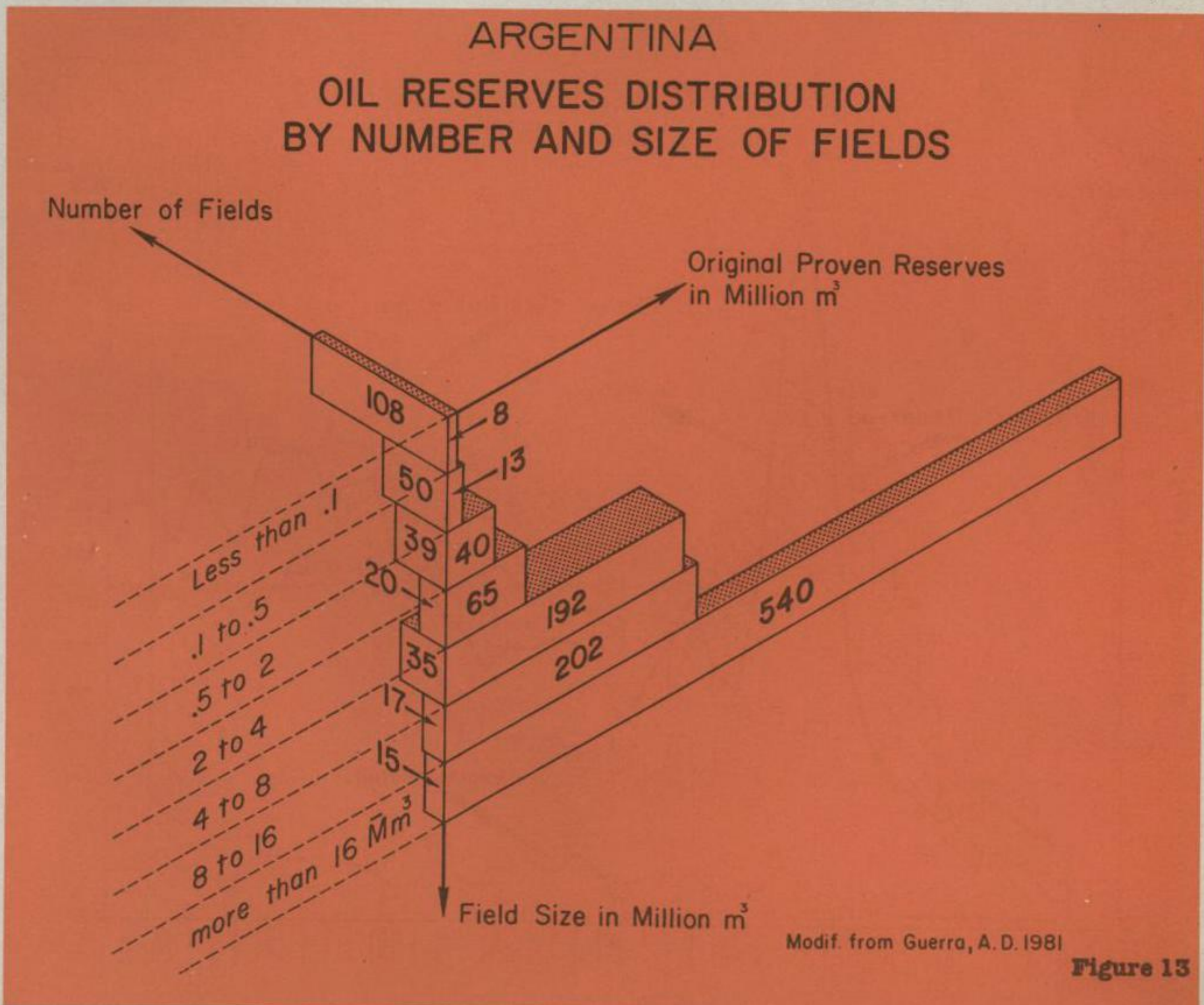

Figure 13

remaining proven oil reserves (126 million m³) are in more than 200 small fields of the lowest four categories.

If we accept the classification by Halbouty et al. (1970), that "giant" oil fields are those having original reserves of more than 500 million barrels (about 80 million m³), in Argentina four giant oil fields have been discovered todate. Two of these giant fields -the North Flank Group with 133.8 million m³ of original reserves and the South Flank Group with 198.3 million m³ of original reserves- are in the San Jorge Basin. A third giant field, Loma de la Lata, with 87 million m³ of reserves of oil and condensate, is in the Neuquén basin; the fourth, the Punta Bardas-Vacas Muertas field, with more than 80 million m³ of reserves, is in the Cuyo basin.

Synoptic information on the most important oil/gas fields in Argentina is presented in Table 4. After the field name, the basin and year of discovery is given, as well as a general description of the main reservoirs. The last two columns of Table 4 indicate the cumulative oil and gas production as of December 31, 1990 and the remaining oil/gas reserves at the same date.

6 EVOLUTION OF HYDROCARBON RESERVES IN ARGENTINA

In the country, the rate of increase in oil and gas reserves is closely related to drilling activity. Figure 14 compares annual drilling rates and oil and gas reserves from 1950 until the end of 1990. As it can be observed, and based on official figures, oil reserves in Argentina reached their highest peak in 1961 with total proven reserves of 598 million m³. After 1961, reserves gradually decreased to 250 million m³ in 1967, somewhat coincident with the drilling rate decrease. From 1970 to 1983, proven oil reserves remained at a nearly constant level of 370 million m³ but later on started to descend to 345 million m³ in 1989. Finally, a sudden dramatic drop to 250 million m³ is noticeable in 1990. This is due not only to historical decline, it also reflects official figures resulting from an auditing of hydrocarbon reserves requested by the state oil agency YPF to a private consultant company.

The evolution of proven reserves of natural gas differs substantially from that of proven oil reserves. Since 1978, gas reserves have been considerably higher than oil reserves, chiefly because of the discovery of the giant Loma de la Lata field in the Central part of the Neuquén basin. This field has reserves of 367,000 million

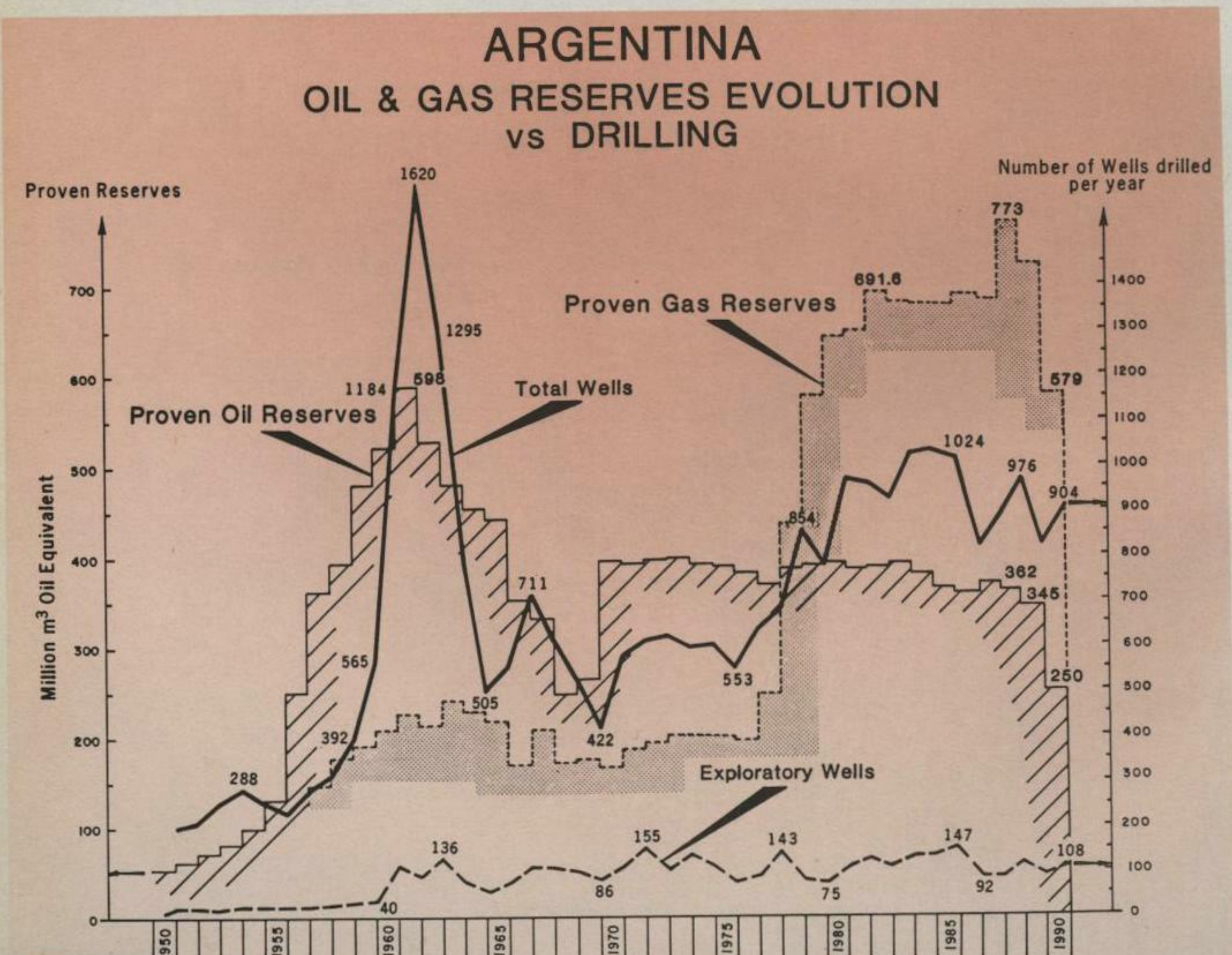

Figure 14

Table 4: Selected Oil and Gas Fields in Argentina
Planilla 4: Principales Campos de Petróleo y Gas de Argentina

(partially updating of M.R. Yrigoyen, 1991)

Field Name / Yacimiento	Basin / Cuenca	Year disc. / Año descub.	Major Reservoir / Reservorio Principal: Fm. name / Formación	Age / Edad	Lithology / Litología	Av. depth (') / Profund. (m)	Type of Trap / Entrampamiento	Cum. Produc. / Prod. Acum.* 31-XII-90	Rem. Reserves / Reserva Rem.* 01-XII-91
Flanco Norte (1)	San Jorge	1907	Chubutiano	Cretac.	SS. aren.	2000-10500'	fault block		
			Glauconítico	Paleoc.	SS. aren.	600-3150 m	monocl. fallado	97838+ ? G	36031+ ? G
Flanco Sur (2)	San Jorge	1946	Chubutiano	Cretac.	SS. aren.	1600-8500'	fault block	116762+ ? G	81600+ ? G
						480-2550 m	monocl. fallado		
Loma de la Lata	Neuquén	1977	Sas. Blancas	Juras.	SS. aren.	7200'-2200 m	strat.-struct.	7882+40868 G	25367+194843 G
			Quintuco	Cretac.	Lms. Calc.	6200'-1860 m	estrat.-estruct.		
Punta de Bardas/ Vacas Muertas	Cuyo	1961	Barrancas/ Victor	Cretac. Trias.	SS. aren.	7400'-2220 m	anticlin.	56537+ ? G	22958+ ? G
Caimancito	Orán	1969	Yacoraite	Cret. Ter.	Lms. calc.	12000'-4000 m	anticlin.	9852+2720 G	394+112 G
Aguaragüe	Tarija	1927	Sta. Rosa	Devon.	SS. aren.	11000'-3300 m	anticlin.	3421+9845 G	10678+57436 G
Campo Durán	Tarija	1951	Tupambi	Carbon.	SS. aren.	10800'-3250 m	anticlin.	12060+36767 G (Campo Durán + Madrejones)	713+7399 G (Campo Durán + Madrejones)
Madrejones	Tarija	1953	Tupambi	Carbon.	SS. aren.	13100'-3930 m	anticlin.		
Ramos	Tarija	1979	Sta. Rosa	Devon.	SS. aren.	12600'-3800 m	anticlin.	1446+9211 G	8504+77769 G
Barrancas	Cuyo	1939	Barrancas/	Cretac.	SS. aren.	6500'-2000 m	anticlin.	30112+698 G	3399+84 G
			Brecha Verde	Trias.	SS. aren.				
Vizcacheras	Cuyo	1963	Barrancas/ Papagayos	Cretac. Ter.	SS. aren.	7000'-2100 m	anticlin.	42565+957 G	8475+371 G
Tupungato/ Refugio	Cuyo	1934	Victor/ Potrerillos	Trias.	SS. aren.	6600'-2000 m	anticlin.	9333+859 G	2112+137 G
Sa. Barrosa	Neuquén	1957	Las Lajas	Juras.	SS. aren.	6900'-2100 m	anticlin.	5443+13745 G	404+5398 G
Centenario	Neuquén	1977	Sas. Blancas	Juras.	SS. aren.	8400'-2520 m	fault ant.	7940+7003 G	2081+1719 G
Río Neuquén	Neuquén	1971	Quintuco/ Sas. Blancas	Cretac. Juras.	SS. aren.	7200'-2200	anticlin.	7715+16771 G	1362+8146 G
Lindero atrav.	Neuquén	1971	Las Lajas/ Sas. Blancas	Juras.	SS. aren.	9500'-2850 m	fault ant.	4881+18504 G	608+8187 G
Pto. Hernández	Neuquén	1968	Avilé-Agrio	Cretac.	SS. aren.	3900'-1200 m	anticlin.	24931+5525 G	14426+1657 G
Medanito	Neuquén	1959	Loma Montosa	Cretac.	SS. aren.	3900'-1200 m	stratigr.	20464+2555 G	1592+33 G
			Sas. Blancas	Juras.					
Entre Lomas	Neuquén	1967	Loma Montosa	Cretac.	SS. aren.	7200'-2160 m	stratigr.	17300+12812 G	1790+1978 G
El Trébol	San Jorge	1933	Chubutiano	Cretac.	SS. aren.	7000'-2100 m	fault block	12383+334 G	3141+154 G
El Tordillo	San Jorge	1935	Chubutiano	Cretac.	SS. aren.	7000'-2100 m	fault block	21591+2136 G	6867+700 G
Dragón gr.	San Jorge	1958	Chubutiano	Cretac.	SS. aren.	6500'-1950 m	fault block	72854+1796 G	10664+5866 G
Koluel Kaike	San Jorge	1957	Chubutiano	Cretac.	SS. aren.	8100'-2430 m	fault block	21904+12780 G	5476+1616 G
San Sebastián	Magallanes	1966	Springhill	Cretac.	SS. aren.	6000'-1800 m	anticlin.	2670+18740 G	2325+21406 G
Cañ. Alfa gr.	Magallanes	1972	Springhill	Cretac.	SS. aren.	6100'-1830 m	anticlin.	9423+2315 G	16816+16258 G
Cóndor	Magallanes	1966	Springhill	Cretac.	SS. aren.	6000'-1800 m	anticlin.	4962+32965 G	912+6525 G
Hidra	Magallanes	1988	Springhill	Cretac.	SS. aren.	6000'-1800 m	fault ant.	2027+103 G	4973+401 G

(*) Oil + condensate (= petróleo + condensado) x 1000 m3; gas x 1,000,000 m3 Gas

(1) Gian Flanco Norte = Zona Central + Diadema + M. Behr + Petroquímica + Escalante + Km 20 + Cañ. Perdido + Restinga Alí + Caleta Córdova

(2) Giant Flanco Sur = Cañ. León + Cal. Olivia + Cañ. Seco + Pico Truncado + Meseta Espinosa + Huemul + Cañ. Minerales + El Valle

m^3 of natural gas plus 67.2 million m^3 of condensate in the Sierras Blancas reservoir, of Callovian age, and 19.5 million m^3 of oil in the Quintuco (Berriasian limestone) reservoir.

The magnitude of Argentine gas reserves has increased in recent years with new gas discoveries, mainly in the Tarija basin, which reached a maximum of 691,000 million m^3 in 1981/82 and then decreased to the present value of 579,056 million m^3, or 20.4 trillion cubic feet of gas, at December 31, 1990.

Drilling rate curves in Figure 14 show that the most intensive drilling was performed in 1961 when a total of 1620 wells were completed. Drilling rate declined to a minimum of 422 wells in 1969 and then increased gradually to 1024 wells in 1984. Figure 14 also shows that yearly exploration drilling was also variable, reaching a maximum of 155 wildcats in 1971, and decreasing to 108 N.F.W. in 1990.

An evaluation of required drilling rates until year 2000 to maintain both self-sufficiency and the current reserves/demand relationship was made by the Chamber of Argentine Oil Companies some five years ago. This study reveals that new reserves tantamount to the oil discovered and proven from 1907 to 1984 will have to be added till year 2000, or around 1,000 million m^3. On the basis of historical experience and assuming a cumulative annual consumption growth of 3 to 4% per year, it was estimated that 23,000 development wells (1,450 wells per year) and a total of 3,300 wildcats (200 exploration wells per year) will be required to achieve this target. These drilling rates are far beyond the present 1990 rates.

Buenos Aires, August 1991

REFERENCES CITED

(Referencias citadas en el texto)

Cáceres, A.E., and G. Montangero, 1985, Reservorios precretácicos argentinos: Asistencia Recíproca de Empresas Petroleras Latinoamericanas, LV Reunión a nivel de expertos, p. 1-31, Quito, Ecuador.

Halbouty, M.T., A.A. Meyerhoff, R.E. King, R.H. Dott, Sr., D. Klemme, and T. Shabad, 1970, World's giant oil and gas fields, geologic factor affecting their formation and basin classification. Geology of giant petroleum fields: American Association of Petroleum Geologists Memoir 14, p. 502-575.

Lesta P., J. Digregorio, and M.E. Mozetic, 1985, Presente y futuro de la exploración de petróleo en las cuencas subandinas argentinas: II Simposio Bolivariano-Exploración Petrolera de las Cuencas Subandinas, v. 3, p. 1-34, Bogotá, Colombia.

Turic, M., C. Fernández-Garrasino, R. Pombo, J.L. Bianchi, and H. Dibenedetto, 1981, Cuencas sedimentarias en la Argentina: Published communication of Yacimientos Petrolíferos Fiscales, p. 3-40, Buenos Aires.

Yrigoyen, M.R., 1989, Geology of the Andes and its relation to hydrocarbon and mineral resources. Chapter 32: Sub-Andean hydrocarbon resources of Argentina. (Earth Science Series, v. 11): Houston, Texas, Circum-Pacific Council for Energy and Mineral Resources, p. 439-452.

Yrigoyen, M.R., 1991, Explanatory Notes for the Energy Resources Map of the Circum-Pacific region, Southeast Quadrant. (Map CP-39), U.S. Department of the Interior, U.S. Geological Survey, Menlo Park, California, p. 1-59.

EPIGRAPHES OF FIGURES 1 TO 14

Figure 1 - Index map of South America showing sedimentary basins and energy requirements of Argentina.

Figure 2 - Hydrocarbon productive areas in relation to sedimentary basins of Argentina. Location of cross-sections shown in Figures 3 to 8.

Figure 3 - Schematic cross-section of Tarija Basin. (location shown in Figure 2)

Figure 4 - Schematic cross-section of Oran (= Olmedo) Basin. (location shown in Figure 2)

Figure 5 - Schematic cross-section of Cuyo Basin. (location shown in Figure 2)

Figure 6 - Schematic cross-section of Neuquén Basin. (location shown in Figure 2)

Figure 7 - Shematic cross-section of San Jorge Basin. (location shown in Figure 2)

Figure 8 - Schematic cross-section of Magallanes-Malvinas Basins. (location shown in Figure 2)

Figure 9 - Percentage distribution of original and remaining proved oil reserves in Argentine sedimentary basins.

Figure 10 - Percentage distribution of original proved and probable gas reserves and potential gas resources in Argentine sedimentary basins.

Figure 11 - Distribution of oil reserves in Argentina by reservoir age.

Figure 12 - Distribution of oil resources in Argentina by basin and reservoir.

Figure 13 - Distribution of oil reserves in Argentina by number and size of fields.

Figure 14 - Proven oil and gas reserves in Argentina from year 1950 to 1990, in relation to drilling activity.

***Dr. Marcelo Irigoyen**, Doctor of Natural Sciences and of Petroleum Geology. The author of many works on geology and petroleum. At present general manager of Trend International. Is a "Corresponding Academic" of the National Academy of Science. Heads the scientific Committee of the 13th World Petroleum Congress.*