Total Petroleum Systems of the Grand Erg/Ahnet Province, Algeria and Morocco—The Tanezzuft-Timimoun, Tanezzuft-Ahnet, Tanezzuft-Sbaa, Tanezzuft-Mouydir, Tanezzuft-Benoud, and Tanezzuft-Béchar/Abadla

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Foreword

This report was prepared as part of the U.S. Geological Survey World Petroleum Assessment 2000. The primary objective of World Petroleum Assessment 2000 is to assess the quantities of conventional oil, gas, and natural gas liquids outside the United States that have the potential to be added to reserves in the next 30 years. Parts of these assessed volumes reside in undiscovered fields whose sizes exceed the stated minimum-field-size cutoff value for the assessment unit, which is variable but must be at least 1 million barrels of oil equivalent. Another part of these assessed volumes occurs as reserve growth of fields already discovered. However, the contribution from reserve growth of discovered fields to resources is not covered for the areas treated in this report.

In order to organize, evaluate, and delineate areas to assess, the Assessment Methodology Team of World Petroleum Assessment 2000 developed a hierarchical scheme of geographic and geologic units. This scheme consists of regions, geologic provinces, total petroleum systems, and assessment units. For World Petroleum Assessment 2000, regions serve as organizational units and geologic provinces are used as prioritization tools. Assessment of undiscovered resources was done at the level of the total petroleum system or assessment unit.

The world was divided into 8 regions and 937 geologic provinces. These provinces have been ranked according to the discovered known oil and gas volumes (Klett and others, 1997). Then, 76 “priority” provinces (exclusive of the United States and chosen for their high ranking) and 26 “boutique” provinces (exclusive of the United States) were selected for appraisal of oil and gas resources. Boutique provinces were chosen for their anticipated petroleum richness or special regional economic or strategic importance.

A geologic province is an area having characteristic dimensions of hundreds of kilometers that encompasses a natural geologic entity (for example, a sedimentary basin, thrust belt, or accreted terrane) or some combination of contiguous geologic entities. Each geologic province is a spatial entity with common geologic attributes. Province boundaries were drawn as logically as possible along natural geologic boundaries, although in some places they were located arbitrarily (for example, along specific water-depth contours in the open oceans).

Total petroleum systems and assessment units were delineated for each geologic province considered for assessment. It is not necessary for the boundaries of total petroleum systems and assessment units to be entirely contained within a geologic province. Particular emphasis is placed on the similarities of *petroleum fluids* within total petroleum systems, unlike geologic provinces and plays in which similarities of *rocks* are emphasized.

The total petroleum system includes all genetically related petroleum that occurs in shows and accumulations (discovered and undiscovered) generated by a pod or by closely related pods of mature source rock. Total petroleum systems exist within a limited mappable geologic space, together with the essential mappable geologic elements (source, reservoir, seal, and overburden rocks). These essential geologic elements control the fundamental processes of generation, expulsion, migration, entrapment, and preservation of petroleum within the total petroleum system.

An assessment unit is a mappable part of a total petroleum system in which discovered and undiscovered oil and gas fields constitute a single relatively homogeneous population such that the methodology of resource assessment based on estimation of the number and sizes of undiscovered fields is applicable. A total petroleum system might equate to a single assessment unit. If necessary, a total petroleum system may be subdivided into two or more assessment units such that each assessment unit is *sufficiently* homogeneous in terms of geology, exploration considerations, and risk to assess individually. Differences in the distributions of accumulation density, trap styles, reservoirs, and exploration concepts within an assessment unit were recognized and *not* assumed to extend homogeneously across an entire assessment unit.

A numeric code identifies each region, province, total petroleum system, and assessment unit. The criteria for assigning codes are uniform throughout the project and throughout all publications of the project. The numeric codes used in this study are:

Unit	Name	Code
Region	Middle East and North Africa	**2**
Province	Grand Erg/Ahnet	2**058**
Total Petroleum Systems	Tanezzuft-Timimoun	2058**01**
	Tanezzuft-Ahnet	2058**02**
	Tanezzuft-Sbaa	2058**03**
	Tanezzuft-Mouydir	2058**04**
	Tanezzuft-Benoud	2058**05**
	Tanezzuft-Béchar/Abadla	2058**06**
Assessment Units	Tanezzuft-Timimoun Structural/Stratigraphic	205801**01**

Assessment units—Continued	Code
Tanezzuft-Ahnet Structural/Stratigraphic	2058020**1**
Tanezzuft-Sbaa Structural/Stratigraphic	2058030**1**
Tanezzuft-Mouydir Structural/Stratigraphic	2058040**1**
Tanezzuft-Benoud Structural/Stratigraphic	2058050**1**
Tanezzuft-Béchar/Abadla Structural/Stratigraphic	2058060**1**

A graphical depiction that places the elements of the total petroleum system into the context of geologic time is provided in the form of an events chart. Items on the events chart include (1) the major rock-unit names; (2) the temporal extent of source-rock deposition, reservoir-rock deposition, seal-rock deposition, overburden-rock deposition, trap formation, generation-migration-accumulation of petroleum, and preservation of petroleum; and (3) the critical moment, which is defined as the time that best depicts the generation-migration-accumulation of hydrocarbons in a petroleum system (Magoon and Dow, 1994). The events chart serves only as a timeline and does not necessarily represent spatial relations.

Probabilities of occurrence of adequate charge, rocks, and timing were assigned to each assessment unit. Additionally, an access probability was assigned for necessary petroleum-related activity within the assessment unit. All four probabilities, or risking elements, are similar in application and address the question of whether at least one undiscovered field of minimum size has the potential to be added to reserves in the next 30 years somewhere in the assessment unit. Each risking element thus applies to the entire assessment unit and does not equate to the percentage of the assessment unit that might be unfavorable in terms of charge, rocks, timing, or access.

Estimated total recoverable oil and gas volumes (cumulative production plus remaining reserves, called "known" volumes hereafter) quoted in this report are derived from Petroconsultants, Inc., 1996 Petroleum Exploration and Production database (Petroconsultants, 1996a). To address the fact that increases in reported known volumes through time are commonly observed, the U.S. Geological Survey (Schmoker and Crovelli, 1998) and the Minerals Management Service (Lore and others, 1996) created a set of analytical "growth" functions that are used to estimate future reserve growth (called "grown" volumes hereafter). The set of functions was originally created for geologic regions of the United States, but it is assumed that these regions can serve as analogs for the world. This study applied the Federal offshore Gulf of Mexico growth function (developed by the U.S. Minerals Management Service) to known oil and gas volumes, which in turn were plotted to aid in estimating undiscovered petroleum volumes. These estimates of undiscovered petroleum volumes therefore take into account reserve growth of fields yet to be discovered.

Estimates of the minimum, median, and maximum number, sizes, and coproduct ratios of undiscovered fields were made based on geologic knowledge of the assessment unit, exploration and discovery history, analogs, and, if available, prospect maps. Probabilistic distributions were applied to these estimates and combined by Monte Carlo simulation to calculate undiscovered resources.

Illustrations in this report that show boundaries of the total petroleum systems, assessment units, and extent of source rocks were compiled using geographic information system (GIS) software. The political boundaries shown are not politically definitive and are displayed for general reference only. Oil and gas field center points were provided by, and reproduced with permission from, Petroconsultants (1996a and 1996b).

Abstract

Undiscovered, conventional oil and gas resources were assessed within total petroleum systems of the Grand Erg/Ahnet Province (2058) as part of the U.S. Geological Survey World Petroleum Assessment 2000. The majority of the Grand Erg/Ahnet Province is in western Algeria; a very small portion extends into Morocco. The province includes the Timimoun Basin, Ahnet Basin, Sbaa Basin, Mouydir Basin, Benoud Trough, Béchar/Abadla Basin(s), and part of the Oued Mya Basin. Although several petroleum systems may exist within each of these basins, only seven "composite" total petroleum systems were identified. Each total petroleum system occurs in a separate basin, and each comprises a single assessment unit.

The main source rocks are the Silurian Tanezzuft Formation (or lateral equivalents) and Middle to Upper Devonian mudstone. Maturation history and the major migration pathways from source to reservoir are unique to each basin. The total petroleum systems were named after the oldest major source rock and the basin in which it resides.

The estimated means of the undiscovered conventional petroleum volumes in total petroleum systems of the Grand Erg/Ahnet Province are as follows:

[MMBO, million barrels of oil; BCFG, billion cubic feet of gas; MMBNGL, million barrels of natural gas liquids]

Total Petroleum System	MMBO	BCFG	MMBNGL
Tanezzuft-Timimoun	31	1,128	56
Tanezzuft-Ahnet	34	2,973	149
Tanezzuft-Sbaa	162	645	11
Tanezzuft-Mouydir	12	292	14
Tanezzuft-Benoud	72	2,541	125
Tanezzuft-Béchar/Abadla	16	441	22

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Introduction

Undiscovered conventional oil and gas volumes were assessed within total petroleum systems of the Grand Erg/Ahnet Province (2058) as part of the U.S. Geological Survey (USGS) World Petroleum Assessment 2000. This study documents the geology, undiscovered oil and gas volumes, exploration activity, and discovery history of the Grand Erg/Ahnet Province.

The Grand Erg/Ahnet Province is a geologic province delineated by the USGS; it is located primarily in western Algeria (fig. 1). The northwest tip of the province extends slightly into Morocco. The province area encompasses approximately 700,000 km^2 (square kilometers).

The province contains the Timimoun Basin, Ahnet Basin, Sbaa Basin, Mouydir Basin, Benoud Trough, Béchar Basin, Abadla Basin, and part of the Oued Mya Basin. Neighboring geologic provinces, delineated by the USGS, include the Atlas Uplift (2053), Trias/Ghadames Basin (2054), Illizi Basin (2056), Hoggar (7041), Reggane Basin (2060), and Ougarta Uplift (2061).

More than one total petroleum system may exist within each of the basins in the Grand Erg/Ahnet Province (Boote and others, 1998). Data available for this study are insufficient to adequately determine the relative contribution of each system to individual accumulations and therefore preclude further subdivision. Consequently only "composite" total petroleum systems are described in this report, each of which contains one or multiple total petroleum systems. These systems are coincident with the basins in which they exist and are called the Tanezzuft-Timimoun, Tanezzuft-Ahnet, Tanezzuft-Sbaa, Tanezzuft-Mouydir, Tanezzuft-Benoud, Tanezzuft-Béchar/Abadla, and Tanezzuft-Oued Mya Total Petroleum Systems (fig. 2). The Tanezzuft-Oued Mya Total Petroleum System extends across both the Grand Erg/Ahnet and the neighboring Trias/Ghadames Province, and is not described in this study. Tanezzuft refers to the Tanezzuft Formation (Silurian), which is the oldest major source rock in the system; in the total petroleum system name, "Tanezzuft" is then followed by the basin name in which the total petroleum system exists. Due to scarcity of data, province and total petroleum system boundaries can only be approximately delineated and therefore are subject to future modification.

One assessment unit was defined for each total petroleum system; the assessment units coincide with the total petroleum systems (fig. 3). The assessment units are named after the total petroleum system with a suffix of "Structural/Stratigraphic." This suffix refers to the progression from a structural and combination trap exploration strategy to a stratigraphic (subtle) trap exploration strategy.

Grand Erg/Ahnet Province contains more than 5,500 million barrels (MMB) of known (estimated total recoverable, that is cumulative production plus remaining reserves) petroleum liquids (approximately 500 million barrels of oil, MMBO, and 5,000 million barrels of natural gas liquids, MMBNGL), and approximately 114,000 billion cubic feet of known natural gas ($114{\times}10^{12}$ CFG or 114,000 BCFG) (Petroconsultants, 1996a). The Grand Erg/Ahnet Province contains the giant Hassi R'Mel gas field.

Province Geology

The major structural features of the Grand Erg/Ahnet Province are the Idjerane-M'Zab structural axis; the Tilrhemt Arch, Oued Namous Dome, and Maharez Dome (together forming a structural axis); and the Ensellement Zousfana (Zousfana Saddle), Maharez Dome, and Ensellement Beni Abbes (Beni Abbes Saddle) (fig. 1). The Idjerane-M'Zab structural axis extends north to south, generally from the Tilrhemt Arch to the Hoggar Massif. A structural axis consisting of the Ensellement Zousfana, Maharez Dome, and Ensellement Beni Abbes extends from the Saharan Flexure in the north to the Ougarta Range in the south, separating the Béchar and Abadla Basins from the Timimoun Basin (Futyan and Jawzi, 1996). The Tilrhemt-Oued Namous-Maharez structural axis extends east to west from the Béchar and Abadla Basins into the neighboring Triassic Basin (Futyan and Jawzi, 1996).

A total petroleum system (and assessment unit) was identified in each of the basins of the Grand Erg/Ahnet Province. Stratigraphic cross sections showing the major structural features and total petroleum systems are shown in figures 2 (locations of cross sections) and 4.

The Tanezzuft-Timimoun Total Petroleum System is bounded on the north by the Tilrhemt-Oued Namous-Maharez structural axis; on the east by the Idjerane-M'Zab structural axis; on the south by the Djoua Saddle, Azzene High, and Ougarta Range; and on the west by the Ensellement Beni Abbes (figs. 1 and 4*A)*.

The Tanezzuft-Ahnet Total Petroleum System is bounded on the north by the Djoua Saddle, on the east by the Idjerane-M'Zab structural axis, on the south by the Hoggar Massif, and on the west by the Ougarta Range and Sbaa Basin (figs. 1 and 4*A*). Paleozoic rocks, including the major source rocks, crop out along the Hoggar Massif (figs. 2 and 3).

The Tanezzuft-Sbaa Total Petroleum System is bounded on the north and east by the Azzene High, and on the south and west by the Ougarta Range (figs. 1 and 4*A*).

The Tanezzuft-Mouydir Total Petroleum System is bounded on the north by the Oued Mya Basin, on the east by the Amguid-Hassi Touareg structural axis, on the south by the Hoggar Massif, and on the west by the Idjerane-M'Zab structural axis (fig. 1). The boundary between the Mouydir Basin and the neighboring Oued Mya Basin to the north is defined by the Mouydir Structural Terrace, a break or hinge line in the slope of the basement rocks that separates the two basins (figs. 1, 4*B*). The Mouydir Basin is presently perched on a basement high and is not as deep as the neighboring Oued Mya Basin. Like the Tanezzuft-Ahnet Total Petroleum System, Paleozoic rocks crop out along the Hoggar Massif (figs. 2 and 3).

The Tanezzuft-Benoud Total Petroleum System is bounded on the north by the Saharan Flexure, on the east by the Ain Rich High and Tilrhemt Arch, on the south by the Tilrhemt-Oued Namous-Maharez structural axis, and on the west by the Ensellement Zousfana. The Benoud Trough is a shallow foreland basin. The eastern portion is superimposed on part of the Triassic Basin. The approximate extent of Triassic Basin is defined by the extent of Triassic- to Jurassic-aged evaporites (limit of salt shown in fig. 1).

The Béchar and Abadla Basins are partially connected with only one minor structure existing between them (Futyan and Jawzi, 1996). Therefore, these two basins are treated collectively as the Tanezzuft-Béchar/Abadla Total Petroleum

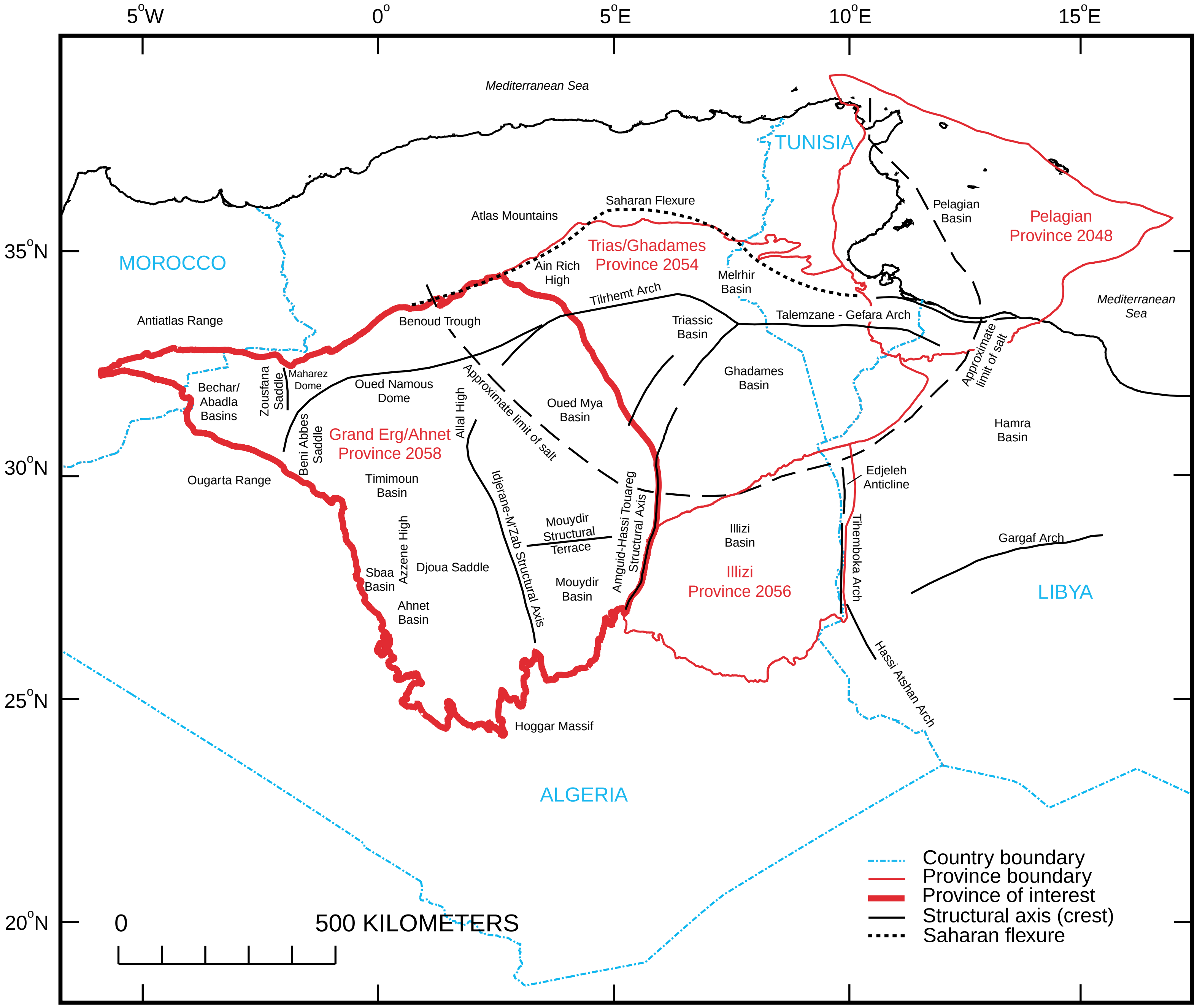


Figure 1. North-central Africa, showing USGS-defined geologic provinces and major structures (modified from Aliev and others, 1971; Burollet and others, 1978; Montgomery, 1994; Petroconsultants, 1996b; Persits and others,1997).

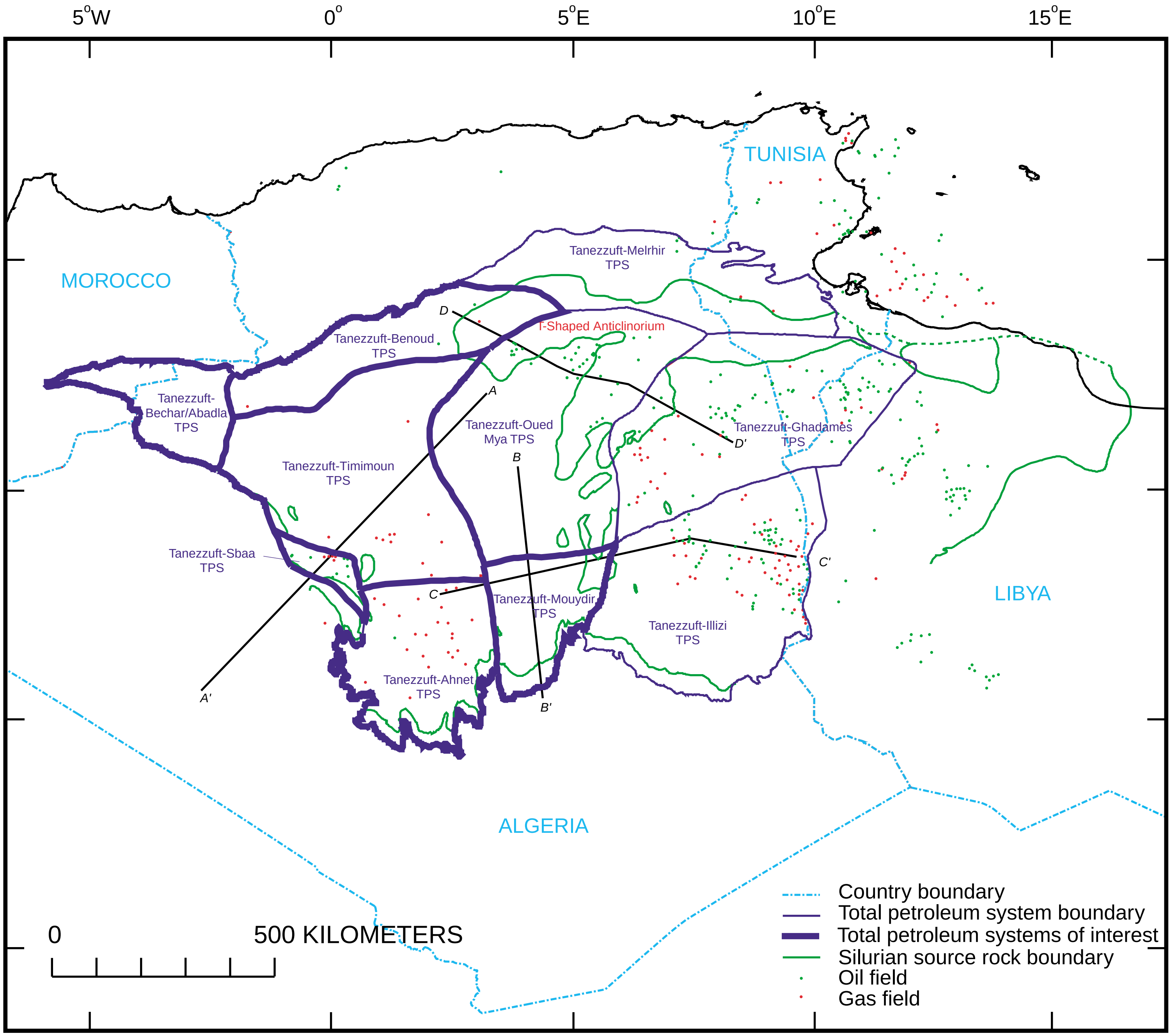


Figure 2. North-central Africa, showing the areal extent of total petroleum systems and Silurian source rocks (Tanezzuft Formation), and locations of stratigraphic cross sections (modified from Petroconsultants, 1996b; Persits and others, 1997; Boote and others, 1998).

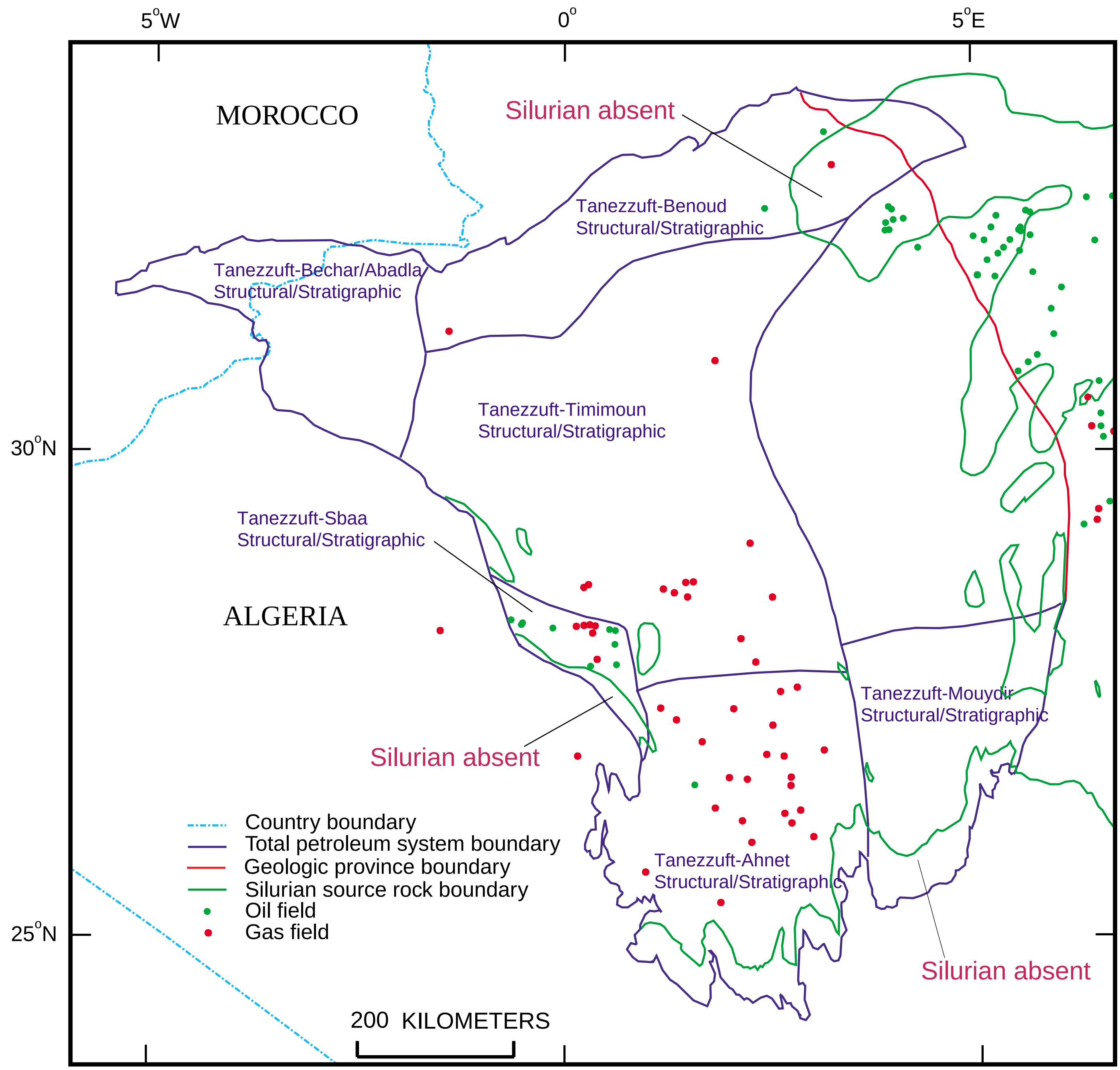
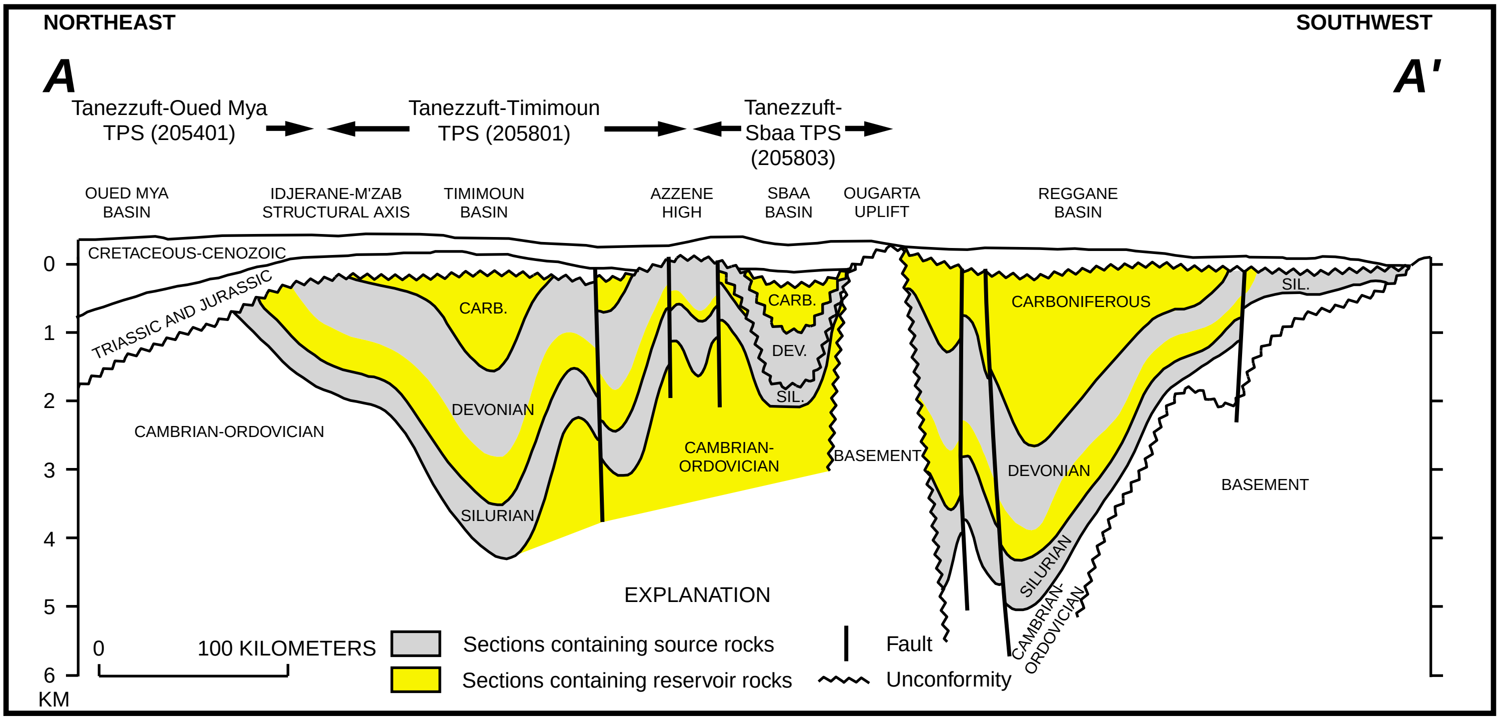
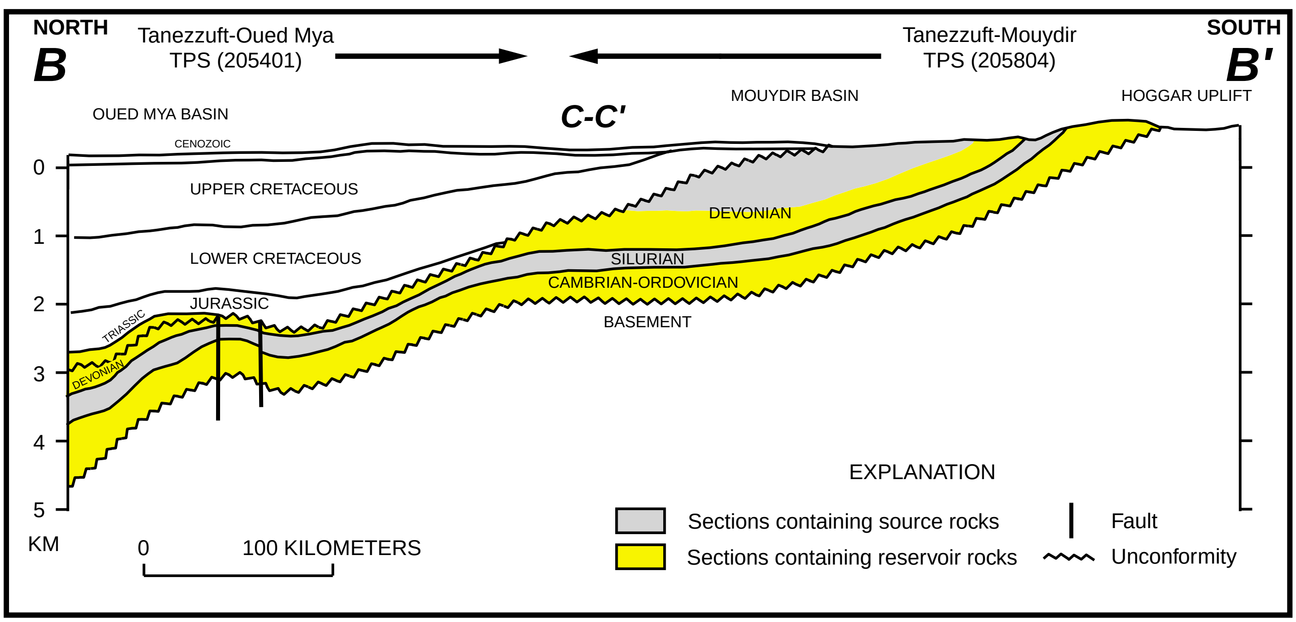


Figure 3. Areal extent of assessment units within the Grand Erg/Ahnet Province (modified from Petroconsultants, 1996b; Persits and others, 1997).



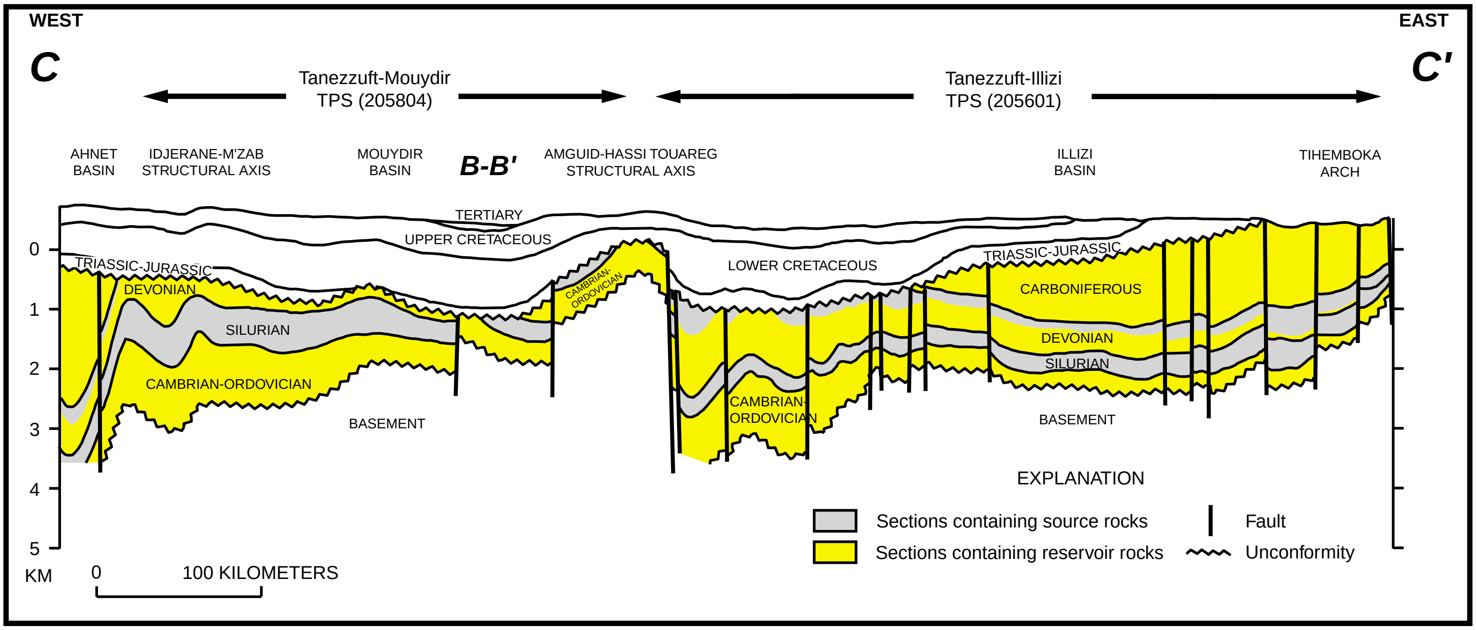
A

Figure 4. Stratigraphic cross sections through Grand Erg/Ahnet and neighboring provinces. *A*, North-to-south stratigraphic cross section through the Oued Mya, Timimoun, Sbaa, and Reggane Basins (modified from Aliev and others, 1971; Makhous and others, 1997).



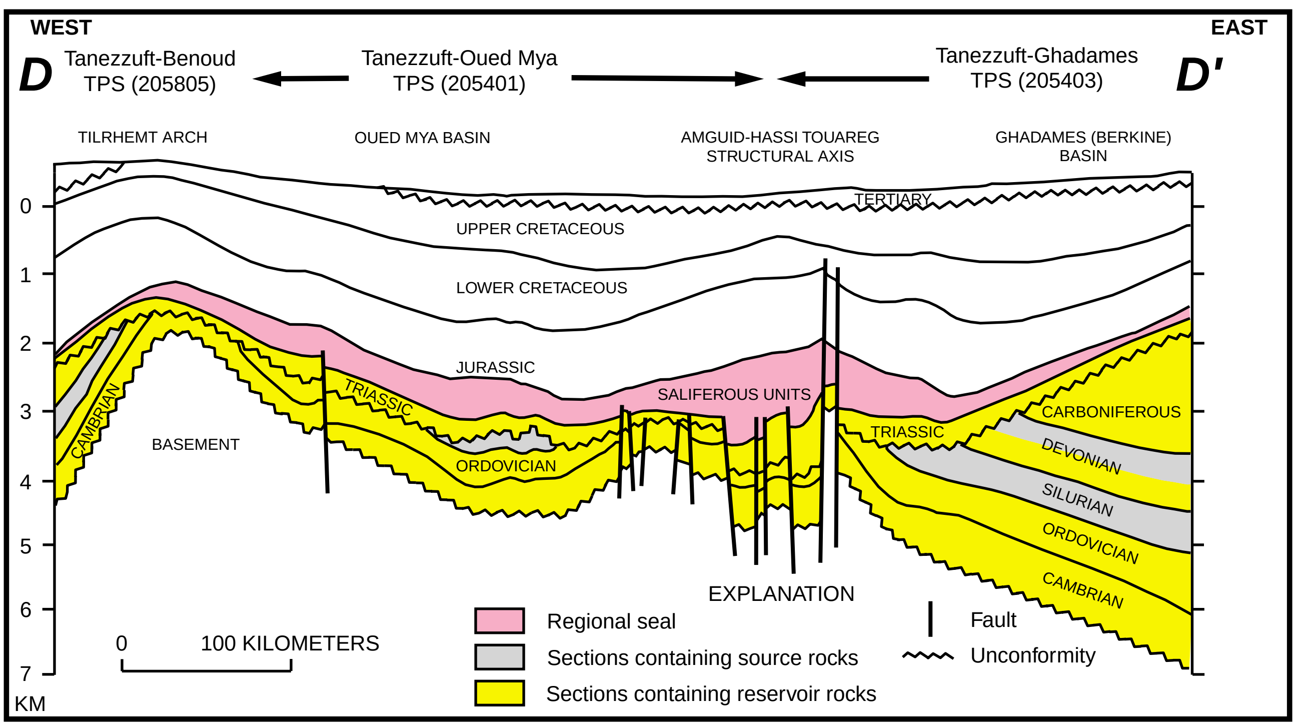
B

Figure 4—Continued. Stratigraphic cross sections. *B*, North-to-south stratigraphic cross section through the Oued Mya and Mouydir Basins (modified from Makhous and others, 1997).



C

Figure 4—Continued. Stratigraphic cross sections. *C*, West-to-east stratigraphic cross section through the Mouydir and Illizi Basins (modified from Makhous and others, 1997).



D

Figure 4.—Continued. Stratigraphic cross sections. *D*, West-to-east stratigraphic cross section through the Benoud, Oued Mya, and Ghadames (Berkine) Basins (modified from van de Weerd and Ware,1994, after Aliev and others, 1971).

System. The Béchar/Abadla Basin is bounded on the north by the Antiatlas Range, on the east by the Ensellement Zousfana-Maharez Dome-Ensellement Beni Abbes structural axis, and on the south and west by the Ougarta Range (fig. 1).

Tectonic History

The regional stratigraphy is continuous across North Africa, but petroleum generation, migration, and entrapment within each total petroleum system have been controlled by the tectonic history of individual basins. Deformational events in the region, most of them minor, are recorded by unconformities reflecting basin tilting, uplift, and erosion of intracratonic structural axes at various times throughout the Phanerozoic. The main deformational events occurred in the Precambrian to Early Cambrian (Pan African event), Late Silurian to Early Devonian, Late Devonian (Frasnian event), Carboniferous to Permian (Hercynian event), Early Jurassic, Early Cretaceous (Aptian, Austrian event), Late Cretaceous, and Tertiary (Eocene to Oligocene, Pyrenean event) (Aliev and others, 1971; Peterson, 1985; Boudjema, 1987; van de Weerd and Ware, 1994).

Throughout most of the Paleozoic, North Africa was a single depositional basin on the northern shelf of the African craton (Aliev and others, 1971; van de Weerd and Ware, 1994). The basin generally deepened northward where deposition and marine influence were greater (Daniels and Emme, 1995). Some gentle but large structures existed in this area throughout the Paleozoic and affected the thickness of the sedimentary cover (Aliev and others, 1971; van de Weerd and Ware, 1994). There was a general conformity of structure throughout most of the Paleozoic until the Hercynian event. In the Late Silurian and Early Devonian, Laurasia separated from Gondwana resulting in minor deformation, uplift, and local erosion (Aliev and others, 1971; Boote and others, 1998). Many of the basins and uplifts preserved today were initially developed during this event from earlier structures (Peterson, 1985). Later, in the Middle to Late Devonian, the initial collision of Laurasia and Gondwana began resulting in erosion and further modification of preexisting structures (Boote and others, 1998).

Minor deformation occurred in the Late Silurian through the Devonian, resulting in uplift and local erosion (Aliev and others, 1971; van de Weerd and Ware, 1994; Boote and others, 1998). Within the Grand Erg/Ahnet Province, uplift and erosion occurred on and near the Amguid-Hassi Touareg structural axis.

The Hercynian event marks the collision between Laurasia and Gondwana and caused regional uplift, folding, and erosion (Aliev and others, 1971; Boote and others, 1998). Paleozoic basins that were delineated by earlier tectonic events were modified, resulting in the development of several intracratonic sag and foreland basins (Aliev and others, 1971; van de Weerd and Ware, 1994; Boote and others, 1998). Petroleum was generated during the Carboniferous Period within deeper portions of the basins, but uplift caused generation to cease (Tissot and others, 1973; Daniels and Emme, 1995; Makhous and others, 1997). Subsequent erosion probably removed or dispersed petroleum that had accumulated in some areas (Boote and others, 1998).

During the Hercynian event, many of the structural traps within the Grand Erg/Ahnet Province resulted from vertical movement of the basement and charged with petroleum (Aliev and others, 1971; Boote and others, 1998). The structural highs separating total petroleum systems within the province, the Idjerane-M'Zab, the Tilrhemt-Oued Namous-Maharez, and the Ensellement Zousfana-Maharez Dome-Ensellement Beni Abbes structural axes, were uplifted at this time. Inversion of the Sbaa Basin also resulted from this event.

Several transgressive-regressive cycles occurred throughout the Paleozoic. Two major flooding events, one in the Silurian and the other in the Late Devonian, were responsible for the deposition of source rocks (Aliev and others, 1971; Boudjema, 1987). Many of the prograding fluvial, estuarine, deltaic, and shallow marine sands that were deposited during these cycles are now reservoirs (Aliev and others, 1971).

During the early Mesozoic, extensional movements caused by the opening of the Tethys and Atlantic oceans developed a cratonic sag basin called the Triassic Basin. The depocenter was superimposed on some of the Paleozoic basins (Aliev and others, 1971; Boudjema, 1987). Triassic fluvial sands followed by a thick Triassic to Jurassic evaporite section were deposited within the sag basin (Aliev and others, 1971; Boudjema, 1987). Sandstones resulting from the fluvial deposition are major reservoirs, and the evaporites provide a regional seal for these fluvial reservoirs as well as Paleozoic reservoirs (Aliev and others, 1971). Clastic then carbonate deposition occurred throughout the remainder of the Mesozoic over much of central North Africa (Aliev and others, 1971; Boudjema, 1987). Sediment deposition gradually diminished in the Tertiary over most of the area (Aliev and others, 1971; Peterson, 1985; Boudjema, 1987).

Transpressional movements (wrenching) during Austrian deformation reactivated older structures causing local uplift and erosion (Claret and Tempere, 1967; Aliev and others, 1971). The initial stages of the Africa-Arabia and Eurasia collision during Late Cretaceous to middle Tertiary caused compressional movements and uplift (Peterson, 1985; Guiraud, 1998).

Compressional movements during the Late Cretaceous and Pyrenean deformation tilted the Triassic Basin to its present configuration (Aliev and others, 1971; Boote and others, 1998). Basins that existed where the present-day Atlas Mountains lie were inverted by these events (Aliev and others, 1971). Inversion and tilting at this time resulted in the development of the shallow Melrhir and Benoud foreland basins (Boote and others, 1998).

Stratigraphy

The stratigraphy of the lower Paleozoic is generally continuous, but the Devonian and overlying sections show more localized depositional systems. Stratigraphic nomenclature varies among the Saharan basins and countries. This study primarily uses nomenclature given in Boudjema (1987), Montgomery

(1993), and Echikh (1998). Columnar sections, stratigraphic nomenclature, and correlations are shown in figure 5.

Principal source rocks are the Silurian Tanezzuft Formation (or its lateral equivalents) and Middle to Upper Devonian mudstone (Givetian to Famennian) (Tissot and others, 1973; Daniels and Emme, 1995). Other minor or relatively unimportant source rocks are also present but contributed significantly less petroleum than did the Silurian or Middle to Upper Devonian mudstone (Daniels and Emme, 1995; Boote and others, 1998). Reservoir rocks include sandstone of Cambrian-Ordovician, Silurian, Devonian, Carboniferous, and Triassic age. Intraformational Paleozoic marine mudstone provides the primary seals. In the Benoud trough, seal rocks also include Triassic to Jurassic evaporites, mudstone, and carbonate rocks.

During the late Precambrian and Early Cambrian, erosion of a preexisting craton to the south occurred due to uplift during the Pan African deformational event. Eroded sediments were deposited northward as alluvial and fluvial deposits and make up a thick Cambrian sandstone section. This sandstone is laterally equivalent to the Hassi Messaoud and Hassi Leila Formations, which are major oil and gas reservoirs in the neighboring Trias/Ghadames and Illizi Provinces (van de Weerd and Ware, 1994; Petroconsultants, 1996a).

Ordovician sandstone and mudstone deposited in marine and marginal marine environments overlie the Cambrian sandstone (Montgomery, 1993; van de Weerd and Ware, 1994). Mudstone laterally equivalent to Argile d'El Gassi, Argiles d'Azzel, and Argile Microconglomerate may be locally important source rocks in the Grand Erg/Ahnet Province (Makhous and others, 1997; Malla and others, 1997).

The organic-rich, graptolitic, marine mudstone of the Silurian Tanezzuft Formation (or its lateral equivalents) overlies the Ordovician section. The Tanezzuft Formation, a principal source rock, was deposited during a major regional flooding event and contains mostly sapropelic and mixed (type I and II) kerogen (Daniels and Emme, 1995; Makhous and others, 1997). The present-day total organic carbon (TOC) content ranges from about 2 to 4 percent across the Timimoun, Ahnet, and Mouydir Basins (Makhous and others, 1997). The TOC content is presumably greatest at the base of the section as in the neighboring Ghadames (Berkine) and Illizi Basins (Daniels and Emme, 1995). The TOC content of the Tanezzuft Formation, however, may be reduced by as much as one-half due to increased thermal maturity (Daniels and Emme, 1995). Equivalent vitrinite reflectance values of the Silurian source rock within the Timimoun, Ahnet, and Mouydir Basins range from 1.2 to 1.6 percent R_o (calculated, Makhous and others, 1997). The thickness, richness, and kerogen type of this source rock are regionally variable and dependent on paleogeography (Daniels and Emme, 1995).

The Devonian rocks unconformably overlie the Upper Silurian sediments. Devonian rocks consist of interbedded marine sandstone and mudstone. Sandstone members are each given a code, F2 to F6 with F6 being the oldest and F2 the youngest (fig. 5). These sandstone members are principal oil and gas reservoirs in the province.

Middle to Upper Devonian mudstone is another major source rock, particularly the Frasnian-aged mudstone, which is the richest in the section (Daniels and Emme, 1995). This mudstone, like the Silurian Tanezzuft Formation, was deposited during a major regional flooding event and contains mostly sapropelic and mixed (type I and II) kerogen (Daniels and Emme, 1995; Makhous and others, 1997). In the Timimoun, Ahnet, and Mouydir Basins, present-day TOC content ranges from about 1 to 8 percent (Makhous and others, 1997). Equivalent vitrinite reflectance values range from 1 to 4 percent R_o (calculated, Makhous and others, 1997). The TOC content in Upper Devonian mudstone generally decreases westward across the Illizi and Grand Erg/Ahnet Provinces (Makhous and others, 1997).

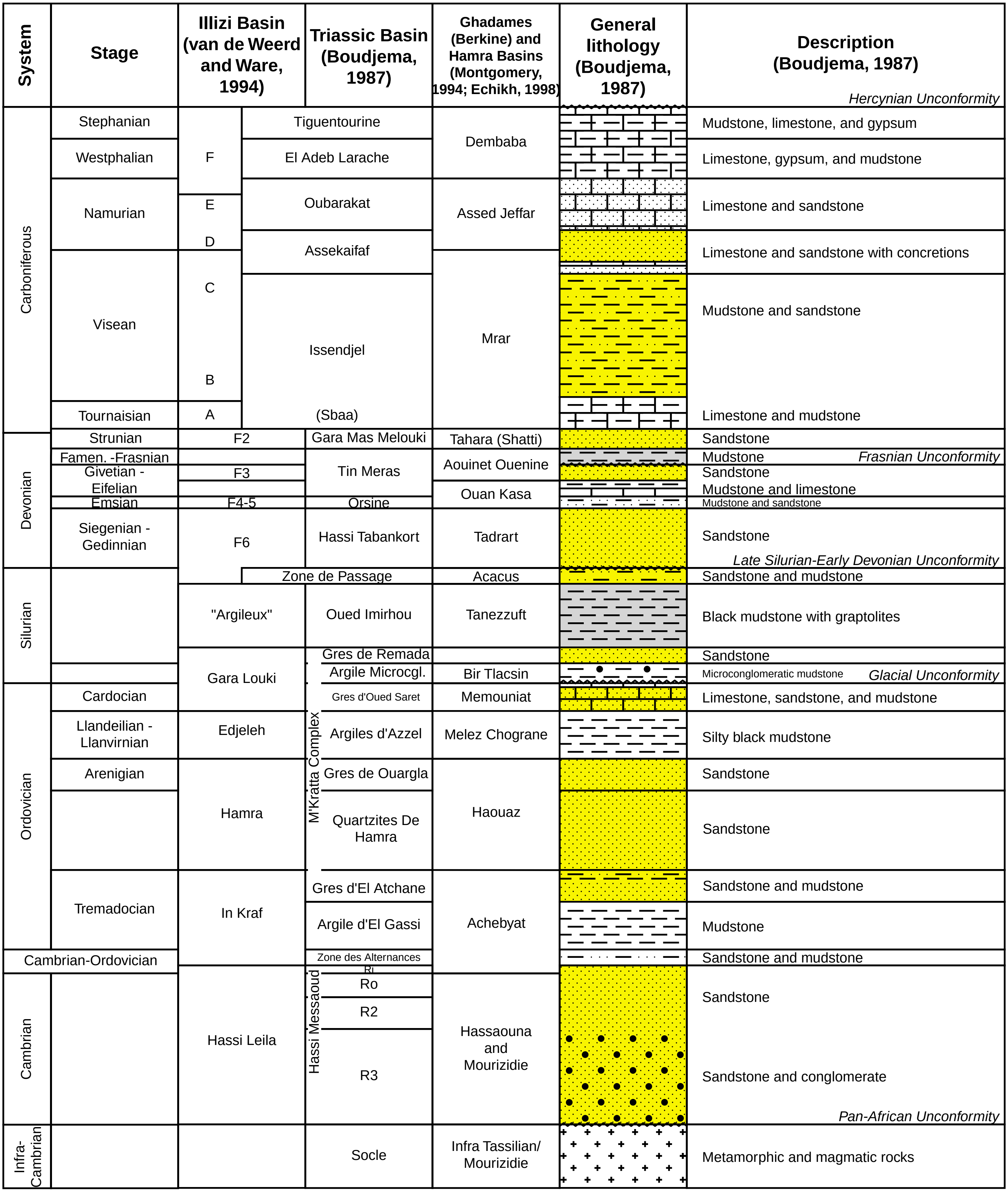
Upper Devonian to Carboniferous formations include the Strunian-Tournaisian Sbaa Formation and overlying unnamed mudstone deposited in deltaic and nearshore marine environments. No Permian rocks are present in the Grand Erg/Ahnet Province. Hercynian deformation started in Late Carboniferous and lasted through Early Permian. Erosion during this event removed most of the Paleozoic section along structural highs.

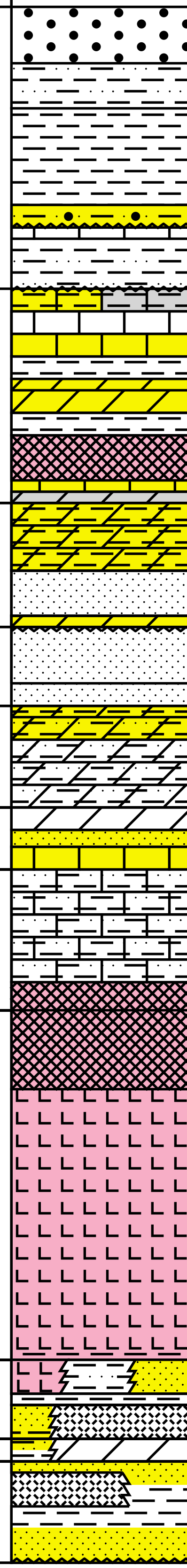
The Mesozoic rock section is thin across much of the Grand Erg/Ahnet Province, but thickens to the northeast in the Oued Mya and Benoud Basins (fig. 4*A*, *B*). Triassic rocks include a lower clastic unit (Middle to Upper Triassic) and an upper evaporite unit that grades into the Jurassic section. The clastic unit is subdivided into the Trias Argilo-Greseux Inferieur, Trias Argilo-Carbonate, and Trias Argilo-Greseux Superieur. Sandstone within this clastic unit is a major oil and gas reservoir. The lowermost Triassic rocks were deposited as continental (fluvial) sandstone and mudstone (Boudjema, 1987; Echikh, 1998). Because these beds were deposited over a dissected erosional surface of the Hercynian unconformity, thickness is variable (Bishop, 1975). The lowermost beds, Trias Argilo-Greseux Inferieur, were deposited as transgressive fluvial sandstone (Ford and Scott, 1997). These lower beds grade upward into dolostone, dolomitic mudstone, and anhydrite beds of the Trias Argilo-Carbonate (Boudjema, 1987; Montgomery, 1993). Rocks of the Trias Argilo-Greseux Superieur consist of alluvial mudstone, siltstone, and fine- to medium-grained sandstone (Boudjema, 1987; Montgomery, 1993). This clastic interval may grade into Jurassic sandstone by backstepping along the southern margins of the Oued Mya Basin (Boote and others, 1998).

Overlying the Triassic clastic unit is an Upper Triassic and Lower Jurassic cyclic sequence of interbedded salt, anhydrite, gypsum, dolostone, and mudstone, called the Saliferous Units (fig. 5) (Bishop, 1975). These rocks form a regional seal for many oil and gas reservoirs (van de Weerd and Ware, 1994). The sequence is thickest near the Saharan Flexure in the north, and it thins southward. The combined maximum thickness (Triassic and Jurassic sections) exceeds 2,000 m.

The Cretaceous section includes nonmarine clastic rocks grading upward into marginal marine clastic rocks, and then into marine carbonate rocks. The thickest Mesozoic section is to the northeast; the section thins to the south and west.

Figure 5 (next two pages). Columnar section and stratigraphic nomenclature for Illizi, Triassic, and Ghadames (Berkine) Basins (modified from Boudjema, 1987). Major reservoir rocks are shown in yellow, source rocks in gray, and seals in red.


System
Stage
Illizi Basin (van de Weerd and Ware, 1994)
Triassic Basin (Boudjema, 1987)
Ghadames (Berkine) and Hamra Basins (Montgomery, 1994; Echikh, 1998)
General lithology (Boudjema, 1987)
Description (Boudjema, 1987)
Hercynian Unconformity
Carboniferous
Stephanian
Westphalian
Namurian
Visean
Tournaisian
F
E
D
C
B
A
Tiguentourine
El Adeb Larache
Oubarakat
Assekaifaf
Issendjel
(Sbaa)
Dembaba
Assed Jeffar
Mrar
Mudstone, limestone, and gypsum
Limestone, gypsum, and mudstone
Limestone and sandstone
Limestone and sandstone with concretions
Mudstone and sandstone
Limestone and mudstone
Devonian
Strunian
Famen. -Frasnian
Givetian - Eifelian
Emsian
Siegenian - Gedinnian
F2
F3
F4-5
F6
Gara Mas Melouki
Tin Meras
Orsine
Hassi Tabankort
Tahara (Shatti)
Aouinet Ouenine
Ouan Kasa
Tadrart
Sandstone
Mudstone
Frasnian Unconformity
Sandstone
Mudstone and limestone
Mudstone and sandstone
Sandstone
Late Silurian-Early Devonian Unconformity
Silurian
Zone de Passage
Acacus
Sandstone and mudstone
"Argileux"
Oued Imirhou
Tanezzuft
Black mudstone with graptolites
Gres de Remada
Sandstone
Gara Louki
Argile Microcgl.
Bir Tlacsin
Microconglomeratic mudstone
Glacial Unconformity
Ordovician
Cardocian
Gres d'Oued Saret
Memouniat
Limestone, sandstone, and mudstone
Llandeilian - Llanvirnian
Edjeleh
Argiles d'Azzel
Melez Chograne
Silty black mudstone
M'Kratta Complex
Arenigian
Gres de Ouargla
Sandstone
Hamra
Quartzites De Hamra
Haouaz
Sandstone
Tremadocian
In Kraf
Gres d'El Atchane
Sandstone and mudstone
Argile d'El Gassi
Achebyat
Mudstone
Cambrian-Ordovician
Zone des Alternances
Sandstone and mudstone
Cambrian
Hassi Leila
Hassi Messaoud
Ri
Ro
R2
R3
Hassaouna and Mourizidie
Sandstone
Sandstone and conglomerate
Pan-African Unconformity
Infra-Cambrian
Socle
Infra Tassilian/ Mourizidie
Metamorphic and magmatic rocks

System	Stage	Illizi Basin (Chaouchi and others, 1998)	Triassic, Ghadames (Berkine), and Hamra Basins (Montgomery, 1994)	General lithology (Boudjema, 1987)	Description (Boudjema, 1987)
Neogene	Pliocene				Conglomerate
					Marl, gypsum, and sandstone
	Miocene				Gypsum, marl, limestone, sandstone, and conglomerate
					Sandstone and marl *Pyrenean Unconformity*
Paleog.	Oligocene				
	Eocene		Al Hamra Group		Limestone and marl
	Paleocene				
Cretaceous	Senonian	Calcaire			Anhydrite, limestone, dolostone, marl, and mudstone
		Marnes			
		Calcaire			
		Argile Gypse			
	Turonian	Serie D'In Akamil	Nefousa Group		Limestone and dolostone
	Cenomanian				Anhydrite, dolostone, and marl
	Albian	Serie de Taouratine			Sandstone, mudstone, and dolostone *Austrian Unconformity*
	Aptian				
	Barremian		Continental Intercalaire		Sandstone and mudstone
	Neocomian		Cabao		Sandstone and dolomitic mudstone
Jurassic	Malm		Scesciuch (Shakshuk)		Anhydrite, limestone, dolostone, marl, and sandstone
	Dogger	Zarzaitine Superieur	Tigi		Mudstone, sandstone, limestone, and anhydrite
	Lias	Zarzaitine Moyen	Saliferous Units		Salt, anhydrite, and mudstone
Triassic		Zarzaitine Inferieur	Argilo-Greseux Superieur (Gassi Touil)		Sandstone, mudstone, salt, and volcanic rocks
			Argilo-Carbonate (Oulad Nsir)		
			Argilo-Greseux Inferieur (Nezla)		*Hercynian Unconformity*

Cenozoic rocks are represented by thin, discontinuous Miocene-Pliocene nonmarine rocks and Quaternary sediments.

Petroleum Occurrence

Most of the oil and gas fields found by the end of 1995 in the Grand Erg/Ahnet Province are associated with anticlines or faulted anticlines that developed during Hercynian deformation (Petroconsultants, 1996a). Many fields are within high-amplitude folds on or near the Djoua Saddle and Azzene High within the Ahnet, Sbaa, and southern Timimoun Basins (fig. 1). Some accumulations are within combination traps, those containing both structural and stratigraphic components, such as Hassi R'Mel and surrounding fields on the broad Tilrhemt Arch.

Regional Exploration History

Exploration activity was not consistent through time in Algeria. Exploration activity in Algeria fluctuated due to its war for independence from 1954 to 1962, nationalization of the oil industry from 1963 to 1971, political and economic problems into the 1980's, and more favorable contractual terms in the late 1980's (Traut and others, 1998; Montgomery, 1994). Since 1963, Algeria had legislation regarding concession contracts and royalties that discouraged exploration by foreign companies (Montgomery, 1994). Since the late 1980's, however, Algeria revised its legislation, encouraging foreign companies to explore and develop oil and gas resources (SONATRACH, c. 1992; Montgomery, 1994; Traut and others, 1998).

Not all areas in Algeria were accessible for exploration. Shifting sand of Saharan Africa deserts presents technical difficulties in exploration and hazards in production operations (Echikh, 1998). Since the 1980's, some of these technical difficulties in exploration have been resolved. Recent advances in gathering, processing, and reprocessing of seismic data allow exploration beneath sand-sea environments such as Grand Erg Occidental where the Timimoun Basin lies (van de Weerd and Ware, 1994; Macgregor, 1998). As of 1996, no pipelines connect the fields of the Timimoun and Ahnet Basins to the existing infrastructure.

Plots showing exploration activity and discovery history for each of the assessment units are presented in the appendices. Due to limited data, however, exploration-activity and discovery-history plots are provided for only the Tanezzuft-Timimoun Structural/Stratigraphic, Tanezzuft-Ahnet Structural/Stratigraphic, and Tanezzuft-Sbaa Structural/Stratigraphic assessment units.

The Tanezzuft-Timimoun Total Petroleum System (205801)

The Tanezzuft-Timimoun Total Petroleum System is an important total petroleum system with respect to known gas volumes. Excluding the contribution from the Hassi R'Mel field, the Tanezzuft-Timimoun Total Petroleum System contains about 50 percent of the discovered gas in the province. An events chart (fig. 6) summarizes the timing of sources, reservoirs, seals, trap development, and generation and migration of petroleum.

Source Rocks

The principal source rocks in the Tanezzuft-Timimoun Total Petroleum System are the Silurian Tanezzuft Formation (or lateral equivalents), and Middle to Upper Devonian mudstone (Makhous and others, 1997; Boote and others, 1998). The present-day TOC content of the Silurian rocks ranges from 2 to 4 percent TOC for the Timimoun, Ahnet, and Mouydir Basins (Makhous and others, 1997). Upper Devonian rocks in the Timimoun Basin contain from 1 to 1.8 percent TOC (Makhous and others, 1997).

Petroleum is presumed to have been generated during the Carboniferous, when the Paleozoic section was thickest, but generation was halted during uplift associated with Hercynian deformation (Makhous and others, 1997; Boote and others, 1998). Migration and charge are presumed to have occurred during the early stages of Hercynian deformation, prior to major uplift and erosion (Boote and others, 1998). Petroleum most likely migrated vertically along faults or fractures (Boote and others, 1998). A later phase of dry gas generation is hypothesized to have occurred due to igneous activity in the Late Triassic, about 200 million years ago (Logan and Duddy, 1998). Some of the petroleum generated prior to or during the early stages of the Hercynian event may have been removed or dispersed by erosion during the late stages of Hercynian and subsequent deformational events.

Overburden Rocks

Overburden rocks are variable across the area mainly due to nondeposition and erosion during the Hercynian and Pyrenean deformational events (fig. 4*A*). Along structural highs, large portions of the Paleozoic section were removed by erosion during Hercynian deformation. Elsewhere, Paleozoic rocks comprise most of the overburden. The Paleozoic section is thickest in the center of the Timimoun Basin. This section thins to the north and east over the Tilrhemt-Oued Namous-Maharez and Idjerane-M'Zab structural axes, and thins to the south over the Azzene High and Djoua Saddle (fig. 4*A*). Mesozoic rocks comprise only a small portion of the overburden. The Mesozoic section is thickest to the north and east and thins to the south and west (fig. 4*A*). A thin Cenozoic section is present over the northeast part of the total petroleum system.

Reservoir Rocks

The known major reservoir rocks in the Tanezzuft-Timimoun Total Petroleum System are Ordovician marine and glacial sandstone, Devonian shallow marine sandstone, and Carboniferous deltaic to marine sandstone (including the Sbaa Formation) (Petroconsultants, 1996a). Names of laterally equivalent rock units are shown in figure 5, and known reservoir properties are given in table 1.

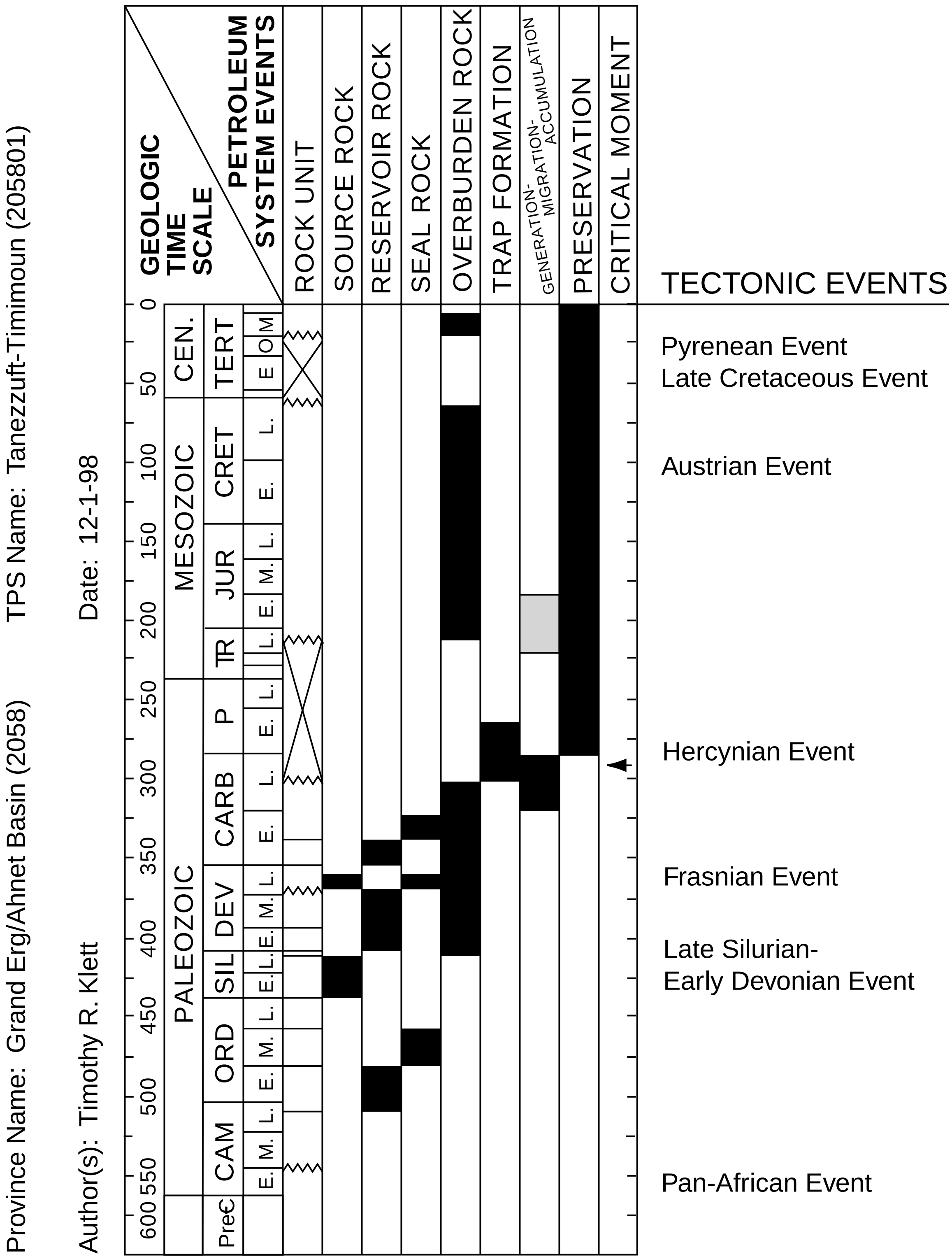


Figure 6. Events chart for Tanezzuft-Timimoun Total Petroleum System. Gray boxes indicate secondary or possible occurrences.

Seal Rocks

Intraformational Paleozoic marine mudstone is the primary seal for most reservoirs in the Tanezzuft-Timimoun Total Petroleum System (Boote and others, 1998).

Trap Types in Oil and Gas Fields

Most of the accumulations discovered prior to 1996 are within high-amplitude anticlines and faulted anticlines (Boote and others, 1998; Petroconsultants, 1996a). Accumulations within combination traps (those containing both structural and stratigraphic components) are assumed to be present; however, none have yet been reported.

The typical trapping style is anticlines containing intraformational Paleozoic mudstone seals. Other proven or potential trap types include lateral sealing of reservoir rocks by impermeable formations due to either faulting or lithofacies changes. Potential traps may occur where the main Paleozoic reservoir rocks subcrop and pinch out beneath Mesozoic and Cenozoic rocks in the northern portion of the total petroleum system; however, overlying rocks may not provide adequate seals (fig. 4*A*).

Most of the discovered petroleum accumulations are gas and are present in the southern portion of the province, near the Djoua Saddle (fig. 3). As of 1996, one gas accumulation exists on top of the Allal High.

Assessment of Undiscovered Petroleum by Assessment Unit

One assessment unit was identified for the Tanezzuft-Timimoun Total Petroleum System, called Tanezzuft-Timimoun Structural/Stratigraphic Assessment Unit (fig. 3). As of 1996, it contained 11 fields, all of which are gas fields (based on USGS oil and gas field definitions). Combined, these fields contained 4,200 BCFG, as known volumes (table 2) (Petroconsultants, 1996a). No volumes of oil or NGL were reported. Minimum field sizes of 4 MMBO and 24 BCFG were chosen for this assessment unit based on the field-size distribution of discovered fields.

The exploration density as of 1996 was approximately three new-field wildcat wells per 10,000 km^2. The overall success rate as of 1996 was approximately 11 discoveries per 62 new-field wildcat wells (or about one discovery per six new-field wildcat wells). The greatest success in terms of discoveries per number of new-field wildcat wells drilled occurred since 1985. Plots showing exploration activity and discovery history are presented in Appendix 1.

Exploration activity was not consistent through time: peaks in activity occurred in the mid-1950's, early 1960's, and early 1990's. The sizes of gas fields discovered have decreased through time and with respect to exploration activity, although much of the area north of the Djoua Saddle experienced little exploration.

Until recently, only structural traps have been explored for oil and gas. Continued exploration of structural and combination traps is expected for the next 30 years, and many more small gas fields could potentially be discovered along the Djoua Saddle and Idjerane-M'Zab structural axis, particularly around the Allal High. New exploration concepts include the search for both structural and stratigraphic traps in the northern portion of the total petroleum system. Potential for discoveries exists within stratigraphic pinchouts in shallow marine or deltaic deposits due to lateral changes of lithofacies.

This study estimates that about half of the total number of fields (discovered and undiscovered) of at least the minimum size has been discovered. Only a small number of undiscovered oil fields containing small volumes of oil was estimated. The estimated median size and number of undiscovered oil fields are 10 MMBO and 2 fields; the same values for undiscovered gas fields are 60 BCFG and 10 fields. The ranges of number, size, and coproduct-ratio estimates for undiscovered fields are given in table 3.

The estimated means of the undiscovered conventional petroleum volumes are 31 MMBO, 1,128 BCFG, and 56 MMBNGL (table 4). In addition, the mean sizes of the largest anticipated undiscovered oil and gas fields are 21 MMBO and 309 BCFG, respectively.

The Tanezzuft-Ahnet Total Petroleum System (205802)

The Tanezzuft-Ahnet Total Petroleum System is an important petroleum system in the Grand Erg/Ahnet Province with respect to known gas volumes. Excluding the contribution from the Hassi R'Mel field, this total petroleum system contains about 35 percent of the discovered gas in the province. An events chart (fig. 7) summarizes the timing of sources, reservoirs, seals, trap development, and generation and migration of petroleum.

Source Rocks

The principal source rocks in the Tanezzuft-Ahnet Total Petroleum System are the Silurian Tanezzuft Formation (or lateral equivalents), and Middle to Upper Devonian mudstone (Makhous and others, 1997; Boote and others, 1998; Macgregor, 1998). In the Timimoun, Ahnet, and Mouydir Basins, present-day TOC content ranges from 2 to 4 percent TOC for Silurian source rocks and from 1 to 8 percent TOC for Middle to Upper Devonian source rocks (Makhous and others, 1997).

Petroleum is presumed to have been generated during the Carboniferous, when the Paleozoic section was thickest, but generation was halted during uplift associated with Hercynian deformation (Makhous and others, 1997; Boote and others, 1998). Migration and charge are presumed to have occurred during the early stages of Hercynian deformation (Boote and others, 1998). Petroleum most likely migrated vertically along faults or fractures (Boote and others, 1998). A later phase of dry gas generation is hypothesized to have occurred due to igneous activity in the Late Triassic, about 200 million years ago (Logan and Duddy, 1998). Some of the petroleum generated prior to or during the early stages of the Hercynian event may have been removed or dispersed by erosion during the late stages of Hercynian and subsequent deformational events.

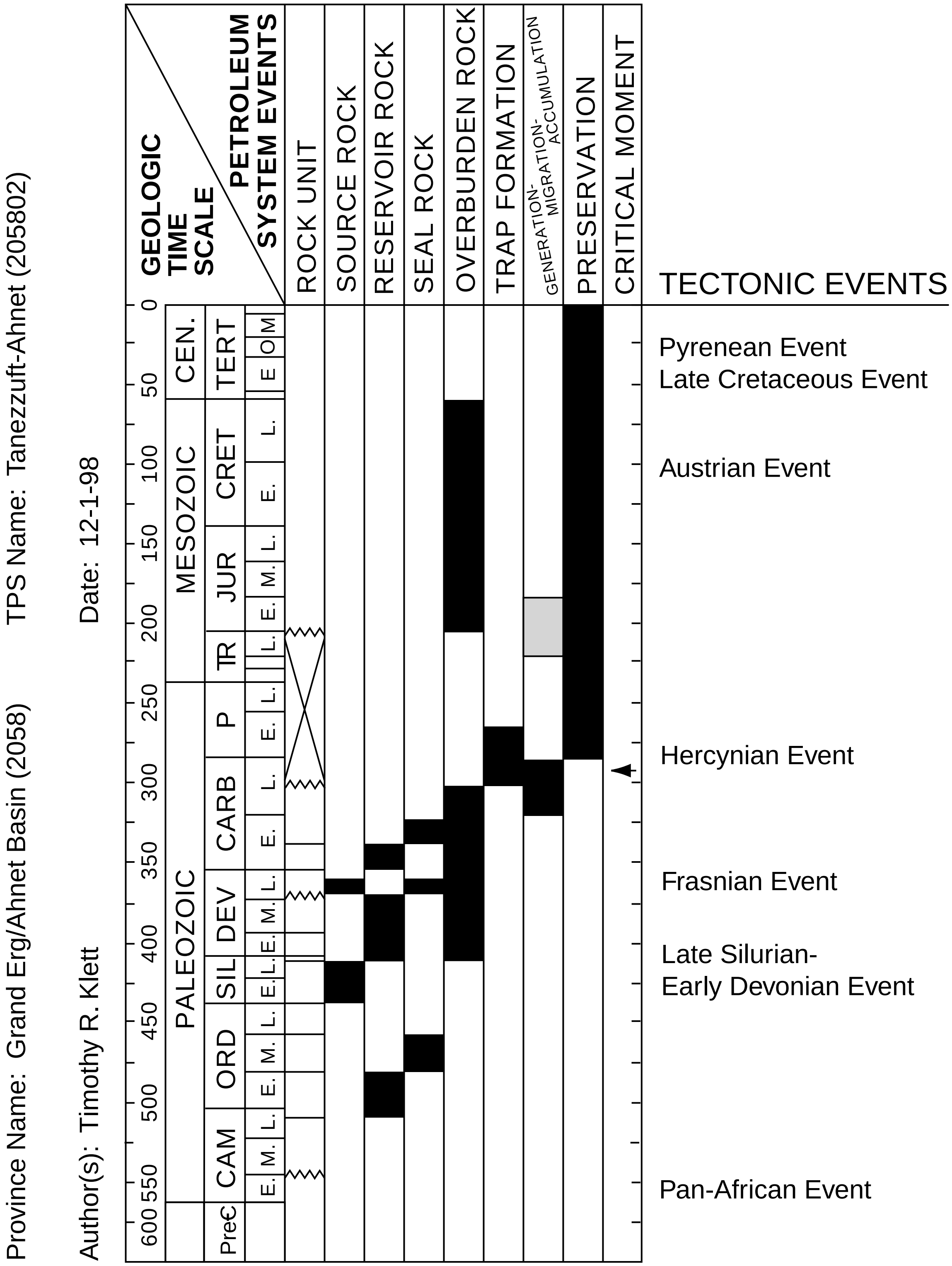


Figure 7. Events chart for Tanezzuft-Ahnet Total Petroleum System. Gray boxes indicate secondary or possible occurrences.

Overburden Rocks

The age and thickness of overburden rocks are variable across the area mainly due to nondeposition and erosion during the Hercynian and Pyrenean deformational events (fig. 4*A*). Although in some areas large portions of Paleozoic section were removed by erosion during Hercynian deformation, Paleozoic rocks comprise most of the overburden, as much as about 4,000 m (Boote and others, 1998). Paleozoic rocks are thickest in the center of the Ahnet Basin (fig. 4*A*). Mesozoic rocks comprise only a small portion of the overburden.

Reservoir Rocks

Known reservoir rocks in the Tanezzuft-Ahnet Total Petroleum System include Cambrian-Ordovician marine and glacial sandstone, Silurian marine sandstone, Devonian sandstone, including the Devonian F6 Member shallow marine sandstone, and Carboniferous deltaic to marine sandstone (Petroconsultants, 1996a). Names of laterally equivalent rock units are shown in figure 5, and known reservoir properties are given in table 1.

Seal Rocks

Intraformational Paleozoic marine mudstone is the primary seal for reservoirs in the Tanezzuft-Ahnet Total Petroleum System (Boote and others, 1998).

Trap Types in Oil and Gas Fields

Most of the accumulations discovered prior to 1996 are within high-amplitude anticlines that formed during Hercynian deformation (Boote and others, 1998; Petroconsultants, 1996a). Accumulations within combination traps are assumed to be present; however, none have yet been reported.

The typical trapping style is anticlines containing intraformational Paleozoic mudstone seals. Other proven or potential trap types include lateral sealing of reservoir rocks by impermeable formations due to lithofacies changes or by juxtaposition of fault blocks.

Most of the discovered petroleum accumulations in the Tanezzuft-Ahnet Total Petroleum System are gas and are present across the entire area, except in the southern portion where Paleozoic rocks are shallow and crop out (fig. 3).

Assessment of Undiscovered Petroleum by Assessment Unit

One assessment unit was identified for the Tanezzuft-Ahnet Total Petroleum System, called Tanezzuft-Ahnet Structural/Stratigraphic Assessment Unit (fig. 3). As of 1996, it contained 24 fields. Of the 24 fields discovered, 1 is an oil field, 20 are gas fields, and 3 fields are not classified because they contain less than 1 million barrels of oil equivalent (MMBOE) (based on USGS oil and gas field definitions). Combined, these fields contain a negligible amount of oil, 3,117 BCFG, and 90 MMBNGL, as known volumes (table 2) (Petroconsultants, 1996a). Minimum field sizes of 4 MMBO and 24 BCFG were chosen for this assessment unit based on the field-size distribution of discovered fields.

The exploration density as of 1996 was approximately five new-field wildcat wells per 10,000 km^2. The overall success rate as of 1996 was approximately 24 discoveries per 58 new-field wildcat wells (or about one discovery per two new-field wildcat wells). Plots showing exploration activity and discovery history are presented in Appendix 2.

Exploration activity was not consistent through time, occurring in the mid- to late 1950's, mid-1970's, and late 1980's to early 1990's. The sizes of gas fields discovered have not significantly decreased through time, and exploration appears to be only moderately mature across much of the area.

Until recently, only structural traps have been explored for oil and gas. Continued exploration of structural and combination traps is expected for the next 30 years and many more gas fields could be discovered. Potential for discoveries exists within stratigraphic pinchouts in shallow marine or deltaic deposits due to lateral changes of lithofacies.

This study estimates that about half of the total number of fields (discovered and undiscovered) of at least the minimum size has been discovered. Little potential exists for significant oil discoveries. The estimated median size and number of undiscovered oil fields are 10 MMBO and 2 fields; the same values for undiscovered gas fields are 60 BCFG and 26 fields. The ranges of number, size, and coproduct-ratio estimates for undiscovered fields are given in table 3.

The estimated means of the undiscovered conventional petroleum volumes are 34 MMBO, 2,973 BCFG, and 149 MMBNGL (table 4). In addition, the mean largest anticipated undiscovered oil and gas fields are 23 MMBO and 557 BCFG, respectively.

The Tanezzuft-Sbaa Total Petroleum System (205803)

The Tanezzuft-Sbaa Total Petroleum System is the only area in the province that contains significant volumes of oil, containing more than 75 percent of the discovered oil. An events chart (fig. 8) summarizes the timing of sources, reservoirs, seals, trap development, and generation and migration of petroleum.

Source Rocks

The principal source rocks in the Tanezzuft-Sbaa Total Petroleum System are the Silurian Tanezzuft Formation (or lateral equivalents), and Middle to Upper Devonian mudstone (Makhous and others, 1997; Boote and others, 1998). The mean present-day TOC content of the Silurian source rocks is 3 percent TOC and mean equivalent vitrinite reflectance values are from 0.9 to 1.0 percent R_o (calculated, Makhous and others, 1997). Petroleum generation occurred during the early stages of Hercynian deformation (Boote and others, 1998) but ceased when the basin was uplifted and eroded during the later stages of this event. Because rocks within the Sbaa Basin were never

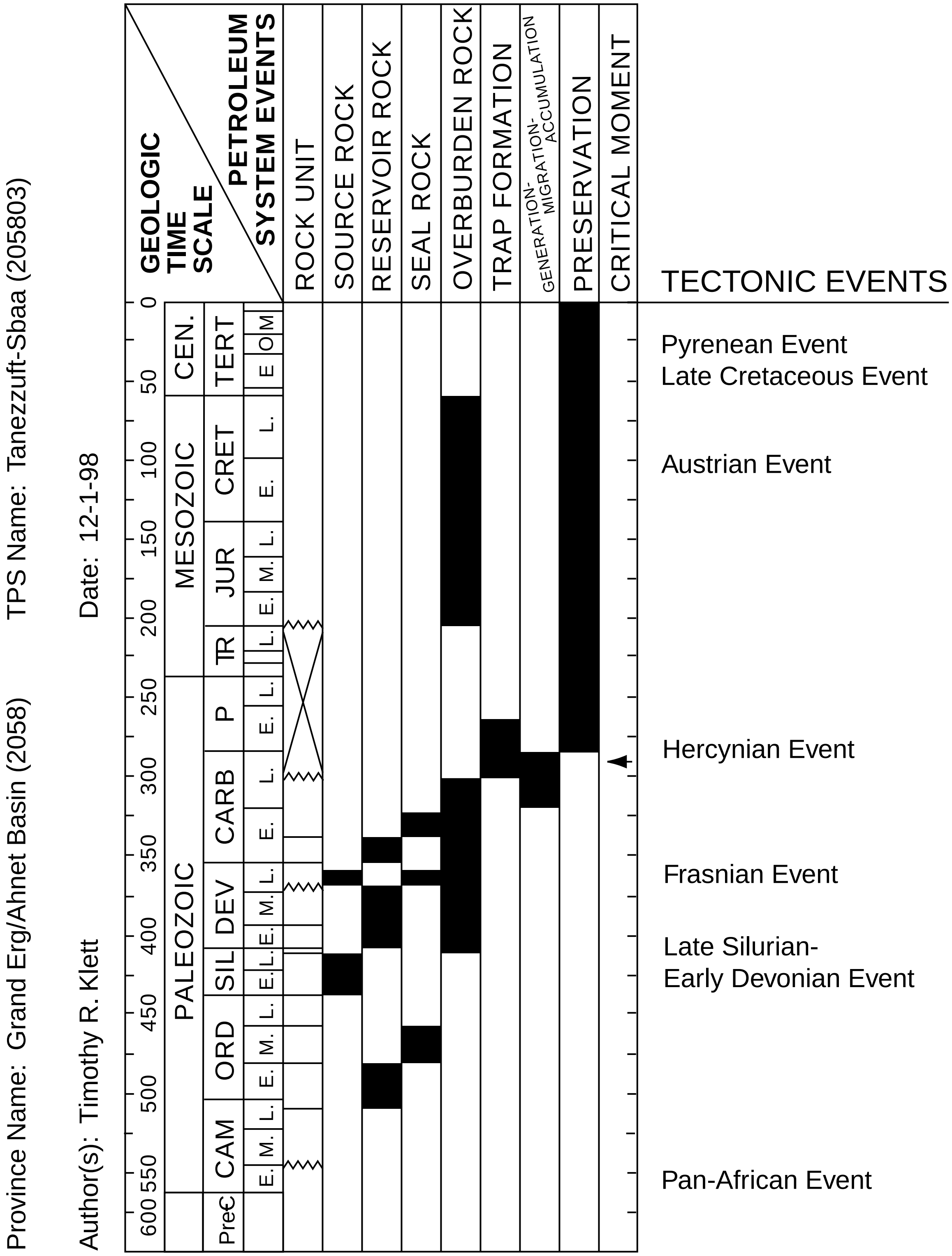


Figure 8. Events chart for Tanezzuft-Sbaa Total Petroleum System.

buried too deeply, source rocks are less mature than those in the surrounding basins, and oil rather than gas was preserved. Petroleum most likely migrated vertically along faults or fractures (Boote and others, 1998).

Overburden Rocks

Overburden rocks are variable across the area mainly due to nondeposition and erosion during the Hercynian and Pyrenean deformational events (fig. 4*A*). Large portions of the Paleozoic section were removed by erosion during Hercynian deformation. Paleozoic rocks comprise most of the overburden and are thickest in the center of the basin (fig. 4*A*). Mesozoic rocks comprise a smaller portion of the overburden.

Reservoir Rocks

Known reservoir rocks in the Tanezzuft-Sbaa Total Petroleum System include Cambrian-Ordovician marine and glacial sandstone, Devonian marine sandstone, and the Carboniferous deltaic to marine sandstone (including the Sbaa Formation) (Petroconsultants, 1996a; Baghdadli, 1988). Strunian-aged reservoir rocks have been reported (Baghdadli, 1988), and are included with the Devonian or Carboniferous rocks previously mentioned. Names of laterally equivalent rock units are shown in figure 5, and known reservoir properties are given in table 1.

Seal Rocks

Intraformational Paleozoic marine mudstone is the primary seal for reservoirs in the Tanezzuft-Sbaa Total Petroleum System (Boote and others, 1998).

Trap Types in Oil and Gas Fields

Most of the accumulations discovered prior to 1996 are within anticlines and faulted anticlines that formed during Hercynian deformation (Petroconsultants, 1996a; Baghdadli, 1988). Depositional pinchouts have also been reported. Other proven or potential trap types include lateral sealing of reservoir rocks by impermeable formations due to lithofacies changes or by juxtaposition of fault blocks. Most of the discovered petroleum accumulations are oil, and are present generally across the entire area.

Assessment of Undiscovered Petroleum by Assessment Unit

One assessment unit was identified for the Tanezzuft-Sbaa Total Petroleum System, called Tanezzuft-Sbaa Structural/Stratigraphic Assessment Unit (fig. 3). As of 1996, it contained 15 fields. Seven fields are oil fields, five are gas fields, and three fields are not classified because they contain less than 1 MMBOE (based on USGS oil and gas field definitions). Combined, these fields contain 284 MMBO, 1,490 BCFG, and 10 MMBNGL, as known volumes (table 2) (Petroconsultants, 1996a). Minimum field sizes of 10 MMBO and 60 BCFG were chosen for this assessment unit.

The exploration density as of 1996 was approximately 17 new-field wildcat wells per 10,000 km^2. The overall success rate as of 1996 was approximately 15 discoveries per 25 new-field wildcat wells (or about 1 discovery per 2 new-field wildcat wells). The success in terms of discoveries per number of new-field wildcat wells drilled remained somewhat constant through time. Plots showing exploration activity and discovery history are presented in Appendix 3.

Exploration activity was not consistent through time: most of the activity occurred since the mid-1980’s through the early 1990’s. Although exploration appears to be mature across much of the area, field sizes have not significantly decreased through time.

Until recently, only structural traps have been explored for oil and gas. Continued exploration of structural and combination traps is expected for the next 30 years and more fields could be discovered.

This study estimates that about half of the total number of fields (discovered and undiscovered) of at least the minimum size has been discovered. The estimated median size and number of undiscovered oil fields are 30 MMBO and four fields; the same values for undiscovered gas fields are 80 BCFG and four fields. The ranges of number, size, and coproduct-ratio estimates for undiscovered fields are given in table 3.

The estimated means of the undiscovered conventional petroleum volumes are 162 MMBO, 645 BCFG, and 11 MMBNGL (table 4). In addition, the mean sizes of the largest anticipated undiscovered oil and gas fields are 63 MMBO and 259 BCFG, respectively.

The Tanezzuft-Mouydir Total Petroleum System (205804)

Little information is available for the Tanezzuft-Mouydir Total Petroleum System. This basin has only been partially explored for oil and gas and has not been thoroughly studied (SONATRACH, c. 1992). An events chart (fig. 9) summarizes the assumed timing of sources, reservoirs, seals, trap development, and generation and migration of petroleum.

Source Rocks

The principal source rocks in the Tanezzuft-Mouydir Total Petroleum System are assumed to be similar to those in the neighboring Ahnet and Illizi Basins, that is, mudstone of the Silurian Tanezzuft Formation (or lateral equivalents), and Middle to Upper Devonian mudstone. In the Timimoun, Ahnet, and Mouydir Basins, present-day TOC content ranges from 2 to 4 percent TOC for Silurian source rocks and from 1 to 8 percent TOC for Middle to Upper Devonian source rocks (Makhous and others, 1997). Upper Devonian rocks in the Mouydir Basin contain from 1 to 3.5 percent TOC (Makhous and others, 1997).

Oil generation probably started in the Carboniferous, but generation was halted by uplift and erosion during the Hercynian

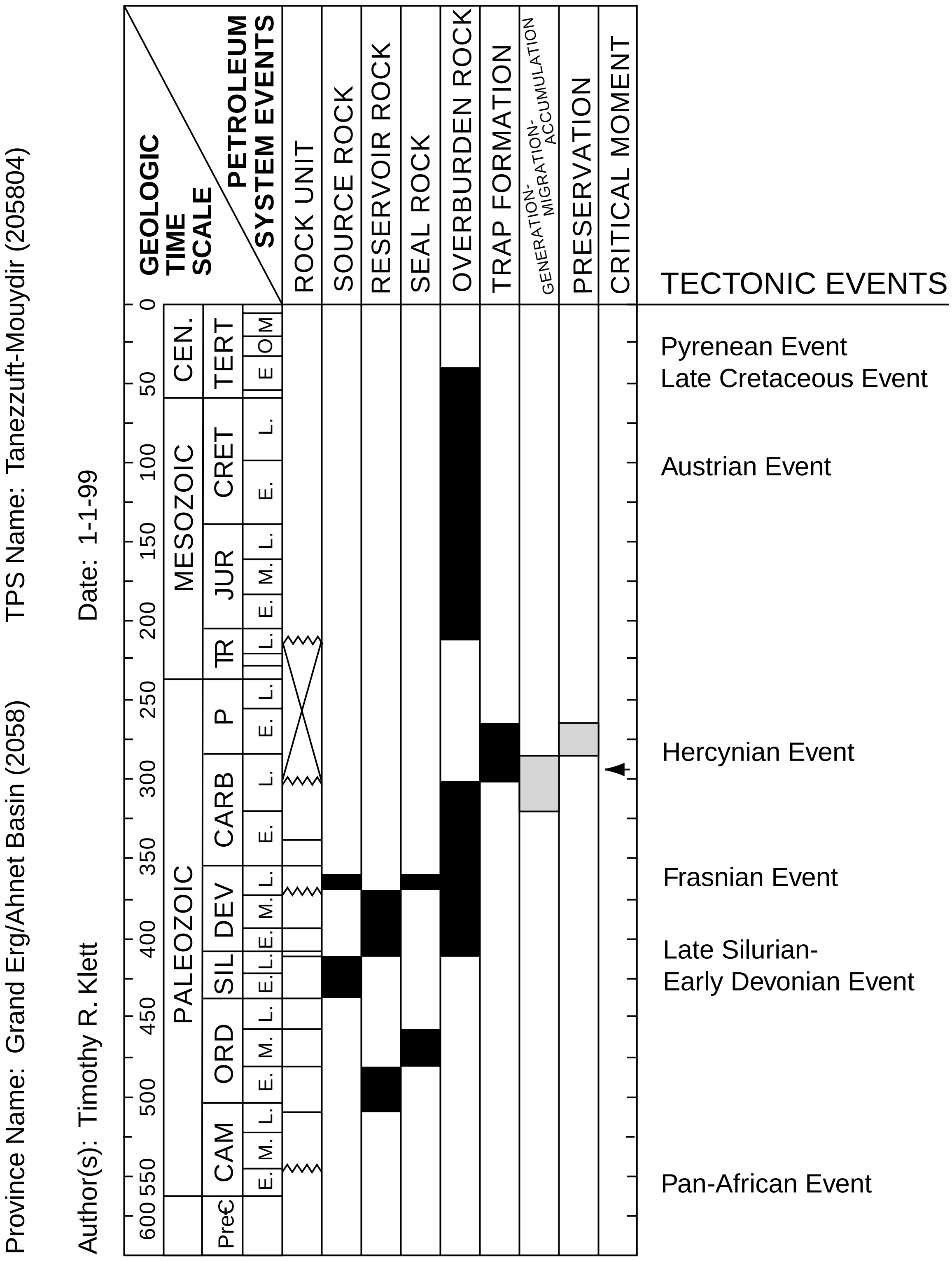


Figure 9. Events chart for Tanezzuft-Mouydir Total Petroleum System. Gray boxes indicate secondary or possible occurrences.

deformational event (Makhous and others, 1997; Boote and others, 1998). Potential source rocks within the Mouydir Basin were never again sufficiently buried to generate petroleum. Most of the petroleum that had accumulated prior to or during the early stages of the Hercynian event was probably removed or dispersed by erosion (Boote and others, 1998; van de Weerd and Ware, 1994). Although unproven, if petroleum was generated within the southern portion of the Oued Mya Basin, the possibility exists that some petroleum may have migrated updip across the Mouydir Structural Terrace and charged traps within the Mouydir Basin.

Overburden Rocks

Overburden rocks are variable across the area because of nondeposition and erosion during Hercynian and Pyrenean deformation (fig. 4*B* and *C*). Both Paleozoic and Mesozoic rocks comprise the overburden. Paleozoic rocks are thickest in the southern portion of the Mouydir Basin and thin northward. Mesozoic rocks are thickest in the northern portion and thin southward. A thin section of Cenozoic rocks is present over the northern part of the area.

Reservoir Rocks

Based on interpretations of the regional geology, reservoir rocks in the Tanezzuft-Mouydir Total Petroleum System are assumed to be similar to those of the neighboring Ahnet and Illizi Basins, that is, Cambrian-Ordovician and Devonian sandstone.

Seal Rocks

Based on the petroleum geology of neighboring total petroleum systems, intraformational Paleozoic marine mudstone is the most likely primary seal for reservoirs in the Tanezzuft-Mouydir Total Petroleum System.

Trap Types in Oil and Gas Fields

Expected trap types should be similar to those within the Ahnet and Illizi Basins. These include anticlines and faulted anticlines, some possibly having stratigraphic components. As with the Timimoun Basin, some potential exists for traps to be present where the main Paleozoic reservoir rocks subcrop beneath Mesozoic and Cenozoic rocks. This potential is mainly in the northern portion of the total petroleum system; however, the overlying rocks may not provide adequate seals (fig. 4*B* and *C*).

Assessment of Undiscovered Petroleum by Assessment Unit

One assessment unit was identified for the Tanezzuft-Mouydir Total Petroleum System, called Tanezzuft-Mouydir Structural/Stratigraphic Assessment Unit (fig. 3). As of 1996, no fields greater than 1 MMBO or 6 BCFG were discovered. Minimum field sizes of 5 MMBO and 30 BCFG were chosen for this assessment unit.

The exploration density as of 1996 was approximately one new-field wildcat well per 10,000 km^2. Only four new-field wildcat wells had been drilled in this assessment unit. Until recently, only structural traps have been explored for oil and gas (Aliev and others, 1971).

Only a small number of undiscovered oil and gas fields, each containing small volumes of oil or gas, was estimated. The estimated median size and number of undiscovered oil fields are 10 MMBO and two fields; the same values for undiscovered gas fields are 60 BCFG and six fields. The ranges of number, size, and coproduct-ratio estimates for undiscovered fields are given in table 3. A probability of 0.4 was given for the existence of at least one undiscovered field of at least minimum size in this assessment unit.

The estimated means of the undiscovered conventional petroleum volumes are 12 MMBO, 292 BCFG, and 14 MMBNGL (table 4). In addition, the mean sizes of the largest anticipated oil and gas fields are 21 MMBO and 230 BCFG, respectively.

The Tanezzuft-Benoud Total Petroleum System (205805)

The Tanezzuft-Benoud Total Petroleum System is an important petroleum system with respect to known oil and gas volumes, containing about 24 percent of the discovered oil and 92 percent of the discovered gas in the province. The giant Hassi R'Mel gas field resides in this total petroleum system. An events chart (fig. 10) summarizes the timing of sources, reservoirs, seals, trap development, and generation and migration of petroleum.

Source Rocks

The principal source rock in the Tanezzuft-Benoud Total Petroleum System is the Silurian Tanezzuft Formation (or lateral equivalents) (Boote and others, 1998). Middle to Upper Devonian mudstone may provide another source of petroleum but is not present over most of the total petroleum system (Makhous and others, 1997; Boote and others, 1998). Middle to Upper Devonian source rocks were truncated by erosion during Hercynian deformation and are present only in the western portions of this total petroleum system. No TOC content or equivalent vitrinite reflectance values were available for the source rock at the time of this study.

Petroleum was generated during the Late Cretaceous into the Tertiary (Boote and others, 1998). In most of the Tanezzuft-Benoud Total Petroleum System, accumulations were charged with gas generated within the Benoud Trough. In the Hassi R'Mel area on the Tilrhemt Arch, however, two sources of petroleum are presumed; gas may have been derived from the Benoud Trough in the north and west whereas oil may have migrated from the Oued Mya Basin in the south (Boote and others, 1998). Petroleum most likely migrated laterally through permeable Paleozoic and Triassic sandstone (Boote and others, 1998).

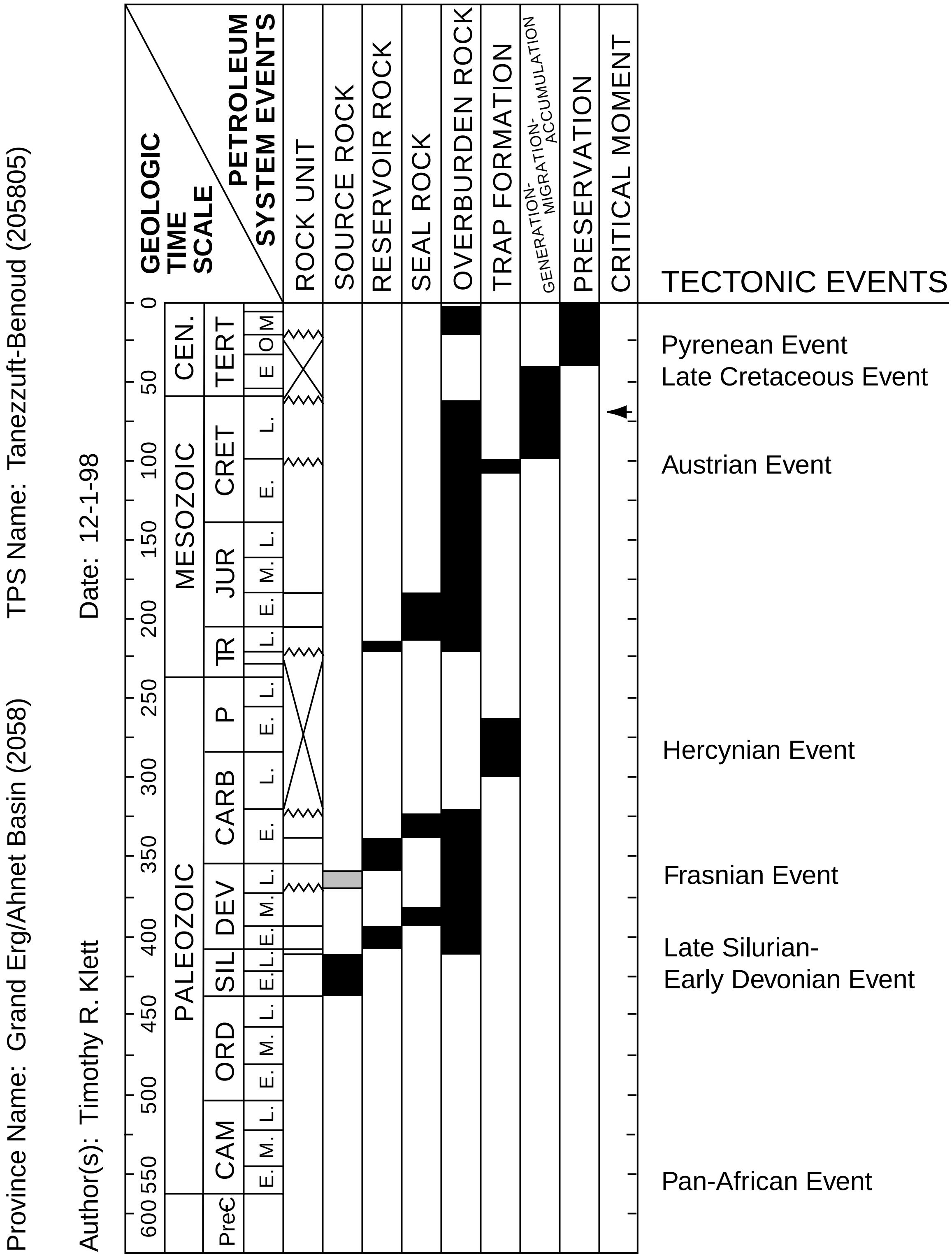


Figure 10. Events chart for Tanezzuft-Benoud Total Petroleum System. Gray box indicates secondary or possible occurrences.

Overburden Rocks

Overburden rocks are variable across the area mainly due to nondeposition and erosion during the Hercynian, Austrian, and Pyrenean deformational events (fig. 4*A*). Large portions of the Paleozoic section were removed by erosion that occurred during Hercynian deformation. Both Paleozoic and Mesozoic rocks comprise most of the overburden; they are thickest along the Saharan Flexure (Peterson, 1985). A thin Cenozoic interval is present over parts of the area.

Reservoir Rocks

Known reservoir rocks in the Tanezzuft-Benoud Total Petroleum System are Lower Devonian and Carboniferous nearshore marine sandstone and Triassic fluvial sandstone (Petroconsultants, 1996a). Triassic reservoirs are basal fluvial sandstone directly beneath a Triassic to Jurassic evaporite section. Names of laterally equivalent rock units are shown in figure 5, and known reservoir properties are given in table 1.

Seal Rocks

As much as 2,000 m of Triassic to Jurassic evaporites, mudstone, and carbonate rocks (Saliferous Units, fig. 5) provide a regional top seal for reservoirs in most of the Tanezzuft-Benoud Total Petroleum System. The Triassic to Jurassic seal rocks, predominantly salt, extend from the Saharan Flexure in the north where the thickest section is present to approximately the Idjerane-M'Zab structural axis (fig. 1). Intraformational Paleozoic marine mudstone is the inferred primary seal for some reservoirs and secondary, lateral seals for others.

Trap Types in Oil and Gas Fields

Most of the accumulations discovered prior to 1996 are within anticlines (Boote and others, 1998; Petroconsultants, 1996a). Accumulations within combination traps, those containing both structural and stratigraphic components, are present and include the Hassi R'Mel gas field.

Except for the Hassi R'Mel field, the typical trapping style includes Paleozoic reservoir rocks within anticlines sealed by intraformational mudstone. Other proven or potential trap types include lateral sealing of reservoir rocks by impermeable formations due to lithofacies changes or by juxtaposition of fault blocks. Potential accumulations may be trapped in Paleozoic reservoir rocks that subcrop directly beneath Triassic to Jurassic evaporites in the northeastern portion of the total petroleum system (fig. 4*D*). The presence of an overlying basal Triassic sandstone, however, would preclude the existence of such traps.

Assessment of Undiscovered Petroleum by Assessment Unit

One assessment unit was identified for the Tanezzuft-Benoud Total Petroleum System, called Tanezzuft-Benoud Structural/Stratigraphic Assessment Unit (fig. 3). As of 1996, it contained four fields. One field is an oil field, two are gas fields, and one field is not classified because it contains less than 1 MMBOE (based on USGS oil and gas field definitions). Combined, these fields contain 88 MMBO, 105,050 BCFG, and 4,935 MMBNGL, as known volumes (table 2) (Petroconsultants, 1996a). Minimum sizes of 4 MMBO and 24 BCFG were chosen for this assessment unit.

The exploration density as of 1996 was approximately six new-field wildcat wells per 10,000 km^2. The overall success rate as of 1996 was approximately four discoveries per 56 new-field wildcat wells (or about one discovery per 14 new-field wildcat wells). Because only a few fields are present in this total petroleum system, no appendix of plots of exploration activity and discovery history is presented in order not to release proprietary data.

Exploration activity was not consistent through time: peaks occurred in the mid-1950's to mid-1960's and again around 1970. Until recently, only structural traps have been explored for oil and gas. Continued exploration of structural and combination traps is expected for the next 30 years and many more small oil fields could potentially be discovered.

This study estimates that about one-fifth of the total number of fields (discovered and undiscovered) of at least the minimum size has been discovered. The estimated median size and number of undiscovered oil fields are 12 MMBO and 4 fields; the same values for undiscovered gas fields are 100 BCFG and 10 fields. The ranges of number, size, and coproduct-ratio estimates for undiscovered fields are given in table 3.

The estimated means of the undiscovered conventional petroleum volumes are 72 MMBO, 2,541 BCFG, and 125 MMBNGL (table 4). In addition, the mean sizes of the largest anticipated undiscovered oil and gas fields are 34 MMBO and 823 BCFG, respectively.

The Tanezzuft-Béchar/Abadla Total Petroleum System (205806)

As of 1996, no oil or gas fields have been discovered and little geologic information is available for the Tanezzuft-Béchar/Abadla Total Petroleum System. An events chart (fig. 11) summarizes the timing of sources, reservoirs, seals, trap development, and generation and migration of petroleum.

Source Rocks

Potential source rocks in the Tanezzuft-Béchar/Abadla Total Petroleum System are assumed to be similar to those in the neighboring Benoud Trough and Timimoun Basin, that is, mudstone of the Silurian Tanezzuft Formation (or lateral equivalents), and possibly Middle to Upper Devonian mudstone. No TOC content or equivalent vitrinite reflectance values for any of the potential source rocks were available at the time of this study.

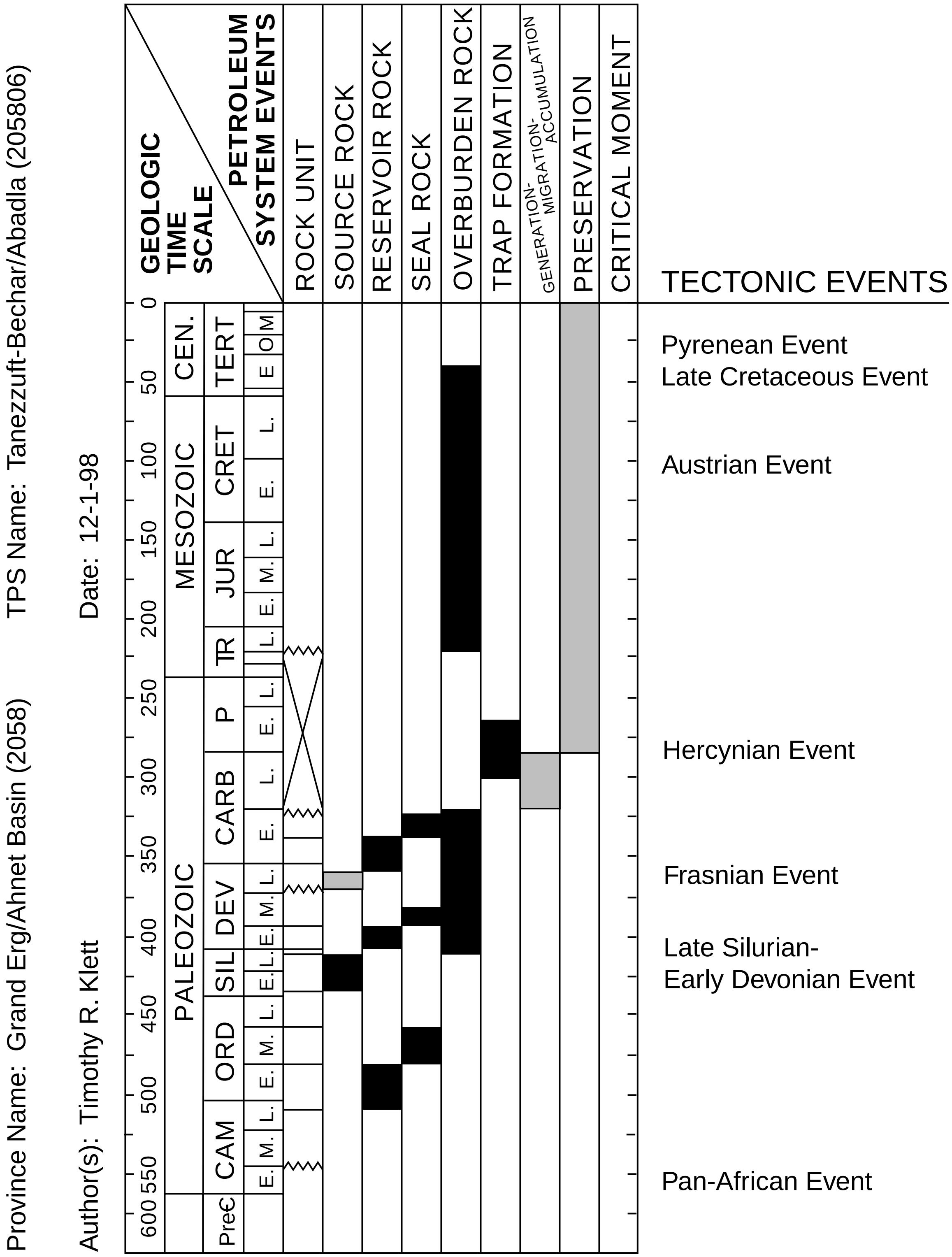


Figure 11. Events chart for Tanezzuft-Béchar/Abadla Total Petroleum System. Gray boxes indicate secondary or possible occurrences.

Petroleum generation probably started during the Carboniferous. Accumulations are presumed to be charged with gas because the potential source rocks may be deeply buried (as much as 5,000 m) in the central part of the basin (Conrad and Lemosquet, 1984; Aliev and others, 1971).

Overburden Rocks

Overburden rocks are variable across the area mainly due to nondeposition and erosion during the Hercynian, Austrian, and Pyrenean deformation events. Both Paleozoic and Mesozoic rocks comprise the overburden. Paleozoic rocks are thickest in the western portion of the Béchar and Abadla Basins thinning eastward (Conrad and Lemosquet, 1984).

Reservoir Rocks

Reservoir rocks in the Tanezzuft-Béchar/Abadla Total Petroleum System are assumed to be similar to those of the neighboring Benoud Trough and Timimoun Basins, that is, Cambrian-Ordovician fluvial to marine sandstone; and Devonian nearshore marine sandstone. Additionally, Wausortian-type bioherm mounds of Carboniferous (Visean) age may be potential reservoirs (Bourque and others, 1995; Madi and others, 1998). Names of laterally equivalent rock units are given in figure 5.

Seal Rocks

Intraformational Paleozoic marine mudstone is presumed to be the primary seal for reservoirs in the Tanezzuft-Béchar/Abadla Total Petroleum System.

Trap Types in Oil and Gas Fields

Expected trap types should be similar to those within the western portion of the Benoud Trough. These include anticlines and faulted anticlines, some possibly having stratigraphic components.

Assessment of Undiscovered Petroleum by Assessment Unit

One assessment unit was identified for the Tanezzuft-Béchar/Abadla Total Petroleum System, called Tanezzuft-Béchar/Abadla Structural/Stratigraphic Assessment Unit (fig. 3). As of 1996, it contained no discoveries greater than 1 MMBO or 6 BCFG. Minimum field sizes of 1 MMBO and 6 BCFG were chosen for this assessment unit.

The exploration density as of 1996 of the Tanezzuft-Béchar/Abadla Structural/Stratigraphic Assessment Unit was approximately one new-field wildcat well per 10,000 km^2. Only six new-field wildcat wells were drilled in this total petroleum system, five of which were in the Moroccan portion. Exploration is relatively immature across much of the area.

The estimated median size and number of undiscovered oil and gas fields within the Tanezzuft-Béchar/Abadla Structural/Stratigraphic Assessment Unit are 5 MMBO and 5 fields; the same values for undiscovered gas fields are 30 BCFG and 15 fields. The ranges of number, size, and coproduct-ratio estimates for undiscovered fields are given in table 3. A probability of 0.4 was given for the existence of at least one undiscovered field of at least minimum size in this assessment unit.

The estimated means of the undiscovered conventional petroleum volumes are 16 MMBO, 441 BCFG, and 22 MMBNGL (table 4). In addition, the mean sizes of the largest anticipated undiscovered oil and gas fields are 18 MMBO and 303 BCFG, respectively.

Summary

Seven “composite” total petroleum systems were identified, each coinciding with a separate basin and each comprising a single assessment unit. These total petroleum systems are called the Tanezzuft-Timimoun, Tanezzuft-Ahnet, Tanezzuft-Sbaa, Tanezzuft-Mouydir, Tanezzuft-Benoud, Tanezzuft-Béchar/Abadla, and Tanezzuft-Oued Mya. The Tanezzuft-Oued Mya Total Petroleum System was not assessed here.

The main source rocks are the Silurian Tanezzuft Formation (or lateral equivalents) and Middle to Upper Devonian mudstone. Petroleum generation and migration occurred in the Carboniferous, but ceased during the Hercynian deformational event. In northern portions of the province, petroleum generation and migration occurred during the Cretaceous and into the Tertiary with the development of the Triassic and Benoud Basins. The major reservoir rocks are Cambrian-Ordovician, Ordovician, Silurian, Devonian, Carboniferous, and Triassic sandstone. Intraformational Paleozoic marine mudstone is the primary seal. In the northeastern part of the province, Triassic to Jurassic evaporites, mudstone, and carbonate rocks provide seals for reservoir rocks. Of the fields discovered thus far, traps are primarily structural and associated with anticlines and faulted anticlines.

The estimated means of the undiscovered conventional petroleum volumes in the Tanezzuft-Timimoun Total Petroleum System are 31 MMBO, 1,128 BCFG, and 56 MMBNGL; volumes in the Tanezzuft-Ahnet Total Petroleum System are 34 MMBO, 2,973 BCFG, and 149 MMBNGL; volumes in the Tanezzuft-Sbaa Total Petroleum System are 162 MMBO, 645 BCFG, and 11 MMBNGL; volumes in the Tanezzuft-Mouydir Total Petroleum System are 12 MMBO, 292 BCFG, and 14 MMBNGL; volumes in the Tanezzuft-Benoud Total Petroleum System are 72 MMBO, 2,541 BCFG, and 125 MMBNGL; and volumes in the Tanezzuft-Béchar/Abadla Total Petroleum System are 16 MMBO, 441 BCFG, and 22 MMBNGL. The estimated means of the undiscovered conventional volumes for these total petroleum systems in Grand Erg/Ahnet Province (excluding the Tanezzuft-Oued Mya Total Petroleum System) are 328 MMBO, 8,018 BCFG, and 377 MMBNGL.

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Table 1. Reservoir properties of discovered accumulations for each assessment unit through 1995. [nd, represents either no data or insufficient data]

USGS Code	Depth (meters)				Gross thickness (meters)				Porosity (percent)				Permeability (millidarcies)			
	Minimum	Mean	Maximum	Number	Minimum	Mean	Maximum	Number	Minimum	Mean	Maximum	Number	Minimum	Mean	Maximum	Number
205801	**Tanezzuft-Timimoun Total Petroleum System**															
20580101	Tanezzuft-Timimoun Structural/Stratigraphic Assessment Unit															
Carboniferous	850	1,308	1,766	2	50	50	50	1	22	24	25	2	450	450	450	2
Devonian	100	1,361	3,048	8	5	16	26	2	11	29	32	8	1,000	1,125	2,000	8
Cambrian-Ordovician	2,200	2,200	2,200	1	nd	nd	nd	0	10	10	10	1	nd	nd	nd	0
205802	**Tanezzuft-Ahnet Total Petroleum System**															
20580201	Tanezzuft-Ahnet Structural/Stratigraphic Assessment Unit															
Carboniferous	395	535	675	2	nd	nd	nd	0	23	24	25	2	30	240	450	2
Devonian	175	1,674	2,444	12	17	21	25	3	9	21	32	15	150	820	2,000	15
Silurian	600	1,267	1,684	3	1	1	1	1	5	15	20	1	nd	nd	nd	0
Cambrian-Ordovician	490	1,668	2,629	15	45	105	222	7	2	6	10	12	0.01	73	110	14
205803	**Tanezzuft-Sbaa Total Petroleum System**															
20580301	Tanezzuft-Sbaa Structural/Stratigraphic Assessment Unit															
Carboniferous	500	590	700	5	143	143	143	1	25	25	25	5	450	450	450	5
Devonian	430	957	1,306	5	70	75	80	2	11	12	15	4	500	1,625	2,000	4
Cambrian-Ordovician	900	1,729	2,400	7	260	260	260	1	10	10	10	6	nd	nd	nd	0
205805	**Tanezzuft-Benoud Total Petroleum System**															
20580501	Tanezzuft-Benoud Structural/Stratigraphic Assessment Unit															
Triassic	2,134	2,152	2,185	3	21	40	61	3	nd	nd	nd	0	nd	nd	nd	0
Carboniferous	446	1,518	2,591	2	13	30	47	2	20	21	22	2	1,000	1,000	1,000	1
Devonian	2,131	2,191	2,250	2	nd	nd	nd	0	nd	nd	nd	0	nd	nd	nd	0

Table 2. Number and sizes of discovered fields for each assessment unit through 1995. The Tanezzuft-Oued Mya Total Petroleum System contains the greatest volume of discovered oil whereas the Tanezzuft-Ghadames Total Petroleum System contains the greatest volume discovered gas and natural gas liquids. The Tanezzuft-Sbaa Total Petroleum System contains the greatest volume of oil wheras the Tanezzuft-Benoud Total Petroleum System contains the greatest volume of discovered gas and natural gas liquids due to the giant Hassi R'Mel gas field. [MMBO, million barrels of oil; BCFG, billion cubic feet of gas; NGL, natural gas liquids; MMBNGL, million barrels of NGL. Volumes reported are summed for oil and gas fields (USGS defined). Oil and gas fields containing known volumes below 1 million barrels of oil or 6 billion cubic feet of gas (BCFG) are grouped. NA, not available. Data from Petroconsultants (1996a)]

USGS Code	Number of fields	Known (discovered) volumes		
		Oil (MMBO)	Gas (BCFG)	NGL (MMBNGL)
205801	**Tanezzuft-Timimoun Total Petroleum System**			
20580101	Tanezzuft-Timimoun Structural/Stratigraphic Assessment Unit			
Oil fields	0	0	0	0
Gas fields	11	0	4,200	0
Fields < 1 MMBOE	0	0	0	0
All fields	11	0	4,200	0
205802	**Tanezzuft-Ahnet Total Petroleum System**			
20580201	Tanezzuft-Ahnet Structural/Stratigraphic Assessment Unit			
Oil fields	1	NA	NA	NA
Gas fields	20	0	3,105	85
Fields < 1 MMBOE	3	0	12	5
All fields	24	NA	3,117	90
205803	**Tanezzuft-Sbaa Total Petroleum System**			
20580301	Tanezzuft-Sbaa Structural/Stratigraphic Assessment Unit			
Oil fields	7	278	105	0
Gas fields	5	5	1,380	10
Fields < 1 MMBOE	3	1	5	0
All fields	15	284	1,490	10

Table 2. Continued.

USGS Code	Number of fields	Known (discovered) volumes		
		Oil (MMBO)	Gas (BCFG)	NGL (MMBNGL)
205804	**Tanezzuft-Mouydir Total Petroleum System**			
20580401	Tanezzuft-Mouydir Structural/Stratigraphic Assessment Unit			
Oil fields	0	0	0	0
Gas fields	0	0	0	0
Fields < 1 MMBOE	0	0	0	0
All fields	0	0	0	0
205805	**Tanezzuft-Benoud Total Petroleum System**			
20580501	Tanezzuft-Benoud Structural/Stratigraphic Assessment Unit			
Oil fields	1	NA	NA	NA
Gas fields	2	82	105,050	4,935
Fields < 1 MMBOE	1	NA	NA	NA
All fields	4	88	105,050	4,935
205806	**Tanezzuft-Bechar/Abadla Total Petroleum System**			
20580601	Tanezzuft-Bechar/Abadla Structural/Stratigraphic Assessment Unit			
Oil fields	0	0	0	0
Gas fields	0	0	0	0
Fields < 1 MMBOE	0	0	0	0
All fields	0	0	0	0
2058	***Total***			
Oil fields	9	284	105	0
Gas fields	38	87	113,735	5,030
Fields < 1 MMBOE	7	1	17	5
All fields	54	372	113,857	5,035

Table 3. Estimated sizes, number, and coproduct ratios of undiscovered oil and gas fields for each assessment unit. [MMBO, million barrels of oil; BCFG, billion cubic feet of gas; CFG/BO, cubic feet of gas per barrel oil, not calculated for gas fields; BNGL/MMCFG or BL/MMCFG, barrels of natural gas liquids or barrels of total liquids per million cubic feet of gas. BNGL/MMCFG was calculated for USGS-defined oil fields whereas BL/MMCFG was calculated for USGS-defined gas fields. Shifted mean, the mean size of the accumulation within a lognormal distribution of field sizes for which the origin is the selected minimum field size]

USGS Code	Size of accumulations (MMBO or BCFG)					Number of accumulations					Gas-to-oil ratio (CFG/BO)					NGL-to-gas ratio (BNGL/MMCFG)				
	Minimum	Median	Maximum	Mean	Shifted mean	Minimum	Median	Maximum	Mean	Mode	Minimum	Median	Maximum	Mean	Mode	Minimum	Median	Maximum	Mean	Mode
205801	**Tanezzuft-Timimoun Total Petroleum System**																			
20580101	Tanezzuft-Timimoun Structural/Stratigraphic Assessment Unit																			
Oil fields	4	10	200	11	15	1	2	4	2	1	1,875	3,750	5,625	3,746	3,750	30	60	90	60	60
Gas fields	24	60	1,500	72	96	4	10	20	11	8						24	48	72	48	48
205802	**Tanezzuft-Ahnet Total Petroleum System**																			
20580201	Tanezzuft-Ahnet Structural/Stratigraphic Assessment Unit																			
Oil fields	4	10	252	12	16	1	2	4	2	1	275	550	825	550	550	30	60	90	60	60
Gas fields	24	60	2,000	80	104	8	26	67	28	10						25	50	75	50	50
205803	**Tanezzuft-Sbaa Total Petroleum System**																			
20580301	Tanezzuft-Sbaa Structural/Stratigraphic Assessment Unit																			
Oil fields	10	30	250	28	38	1	4	10	4	2	275	550	825	550	550	30	60	90	60	60
Gas fields	60	80	3,000	69	129	1	4	10	4	2						5	10	15	10	10
205804	**Tanezzuft-Mouydir Total Petroleum System**																			
20580401	Tanezzuft-Mouydir Structural/Stratigraphic Assessment Unit																			
Oil fields	5	10	200	10	15	1	2	4	2	1	1,875	3,750	5,625	3,749	3,750	30	60	90	60	60
Gas fields	30	60	1,500	64	94	1	6	15	6	3						24	47	70	47	47
205805	**Tanezzuft-Benoud Total Petroleum System**																			
20580501	Tanezzuft-Benoud Structural/Stratigraphic Assessment Unit																			
Oil fields	4	12	200	13	17	1	4	8	4	3	1,875	3,750	5,625	3,754	3,750	30	60	90	60	60
Gas fields	24	100	5,000	180	204	2	10	28	11	3						24	48	72	48	48
205806	**Tanezzuft-Bechar/Abadla Total Petroleum System**																			
20580601	Tanezzuft-Bechar/Abadla Structural/Stratigraphic Assessment Unit																			
Oil fields	1	5	100	7	8	1	5	10	5	4	1,875	3,750	5,625	3,749	3,750	30	60	90	60	60
Gas fields	6	30	1,500	55	61	2	15	30	15	14						24	48	72	48	48

Table 4. Estimated undiscovered conventional oil, gas, and natural gas liquids volumes for oil and gas fields for each assessment unit. [MMBO, million barrels of oil; BCFG, billion cubic feet of gas; NGL, natural gas liquids; MMBNGL, million barrels of natural gas liquids. Volumes of undiscovered NGL were calculated for oil fields whereas volumes of total liquids (oil plus NGL) were calculated for USGS-defined gas fields. Largest anticipated undiscovered field is in units of MMBO for oil fields and BCFG for gas fields. Results shown are estimates that are fully risked with respect to geology and accessability. Undiscovered volumes in fields smaller than the selected minimum field size are excluded from the assessment. Means can be summed, but fractiles (F95, F50, and F5) can be summed only if a correlation coefficient of +1.0 is assumed]

USGS Code	MFS	Prob. (0-1)	Undiscovered conventional volumes												Largest anticipated undiscovered field (MMBO or BCFG)			
			Oil (MMBO)				Gas (BCFG)				NGL (MMBNGL)							
			F95	F50	F5	Mean	F95	F50	F5	Mean	F95	F50	F5	Mean	F95	F50	F5	Mean
205801	**Tanezzuft-Timimoun Total Petroleum System**																	
20580101	Tanezzuft-Timimoun Structural/Stratigraphic Assessment Unit																	
Oil fields	4	1.00	7	25	80	31	24	90	307	118	1	5	19	7	6	15	59	21
Gas fields	24	1.00					387	920	1,942	1,010	17	43	98	48	95	241	765	309
All fields			7	25	80	31	411	1,010	2,249	1,128	18	48	117	56				
205802	**Tanezzuft-Ahnet Total Petroleum System**																	
20580201	Tanezzuft-Ahnet Structural/Stratigraphic Assessment Unit																	
Oil fields	4	1.00	6	25	89	34	3	14	50	19	0	1	3	1	6	16	67	23
Gas fields	24	1.00					872	2,678	5,963	2,955	40	130	316	148	166	457	1,324	557
All fields			6	25	89	34	875	2,691	6,013	2,973	40	131	319	149				
205803	**Tanezzuft-Sbaa Total Petroleum System**																	
20580301	Tanezzuft-Sbaa Structural/Stratigraphic Assessment Unit																	
Oil fields	10	1.00	45	146	334	162	23	78	194	89	1	5	12	5	25	55	132	63
Gas fields	60	1.00					137	443	1,360	555	1	4	14	6	72	159	792	259
All fields			45	146	334	162	160	521	1,553	645	3	9	26	11				

Table 4. Continued.

USGS Code	MFS	Prob. (0-1)	Undiscovered conventional volumes												Largest anticipated undiscovered field (MMBO or BCFG)			
			Oil (MMBO)				Gas (BCFG)				NGL (MMBNGL)							
			F95	F50	F5	Mean	F95	F50	F5	Mean	F95	F50	F5	Mean	F95	F50	F5	Mean
205804	**Tanezzuft-Mouydir Total Petroleum System**																	
20580401	Tanezzuft-Mouydir Structural/Stratigraphic Assessment Unit																	
Oil fields	5	0.40	0	0	54	12	0	0	203	47	0	0	12	3	7	14	56	21
Gas fields	30	0.40					0	0	1,056	245	0	0	51	12	61	170	620	230
All fields			0	0	54	12	0	0	1,259	292	0	0	63	14				
205805	**Tanezzuft-Benoud Total Petroleum System**																	
20580501	Tanezzuft-Benoud Structural/Stratigraphic Assessment Unit																	
Oil fields	4	1.00	21	64	156	72	72	233	607	272	4	14	38	16	10	26	84	34
Gas fields	24	1.00					357	1,880	5,483	2,268	16	88	273	109	144	590	2,363	823
All fields			21	64	156	72	429	2,113	6,090	2,541	20	102	311	125				
205806	**Tanezzuft-Bechar/Abadla Total Petroleum System**																	
20580601	Tanezzuft-Bechar/Abadla Structural/Stratigraphic Assessment Unit																	
Oil fields	1	0.40	0	0	66	16	0	0	256	59	0	0	16	4	5	14	44	18
Gas fields	6	0.40					0	0	1,571	382	0	0	77	18	71	230	812	303
All fields			0	0	66	16	0	0	1,827	441	0	0	93	22				
2058	***Total***																	
Oil fields			79	260	779	328	122	415	1,616	604	7	24	100	36				
Gas fields							1,752	5,920	17,375	7,414	75	265	830	340				
All fields			79	260	779	328	1,874	6,335	18,991	8,018	81	290	930	377				

APPENDICES

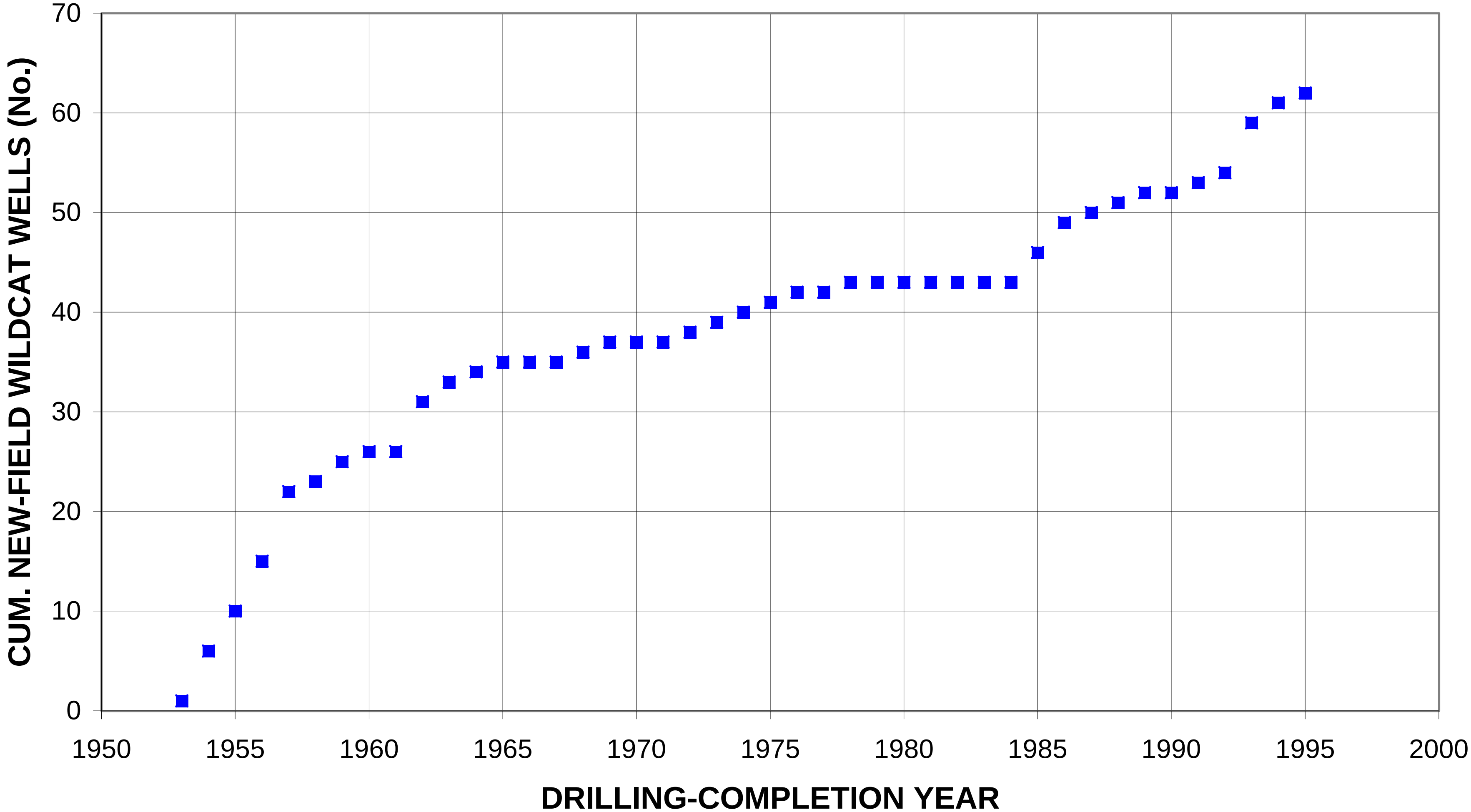
Exploration-activity and discovery-history plots for each of the assessment units. Two sets of plots and statistics are provided, one set showing known field sizes (cumulative production plus remaining reserves) and another showing field sizes upon which a reserve-growth function was applied (labeled grown). Within each set of plots, oil fields and gas fields are treated separately. The plots include:

- Cumulative Number of New-Field Wildcat Wells vs. Drilling-Completion Year
- Number of New-Field Wildcat Wells vs. Drilling-Completion Year
- Oil- or Gas-Field Size (MMBO or BCFG) vs. Oil- or Gas-Field Rank by Size (With Respect to Discovery Halves or Thirds)
- Number of Oil or Gas Fields vs. Oil- or Gas-Field Size Classes (MMBO or BCFG) (With Respect to Discovery Halves or Thirds)
- Volume of Oil or Gas (MMBO or BCFG) vs. Oil- or Gas-Field Size Classes (MMBO or BCFG)
- Oil- or Gas-Field Size (MMBO or BCFG) vs. Field-Discovery Year
- Oil- or Gas-Field Size (MMBO or BCFG) vs. Cumulative Number of New-Field Wildcat Wells
- Cumulative Oil or Gas Volume (MMBO or BCFG) vs. Field-Discovery Year
- Cumulative Oil or Gas Volume (MMBO or BCFG) vs. Cumulative Number of New-Field Wildcat Wells
- Cumulative Number of Oil or Gas Fields vs. Field-Discovery Year

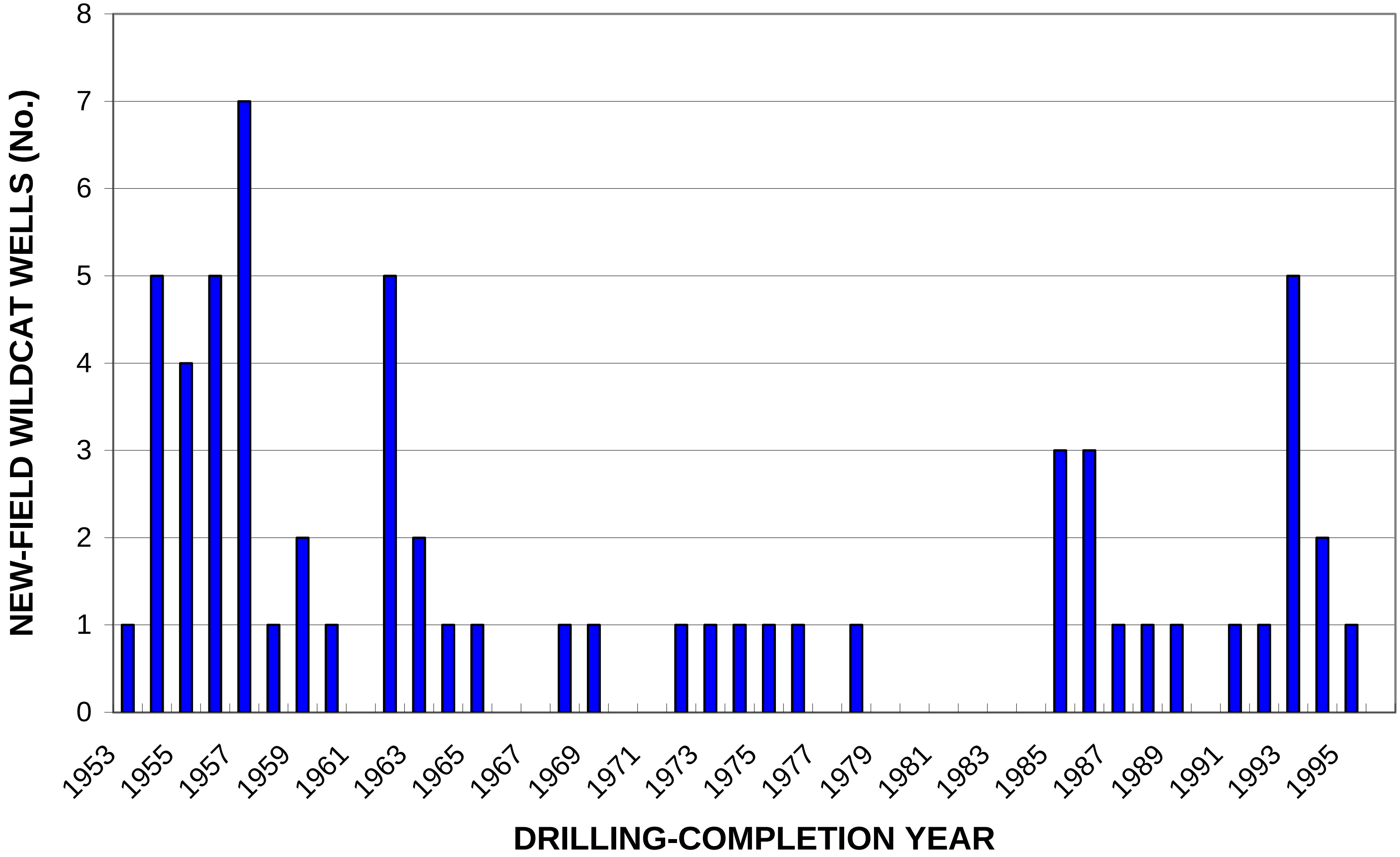
- Cumulative Number of Oil or Gas Fields vs. Cumulative Number of New-Field Wildcat Wells
- Reservoir Depth, Oil or Gas Fields (m) vs. Field-Discovery Year
- Reservoir Depth, Oil or Gas Fields (m) vs. Cumulative Number of New-Field Wildcat Wells
- Gas/Oil, Oil Fields (CFG/BO) vs. Mean Reservoir Depth (m)
- NGL/Gas, Oil Fields (BNGL/MMCFG) vs. Mean Reservoir Depth (m)
- Liquids/Gas, Gas Fields (BL/MMCFG) vs. Mean Reservoir Depth (m)
- Number of Reservoirs in Oil Fields vs. API Gravity (Degrees)

Appendix 1. Exploration-activity and discovery-history plots for the Tanezzuft-Timimoun Structural/Stratigraphic Assessment Unit.

Tanezzuft-Timimoun Structural/Stratigraphic, Assessment Unit 20580101



Tanezzuft-Timimoun Structural/Stratigraphic, Assessment Unit 20580101



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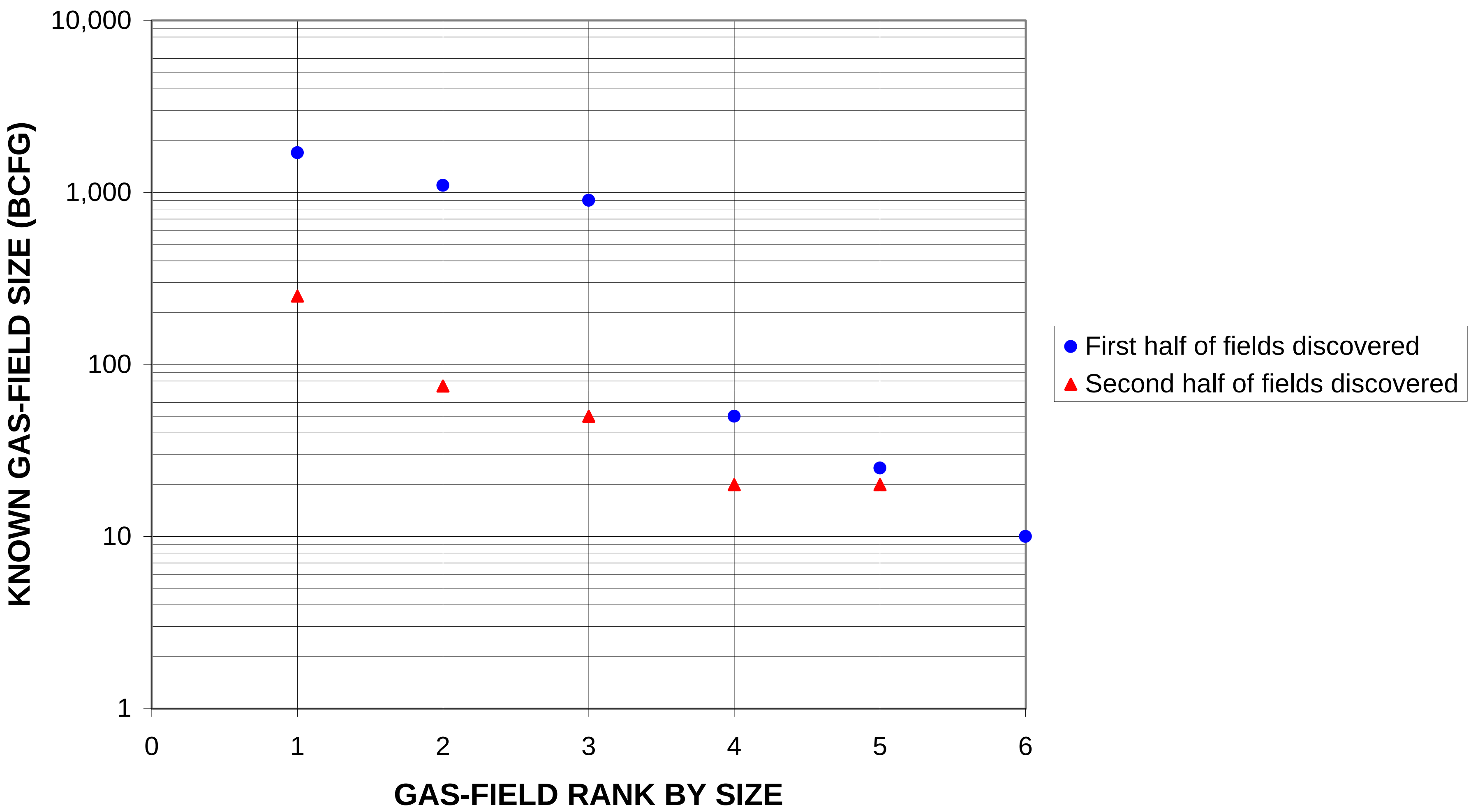

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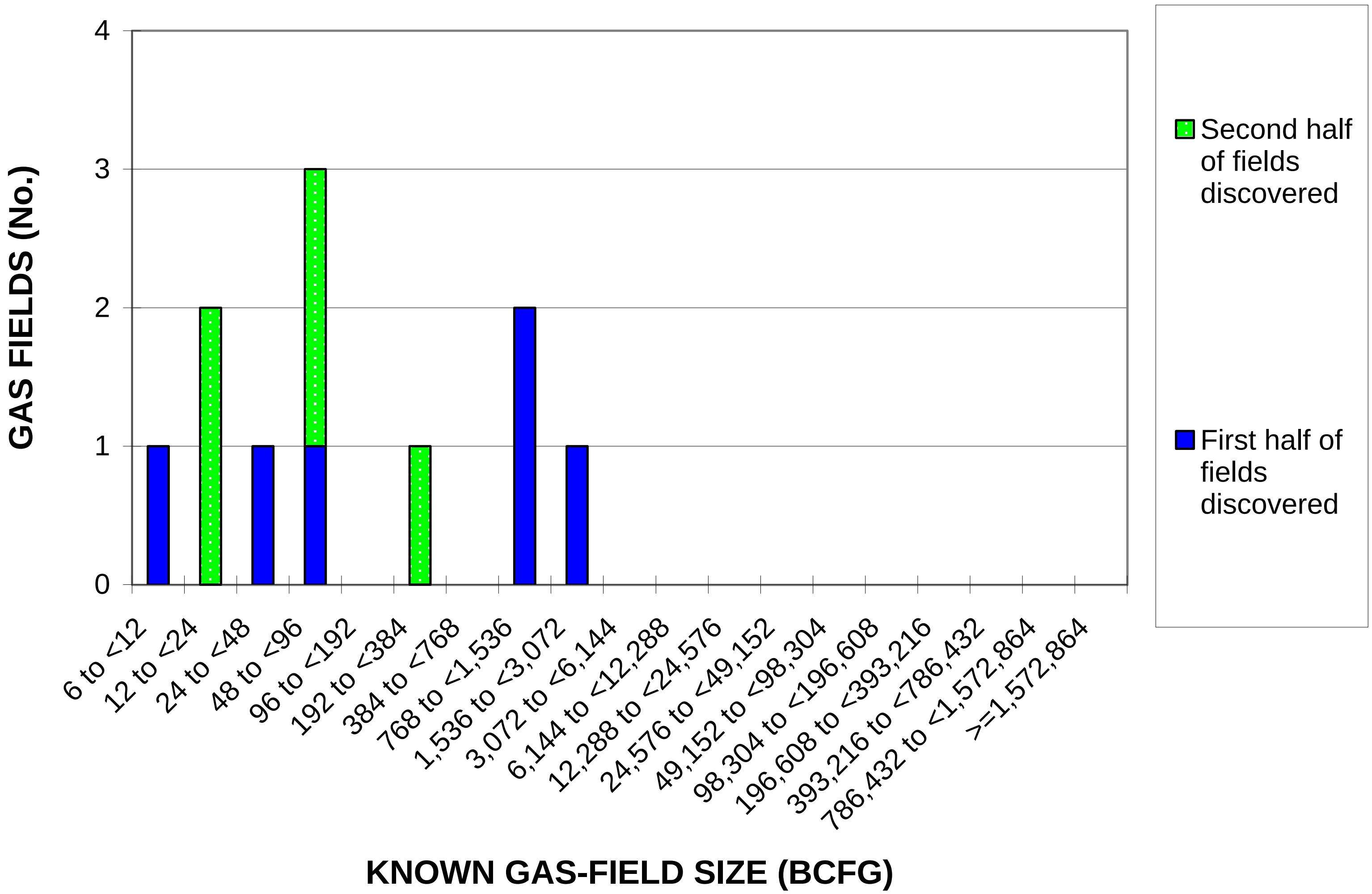

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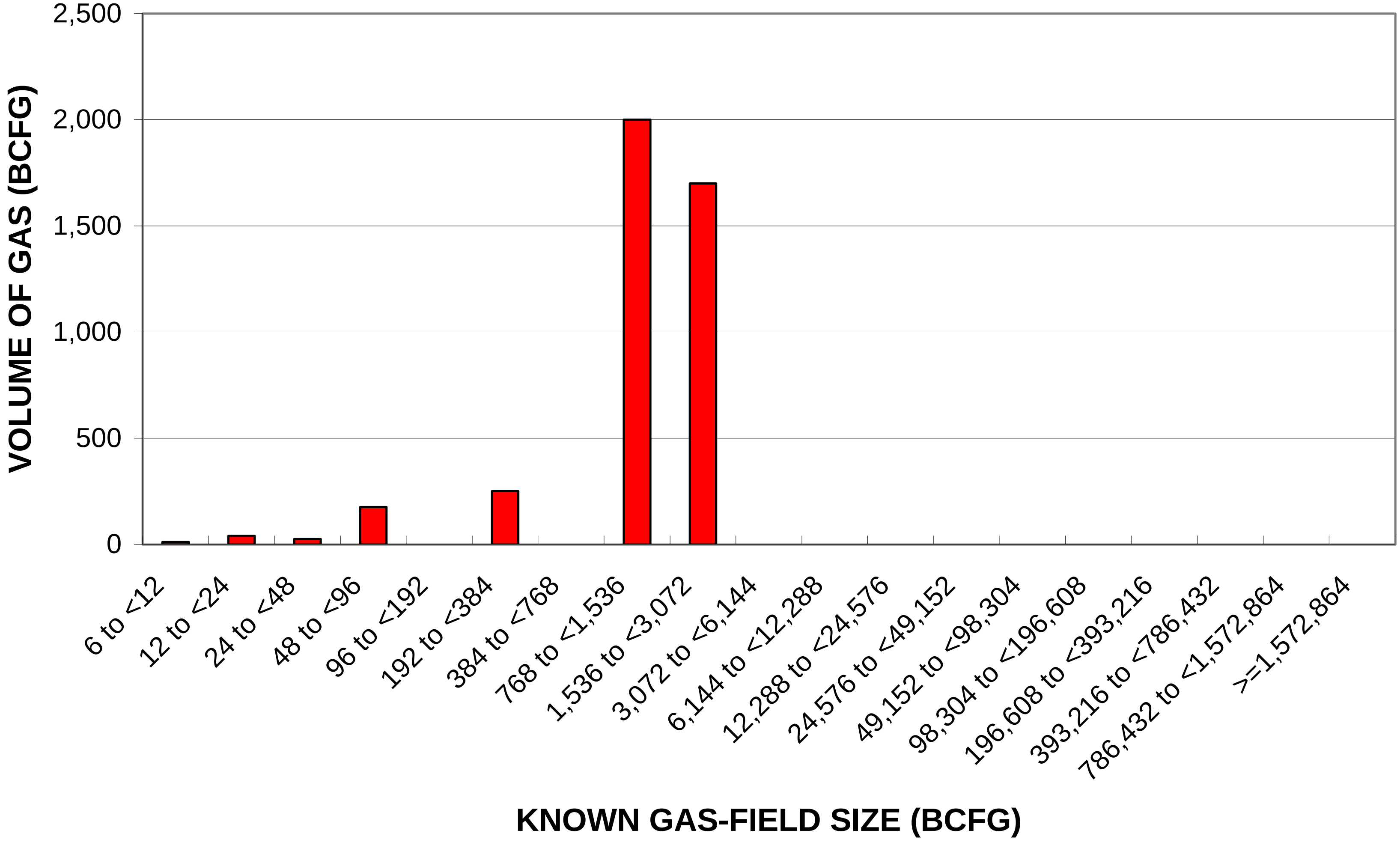
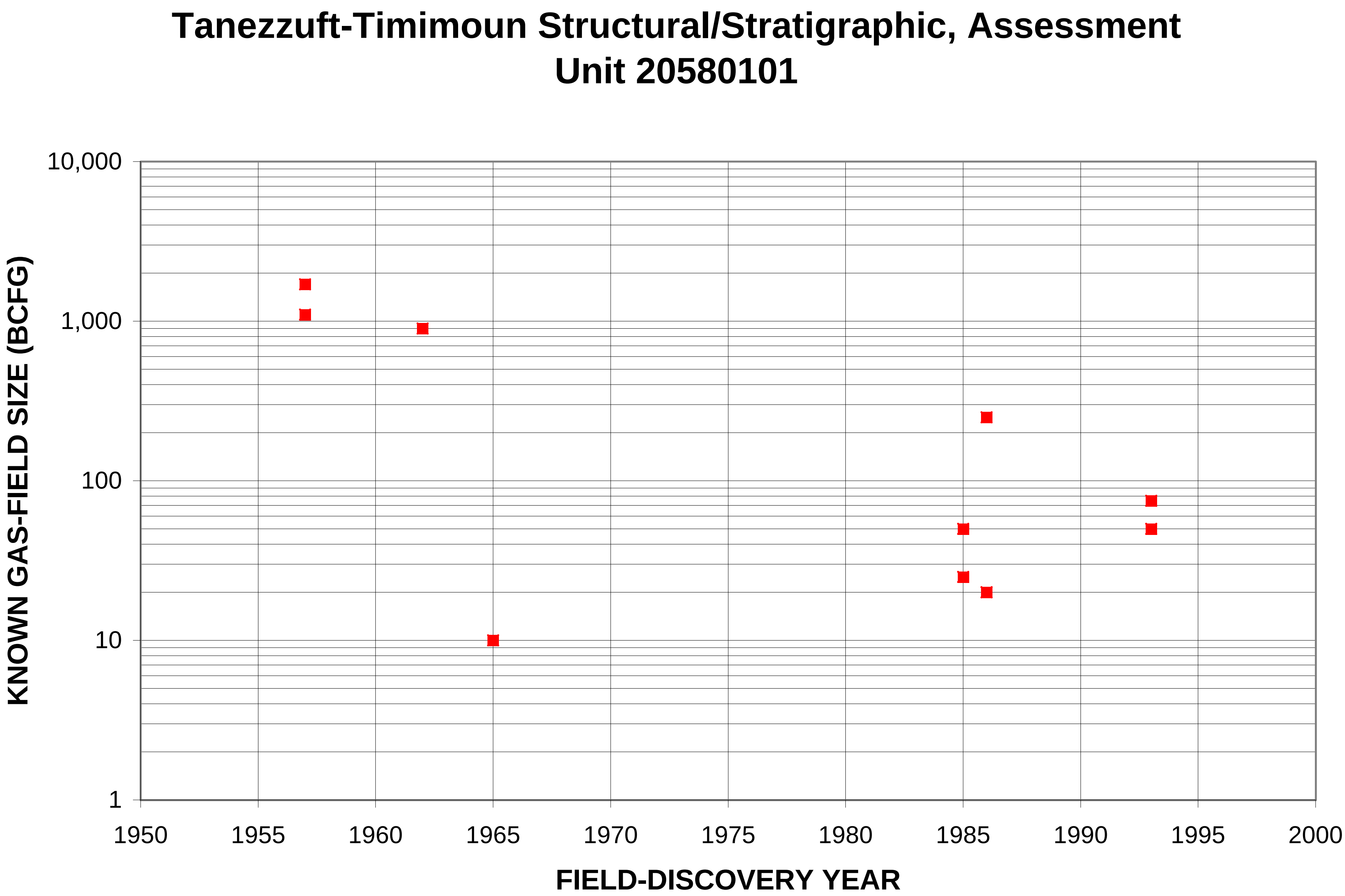
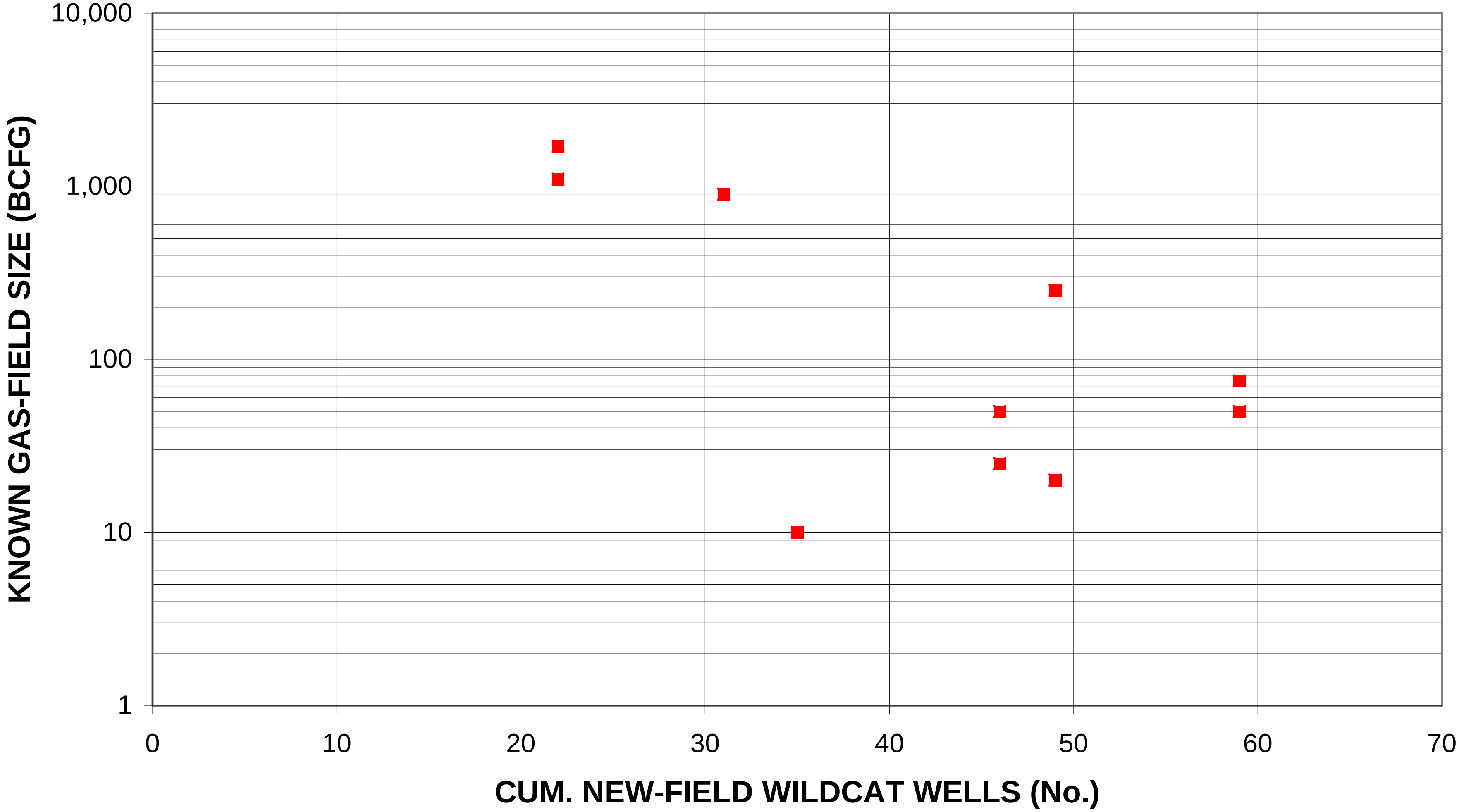
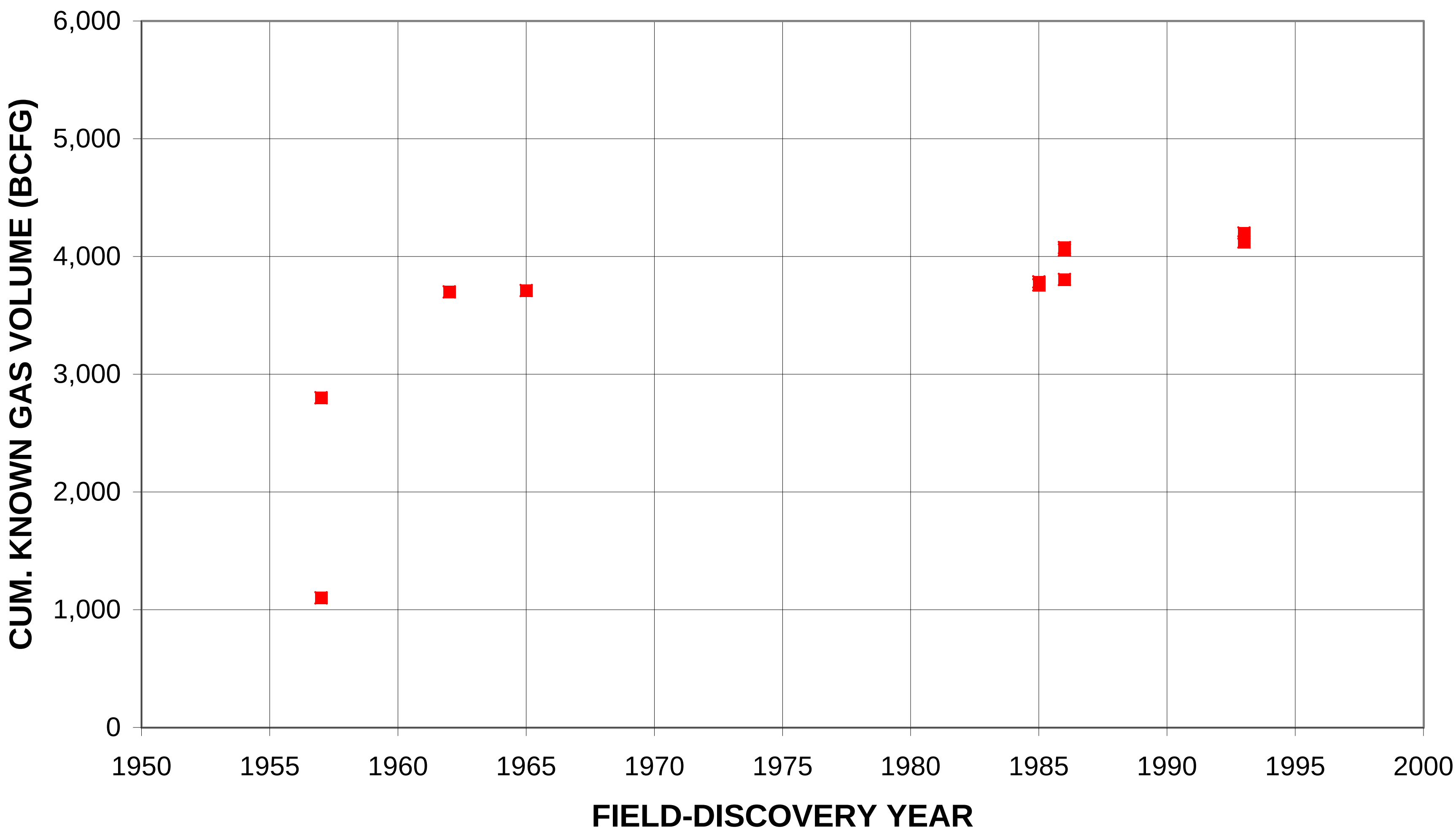



Tanezzuft-Timimoun Structural/Stratigraphic, Assessment
Unit 20580101
KNOWN GAS-FIELD SIZE (BCFG)
10,000
1,000
100
10
1
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
FIELD-DISCOVERY YEAR

Tanezzuft-Timimoun Structural/Stratigraphic, Assessment Unit 20580101



Tanezzuft-Timimoun Structural/Stratigraphic, Assessment Unit 20580101



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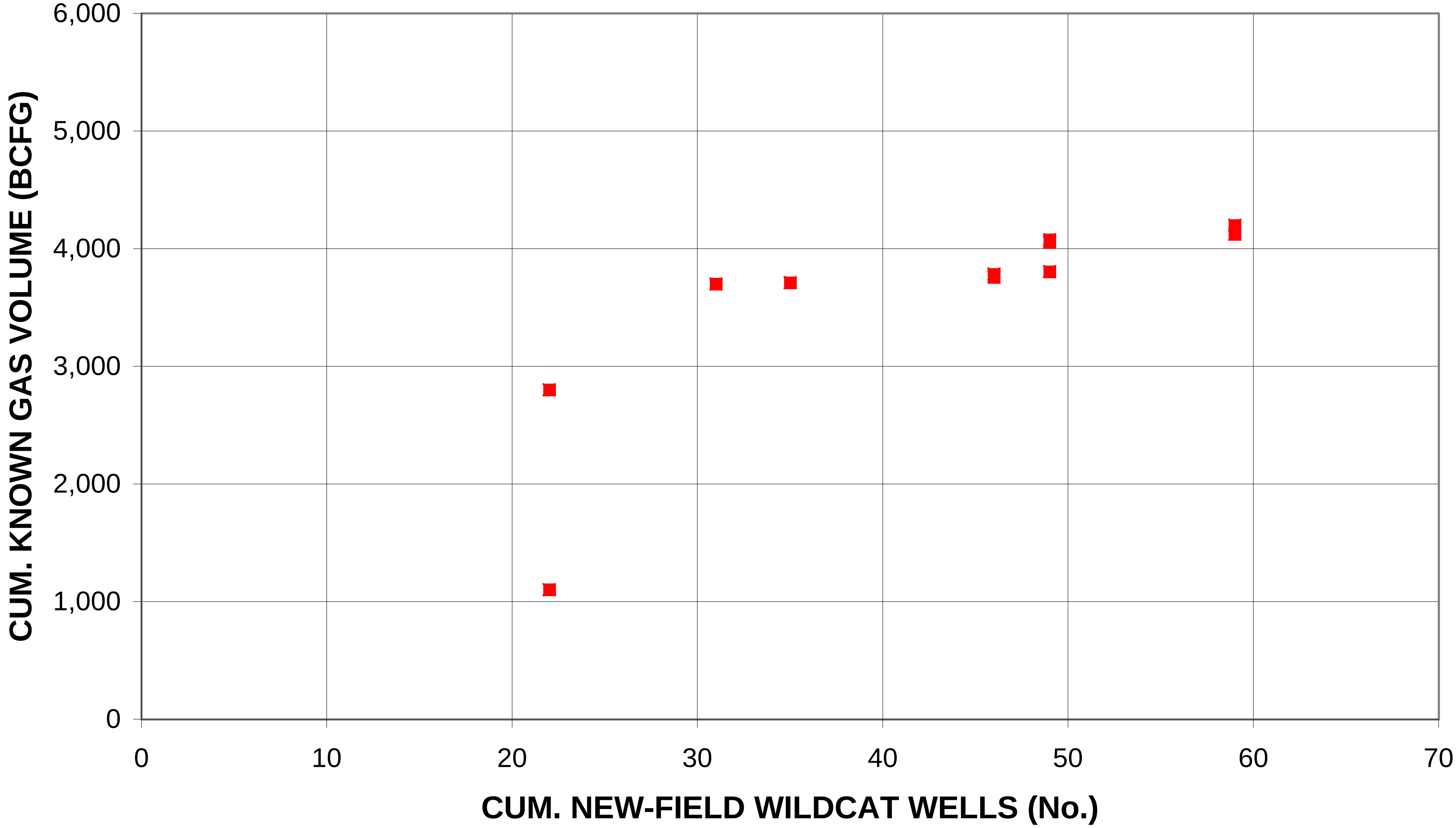

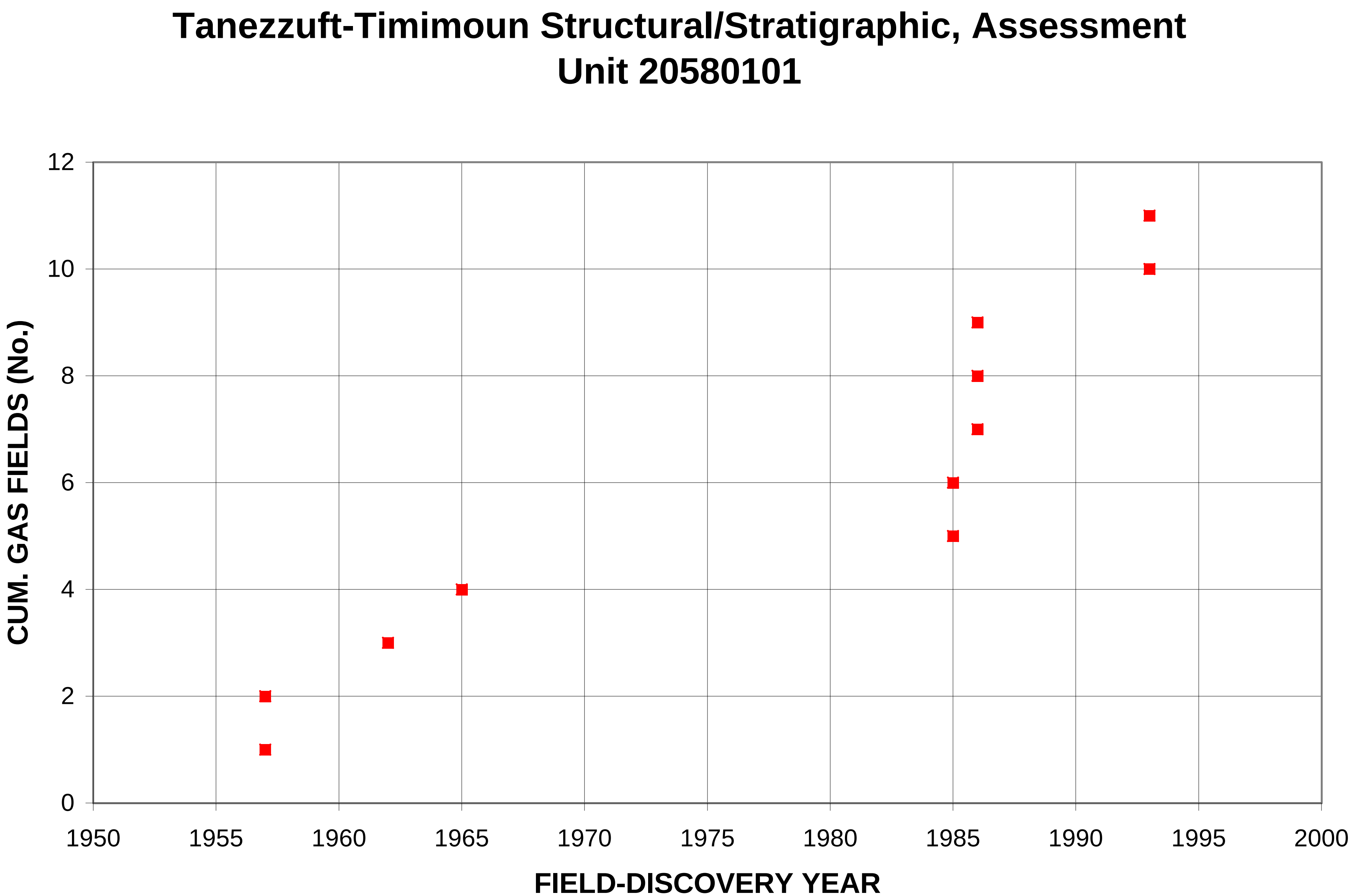
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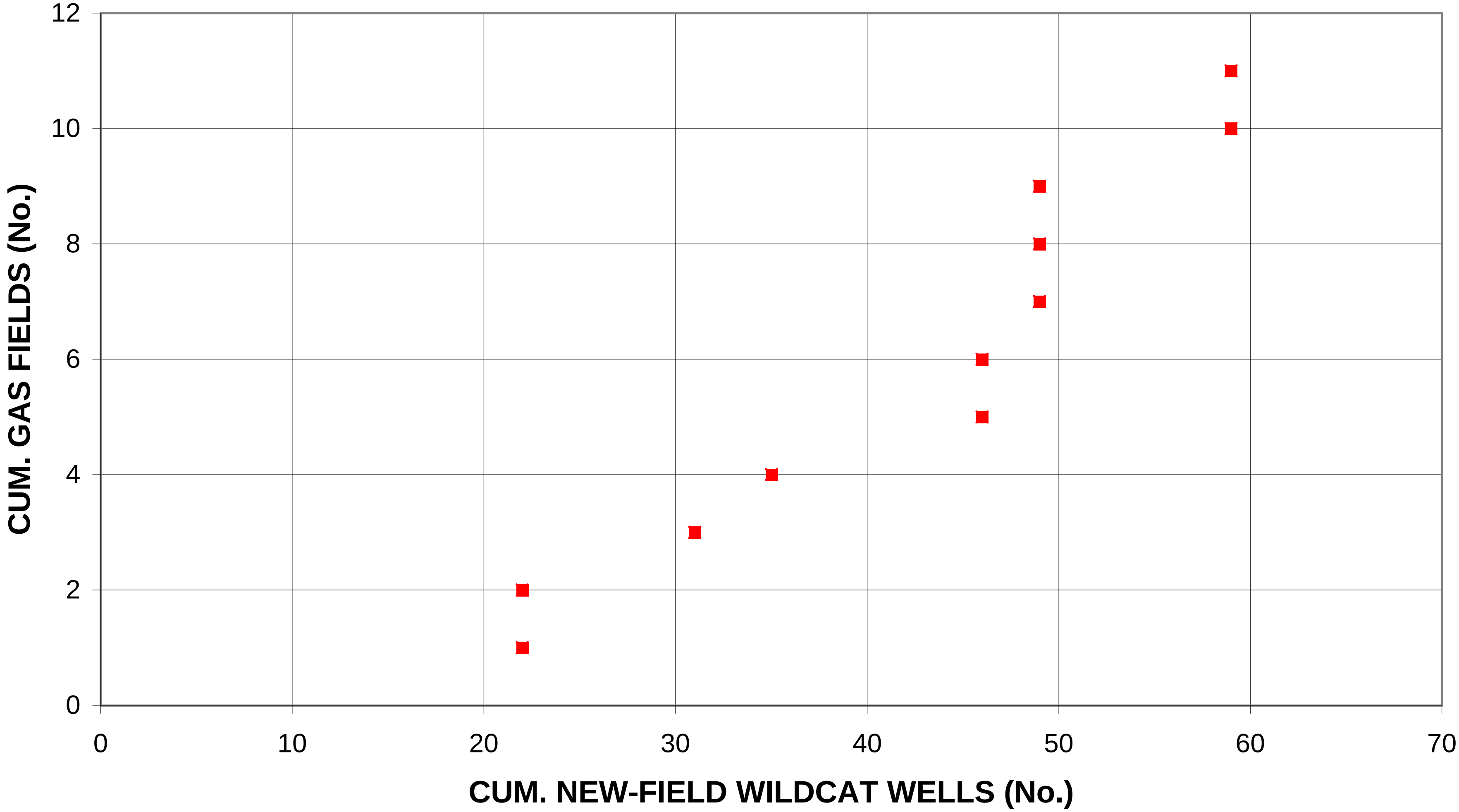
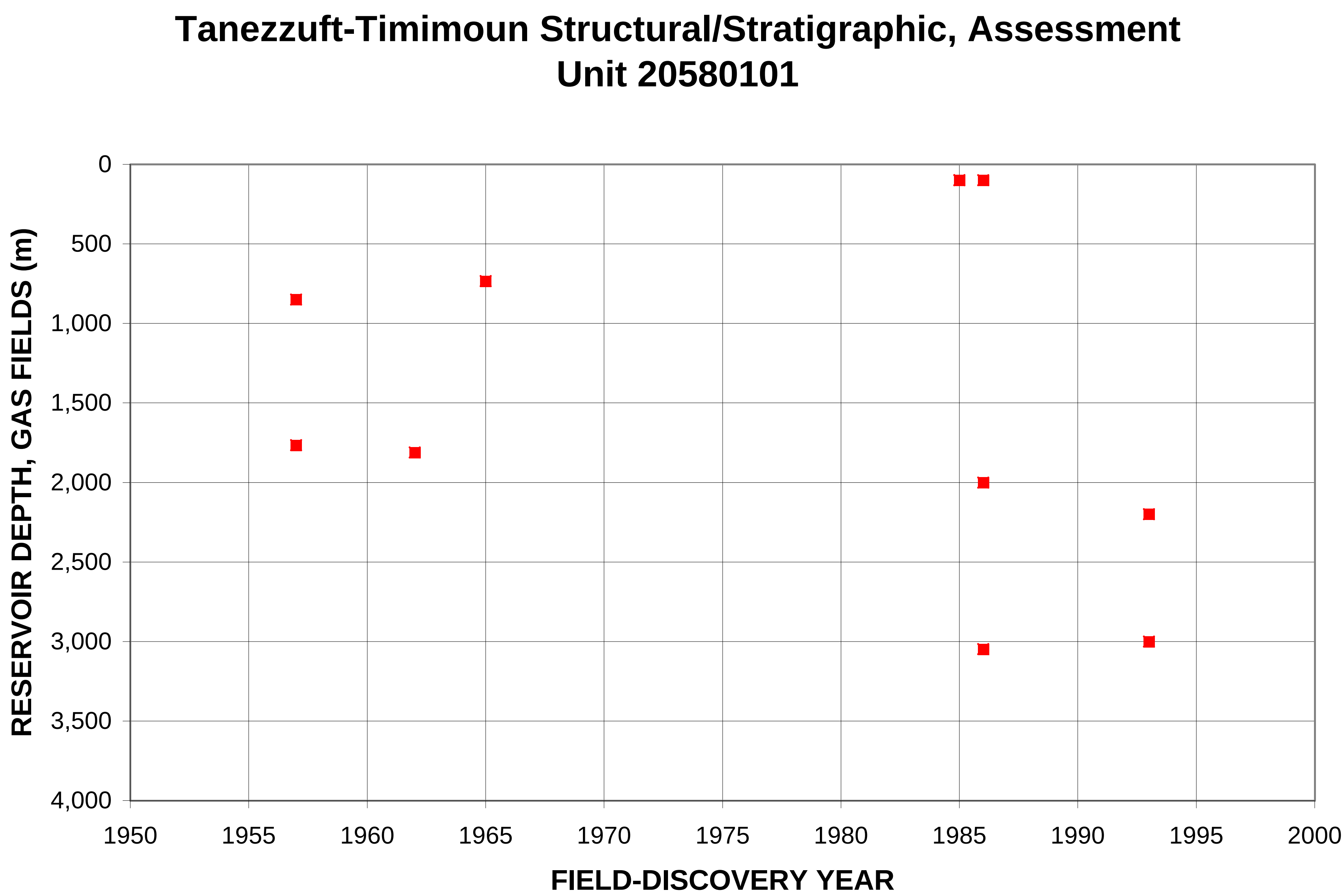
CUM. GAS FIELDS (No.)
0
2
4
6
8
10
12
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
FIELD-DISCOVERY YEAR

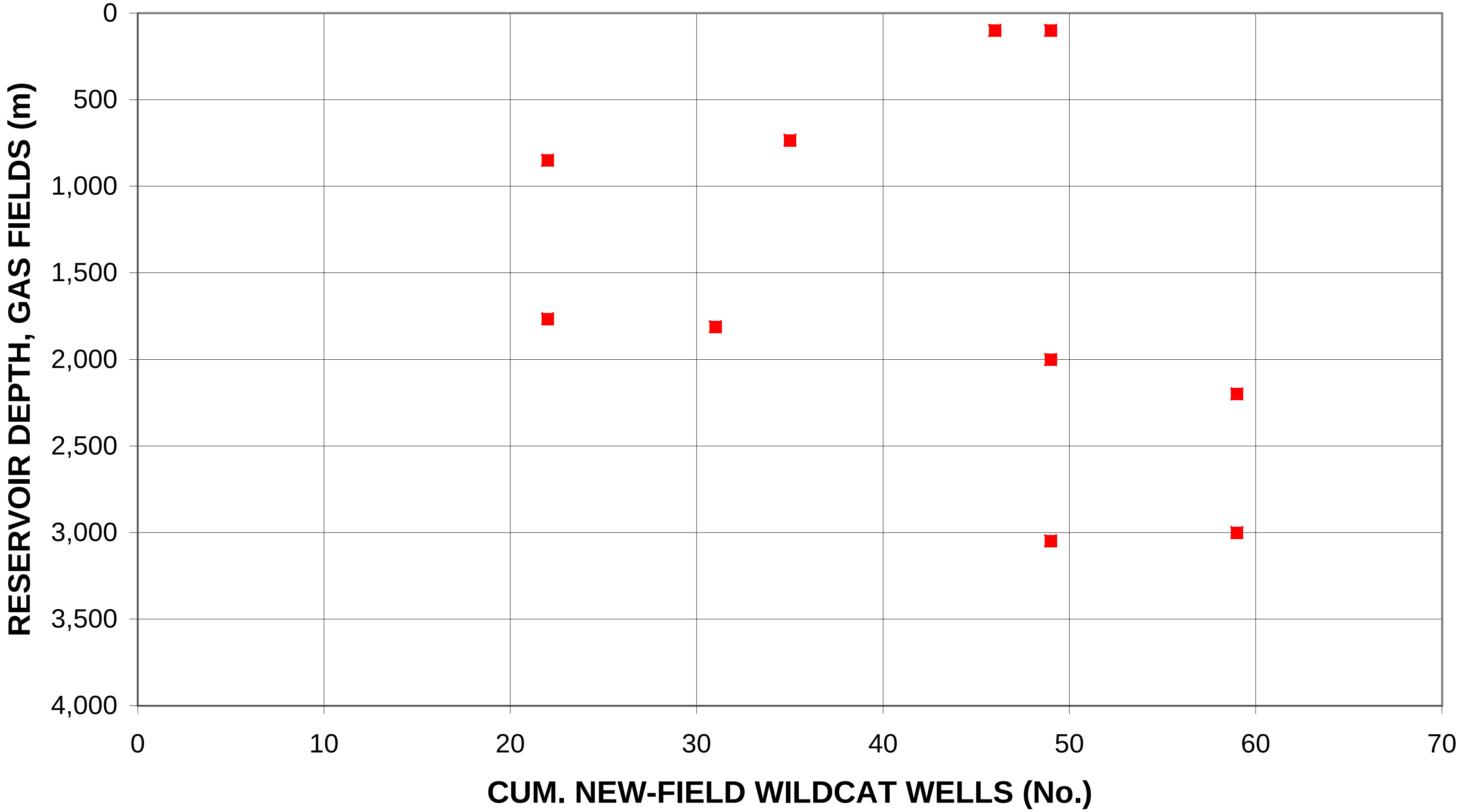
Tanezzuft-Timimoun Structural/Stratigraphic, Assessment Unit 20580101





Tanezzuft-Timimoun Structural/Stratigraphic, Assessment Unit 20580101
RESERVOIR DEPTH, GAS FIELDS (m)
0
500
1,000
1,500
2,000
2,500
3,000
3,500
4,000
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
FIELD-DISCOVERY YEAR

Tanezzuft-Timimoun Structural/Stratigraphic, Assessment Unit 20580101



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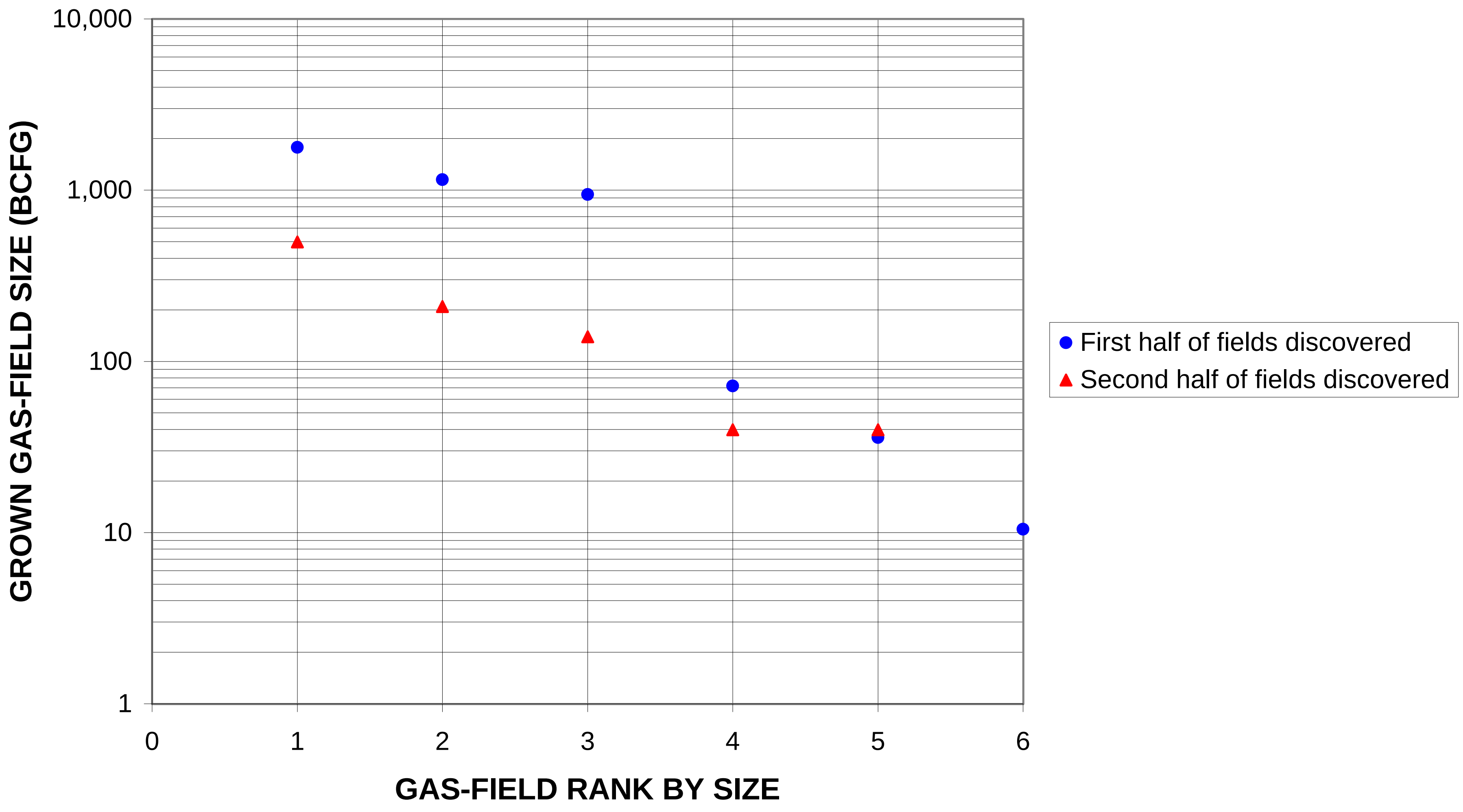

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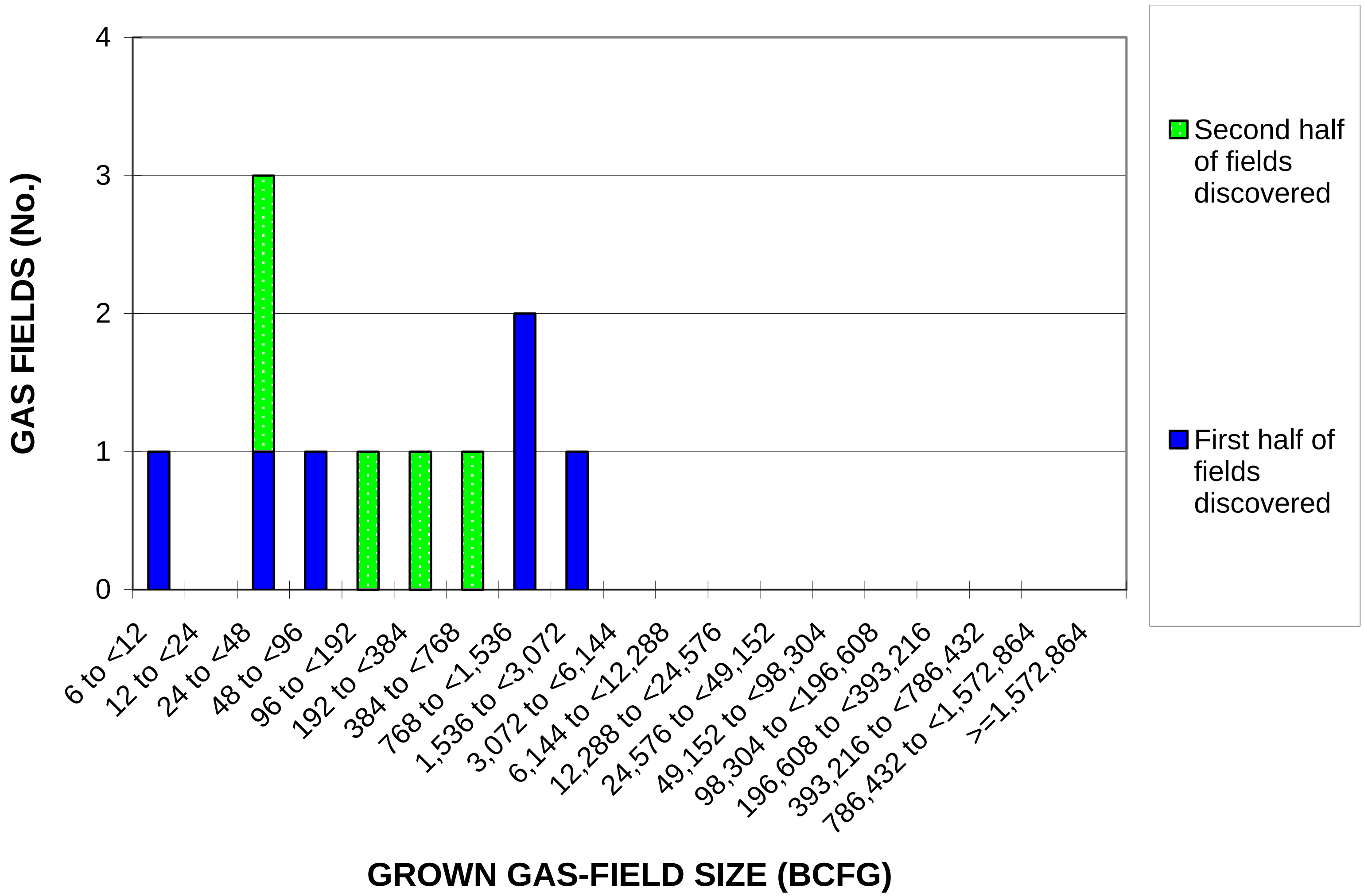

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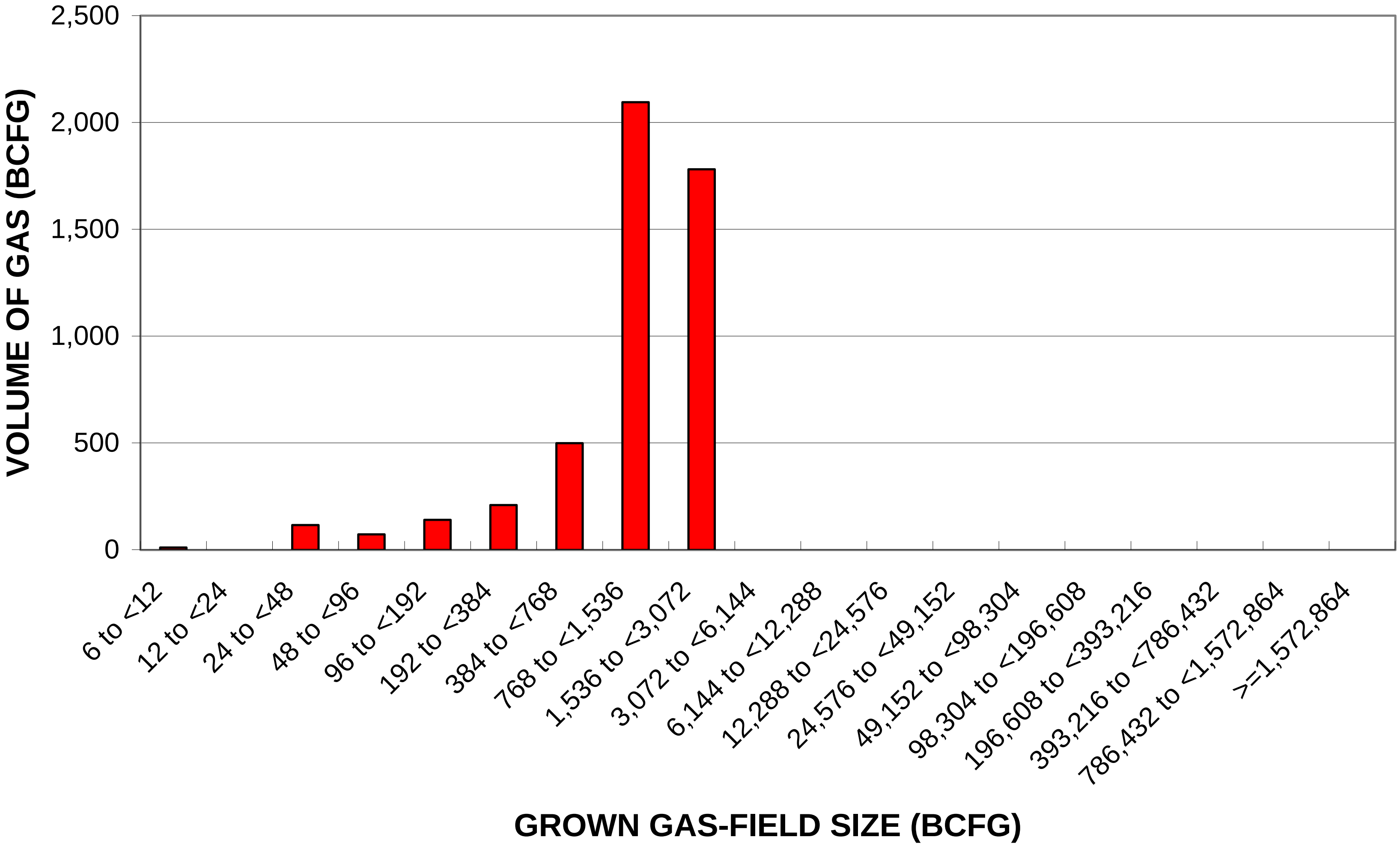
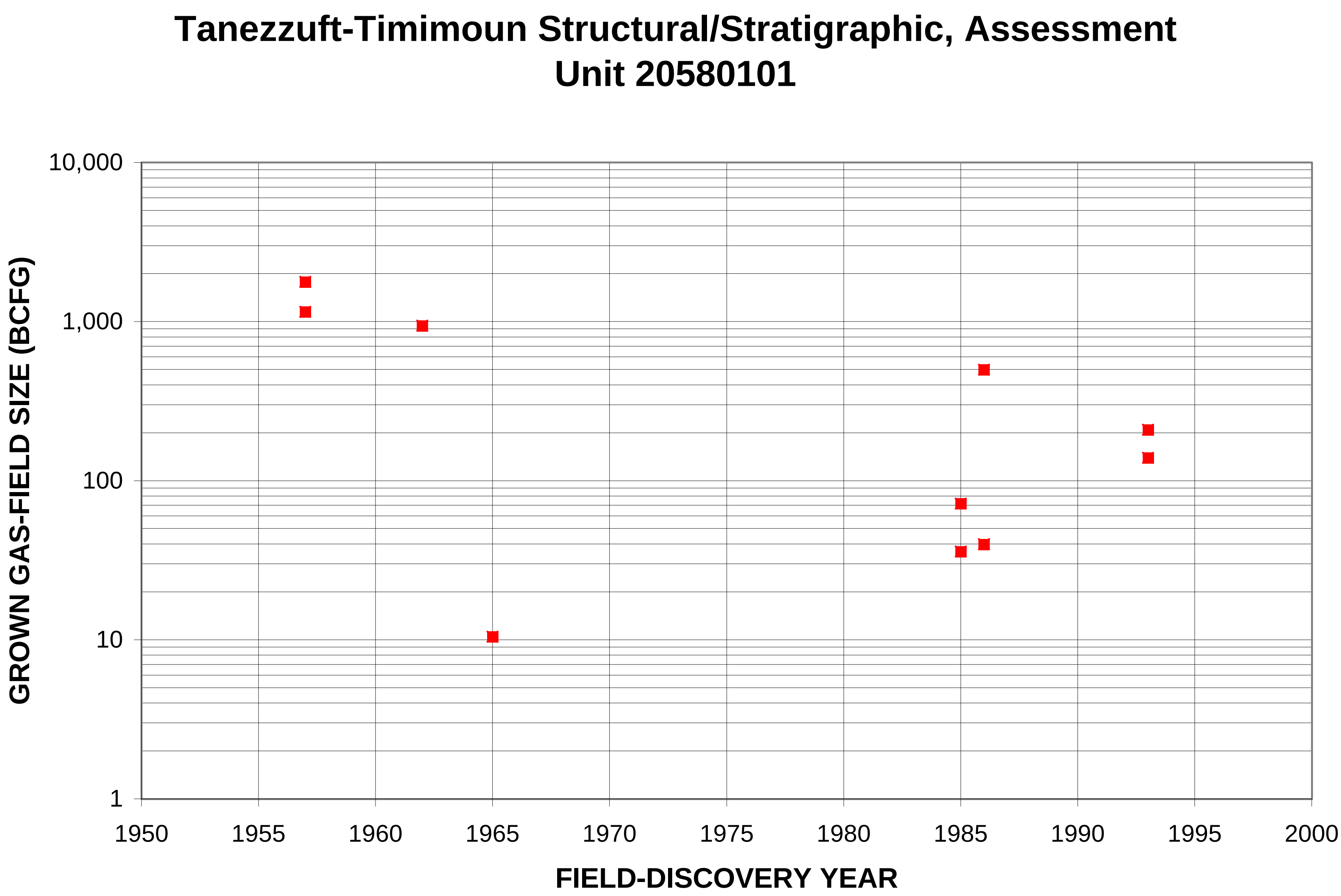
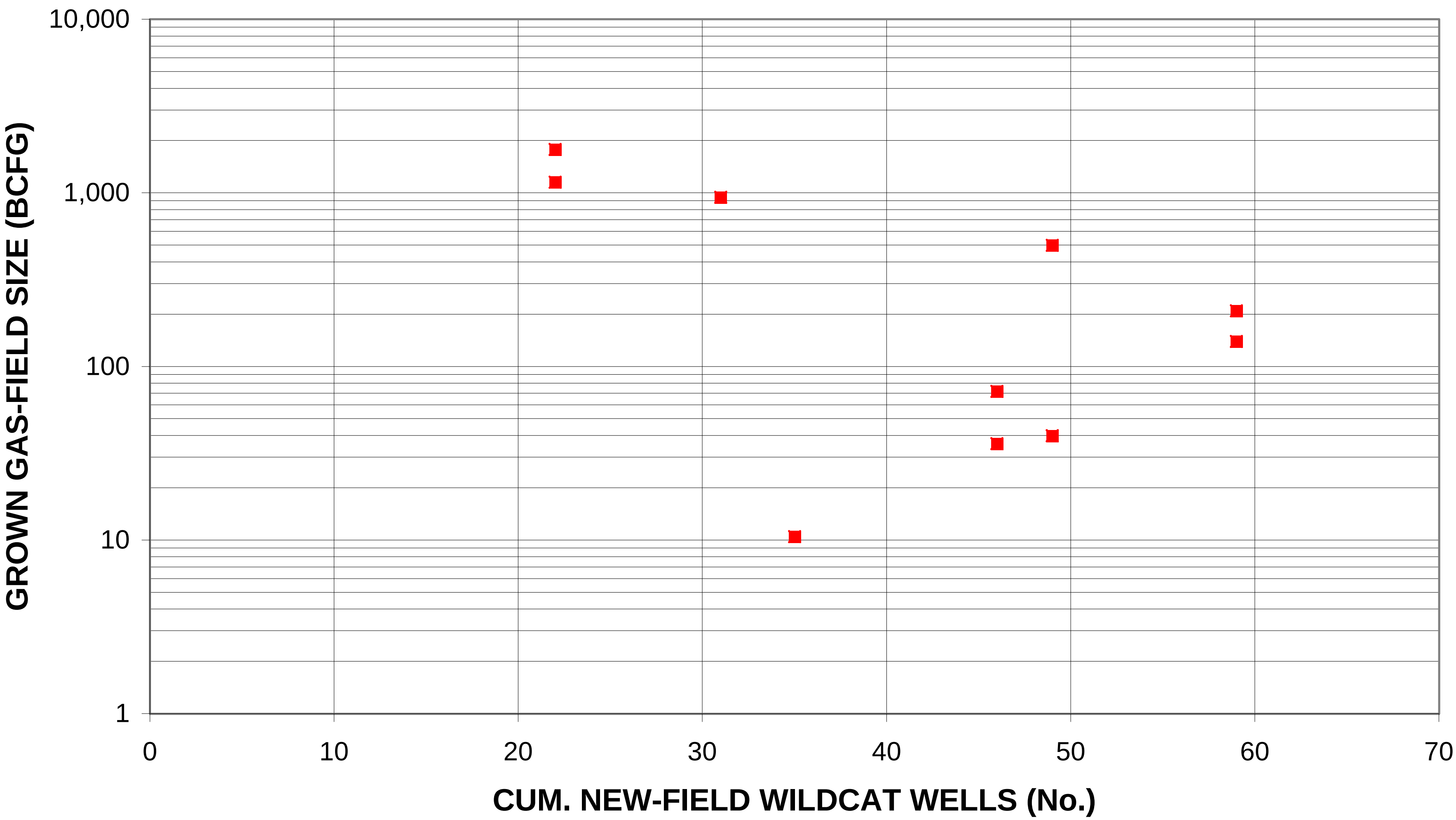



Tanezzuft-Timimoun Structural/Stratigraphic, Assessment Unit 20580101
GROWN GAS-FIELD SIZE (BCFG)
10,000
1,000
100
10
1
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
FIELD-DISCOVERY YEAR

Tanezzuft-Timimoun Structural/Stratigraphic, Assessment Unit 20580101



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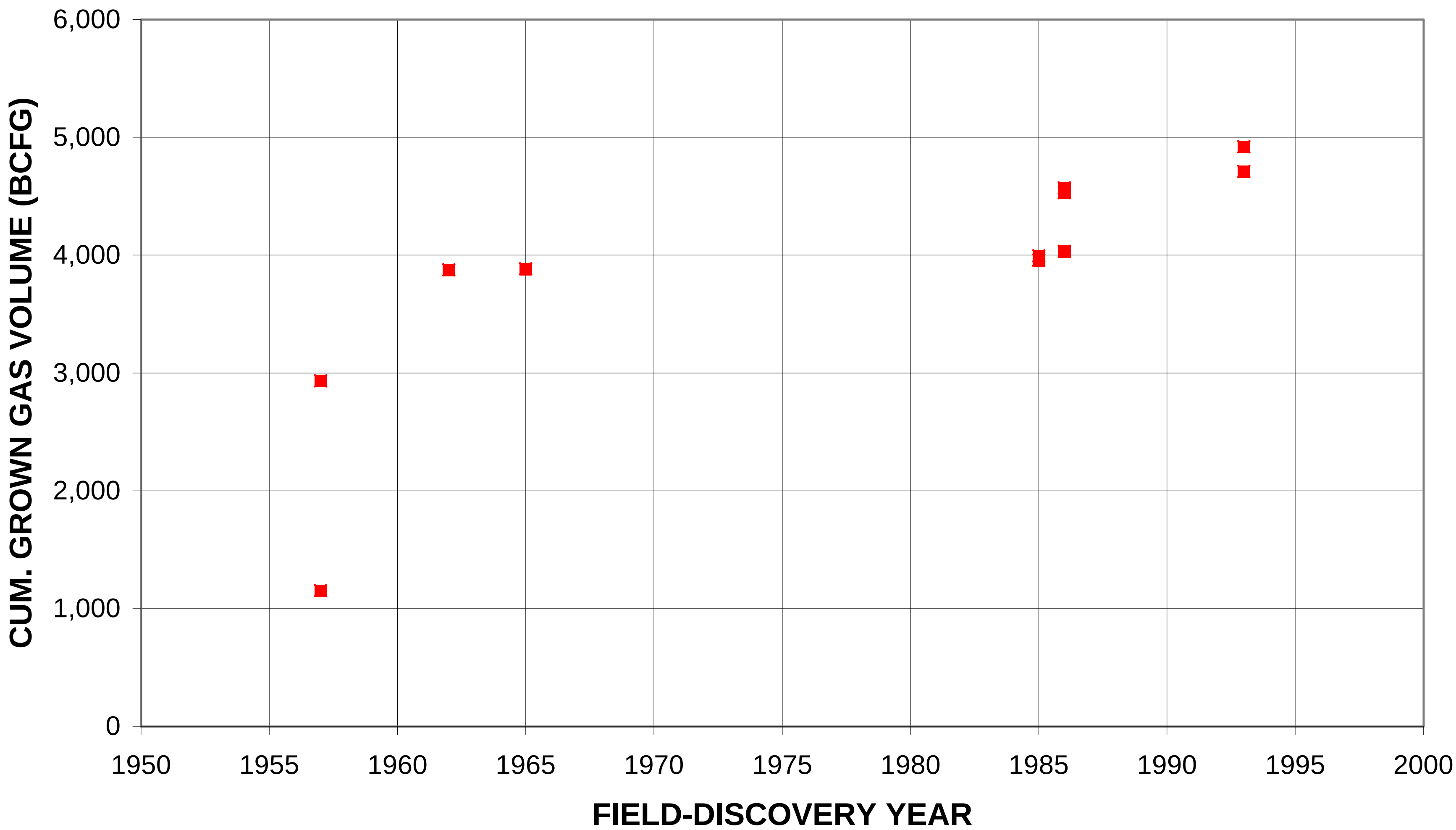

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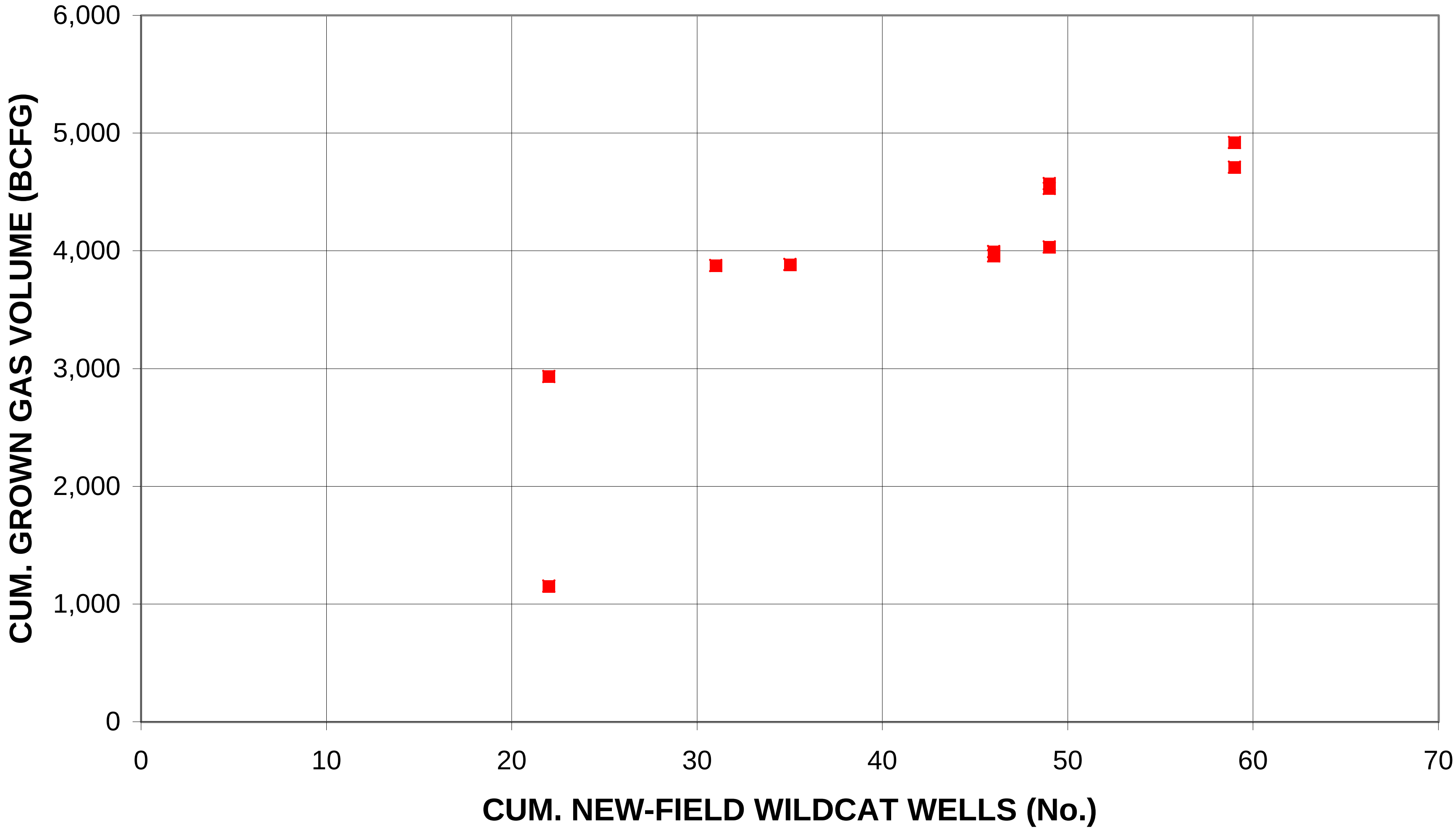

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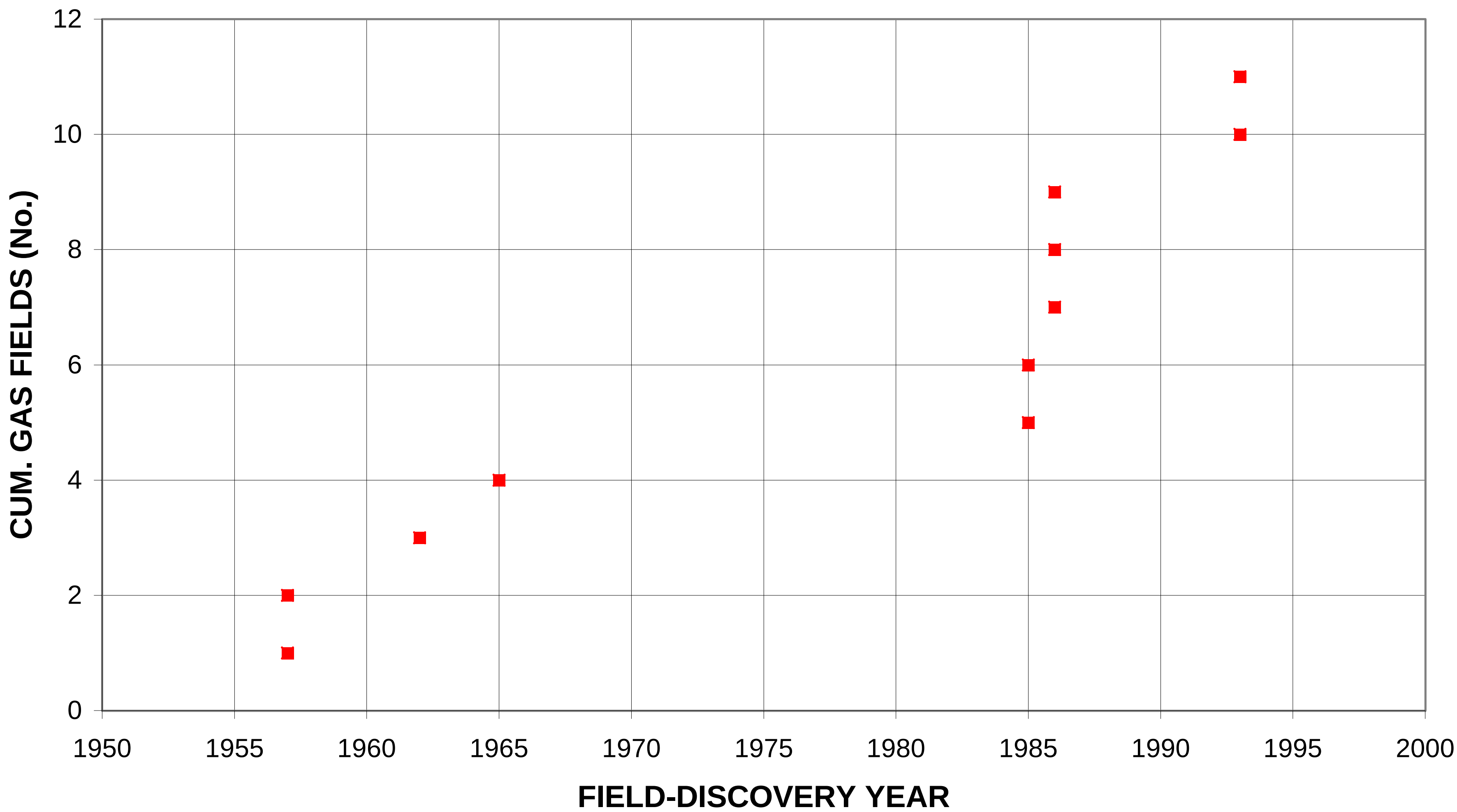

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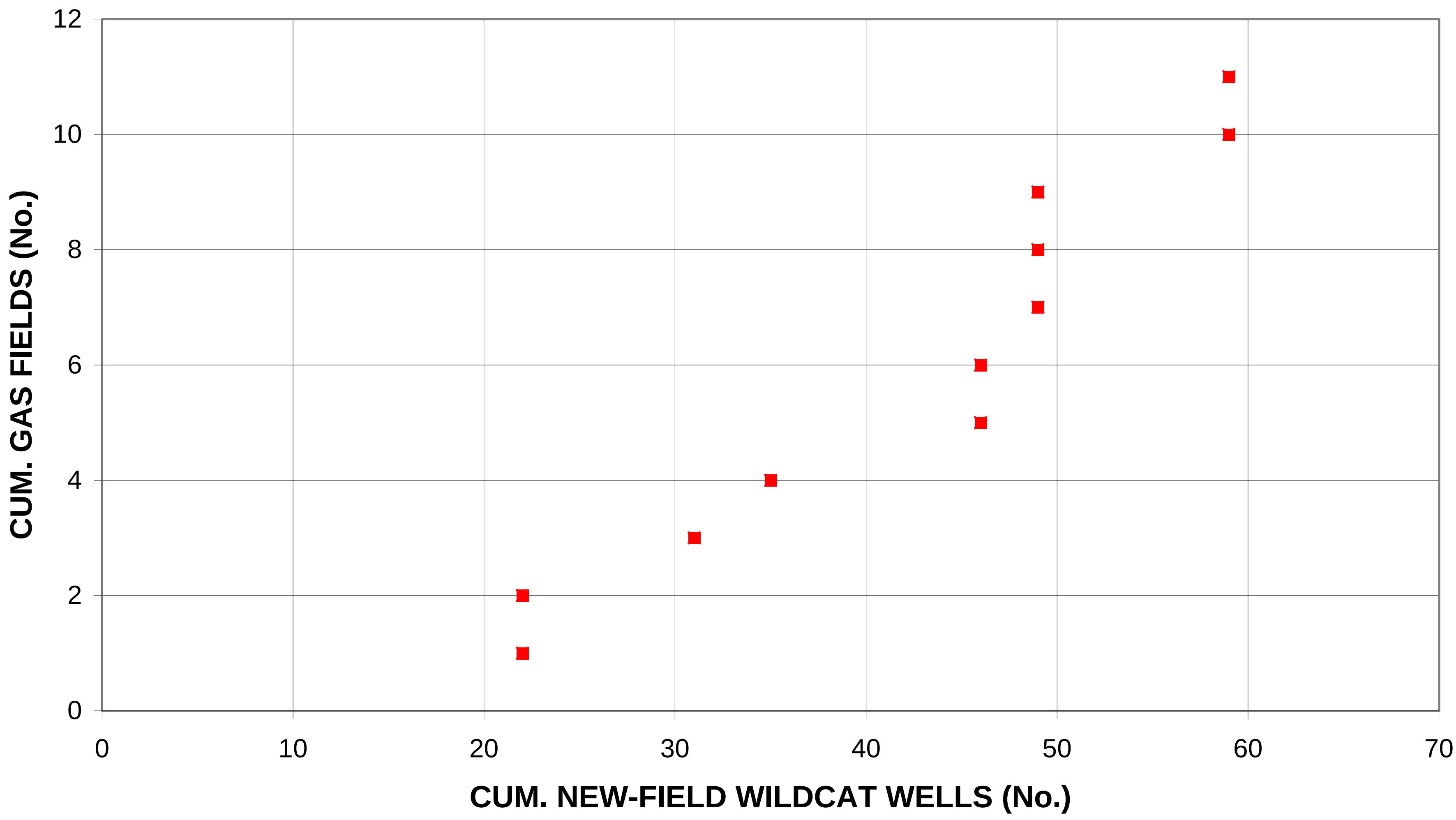
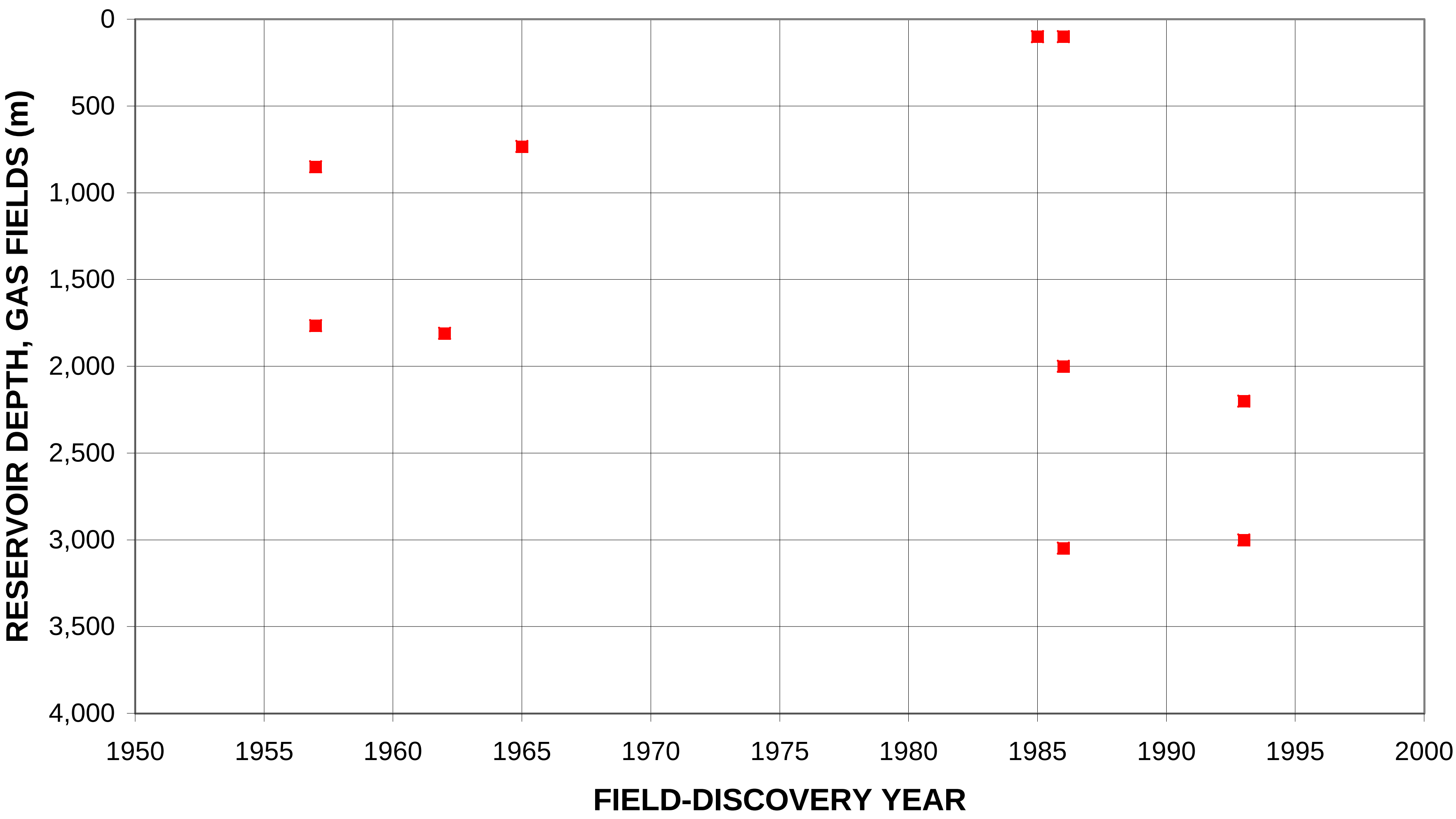
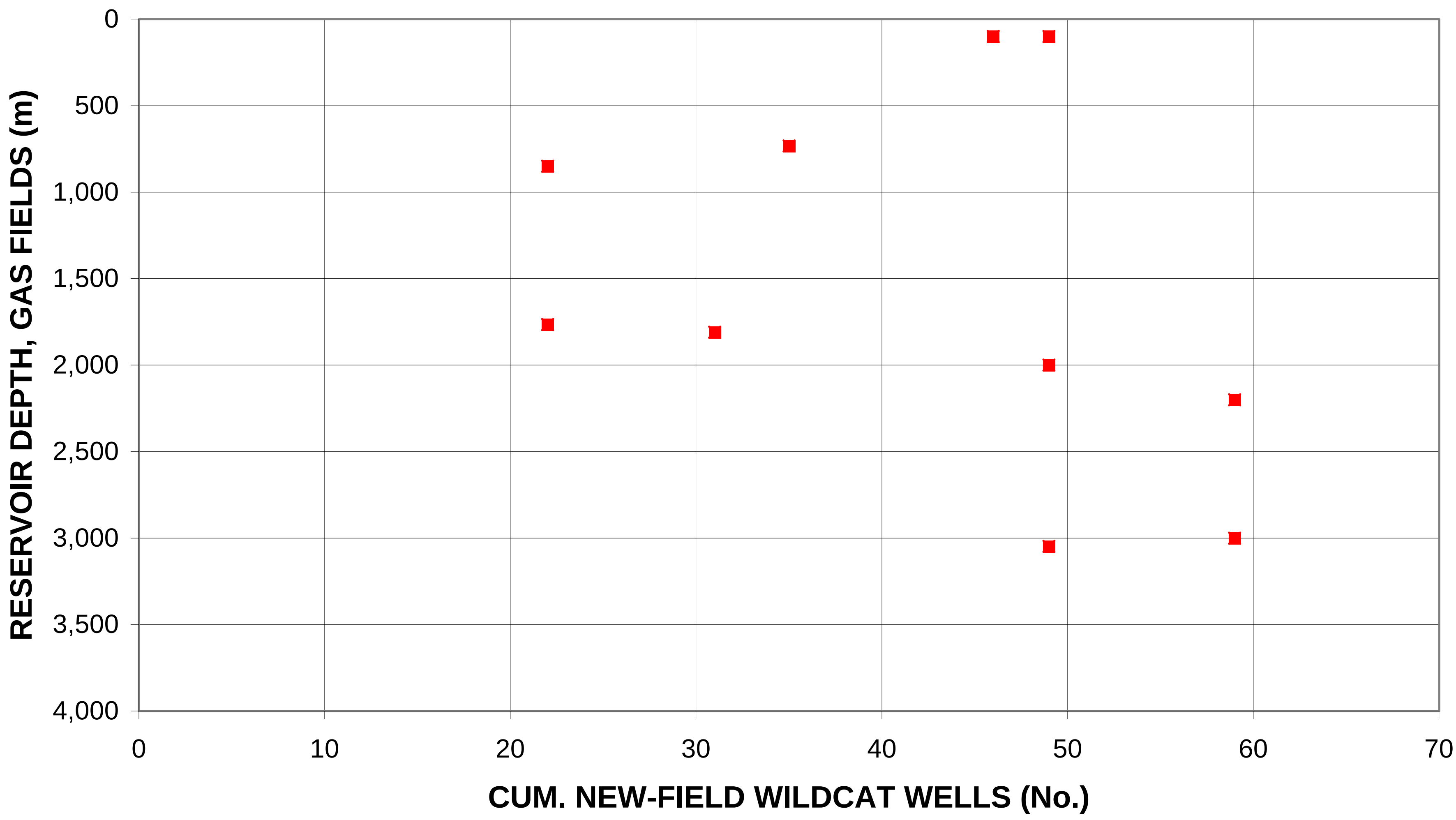


Tanezzuft-Timimoun Structural/Stratigraphic, Assessment Unit 20580101

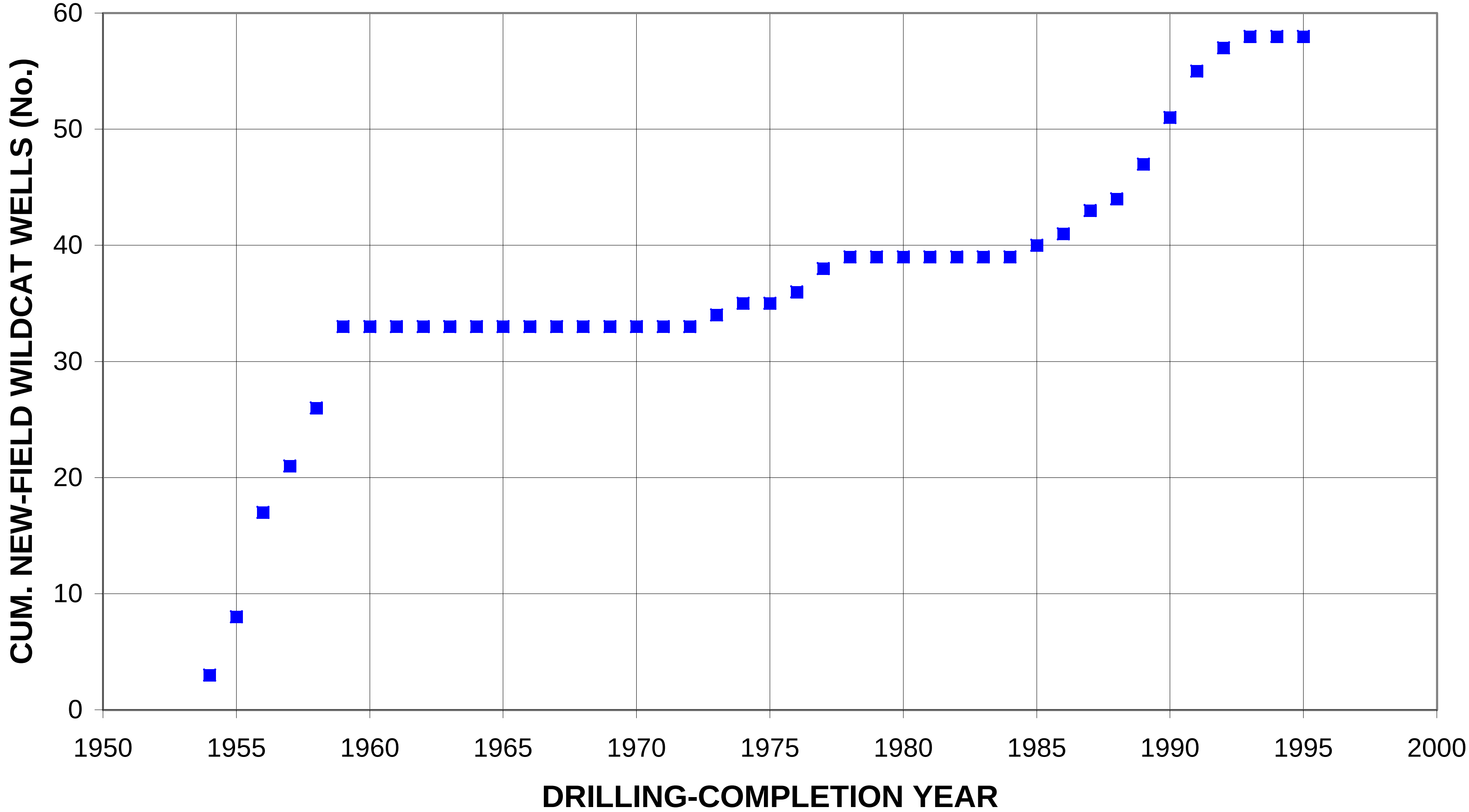


Tanezzuft-Timimoun Structural/Stratigraphic, Assessment Unit 20580101



Appendix 2. Exploration-activity and discovery-history plots for the Tanezzuft-Ahnet Structural/Stratigraphic Assessment Unit.

Tanezzuft-Ahnet Structural/Stratigraphic, Assessment Unit 20580201



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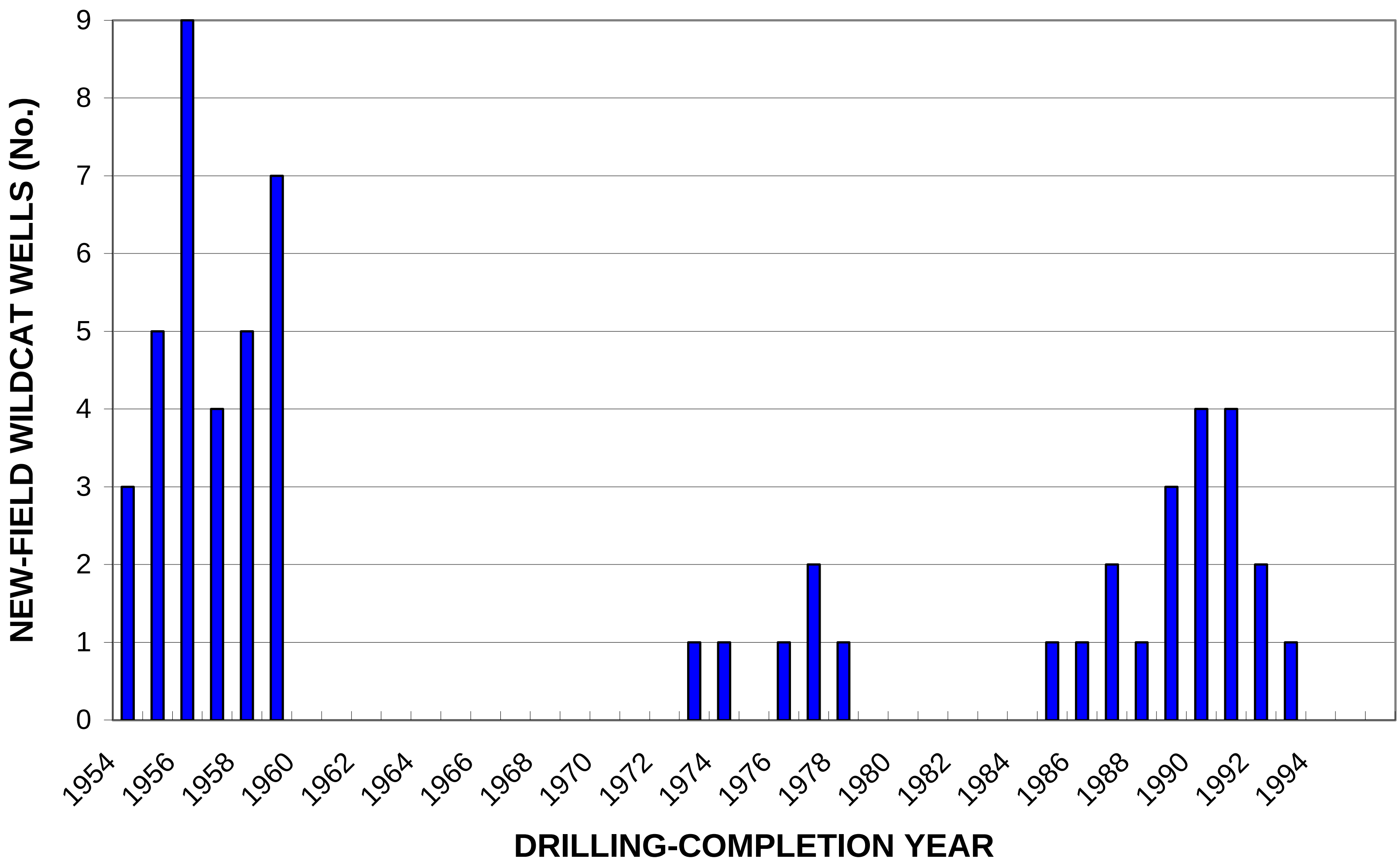
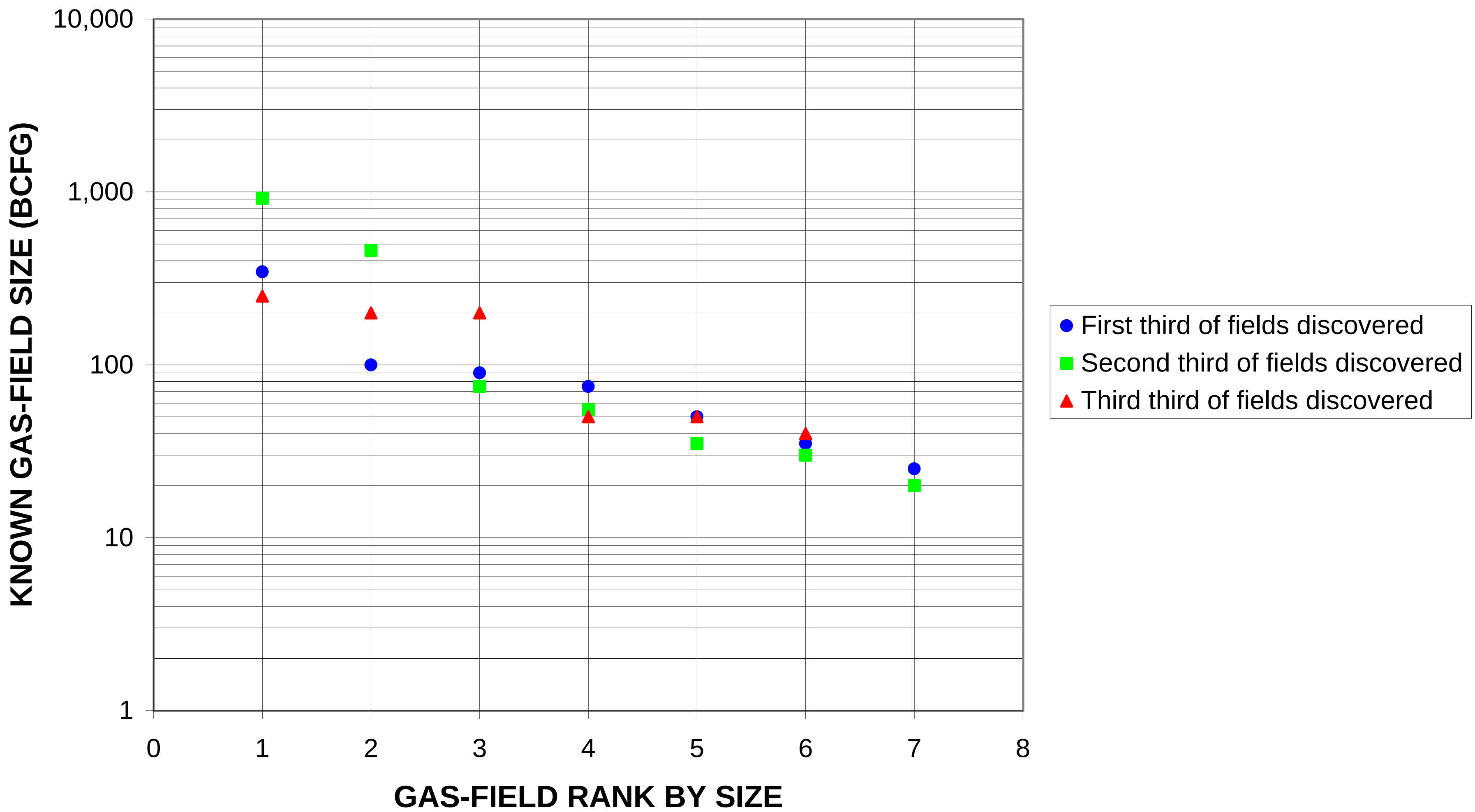
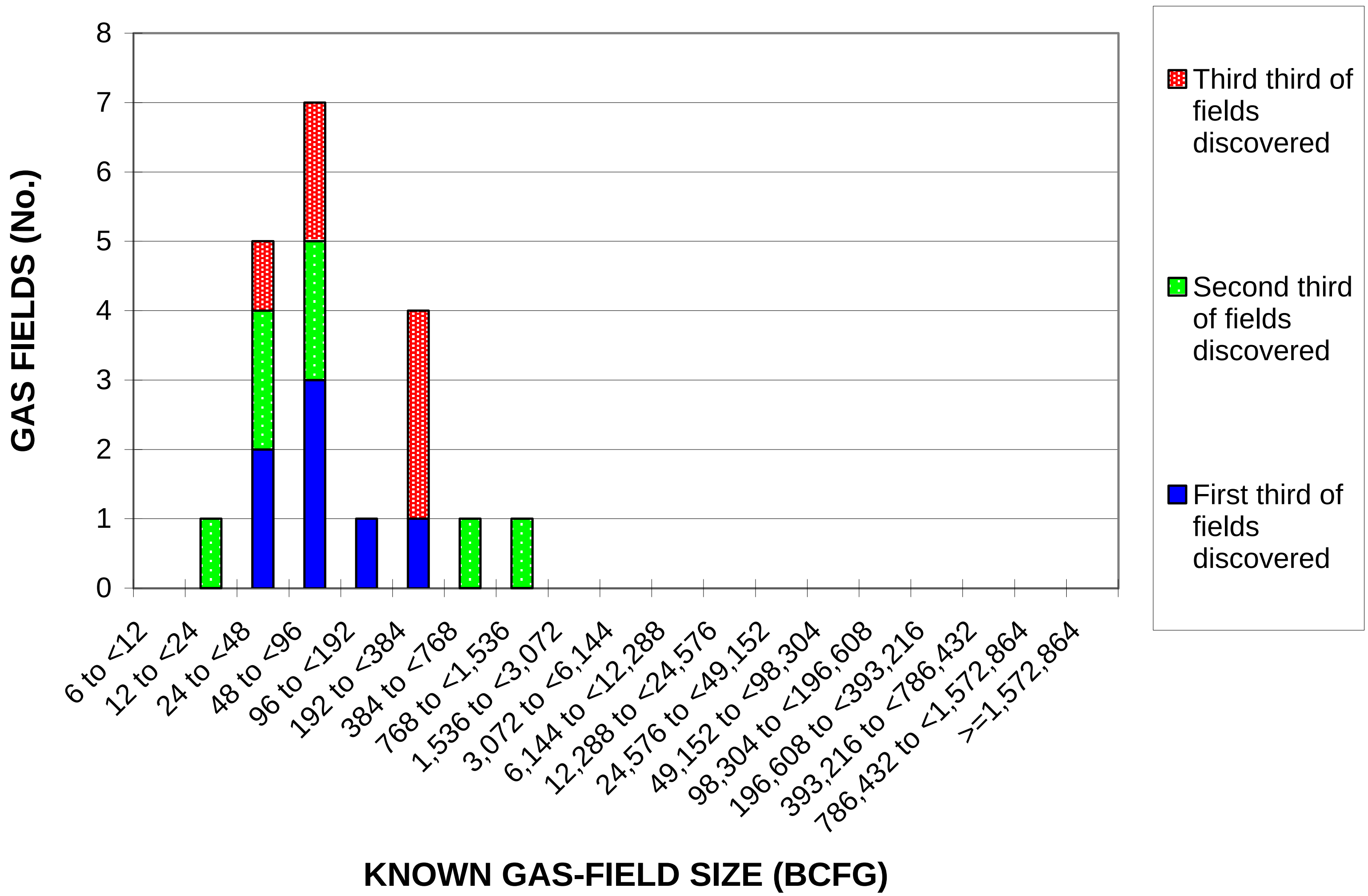


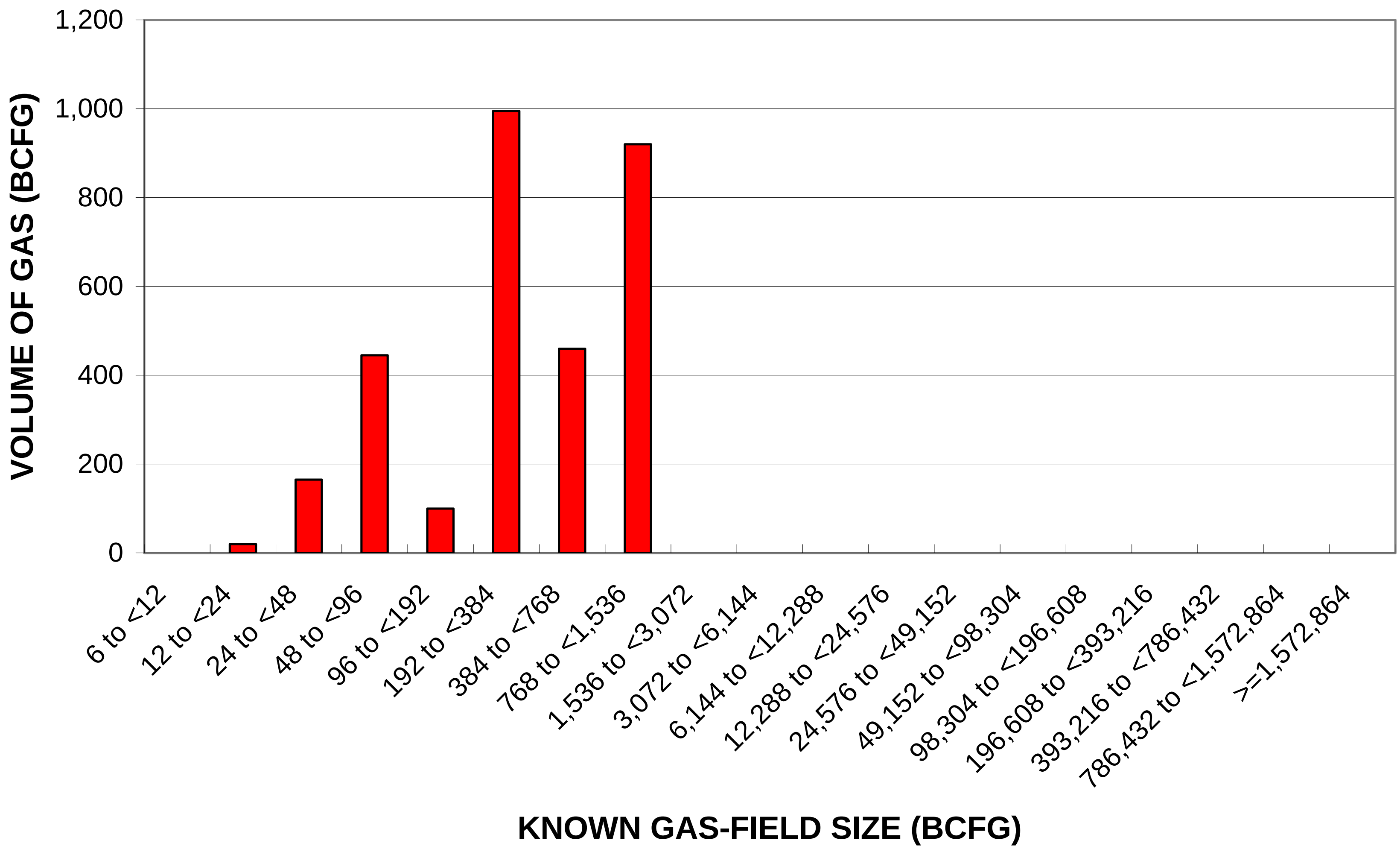
Tanezzuft-Ahnet Structural/Stratigraphic, Assessment Unit 20580201



Tanezzuft-Ahnet Structural/Stratigraphic, Assessment Unit 20580201



Tanezzuft-Ahnet Structural/Stratigraphic, Assessment Unit 20580201



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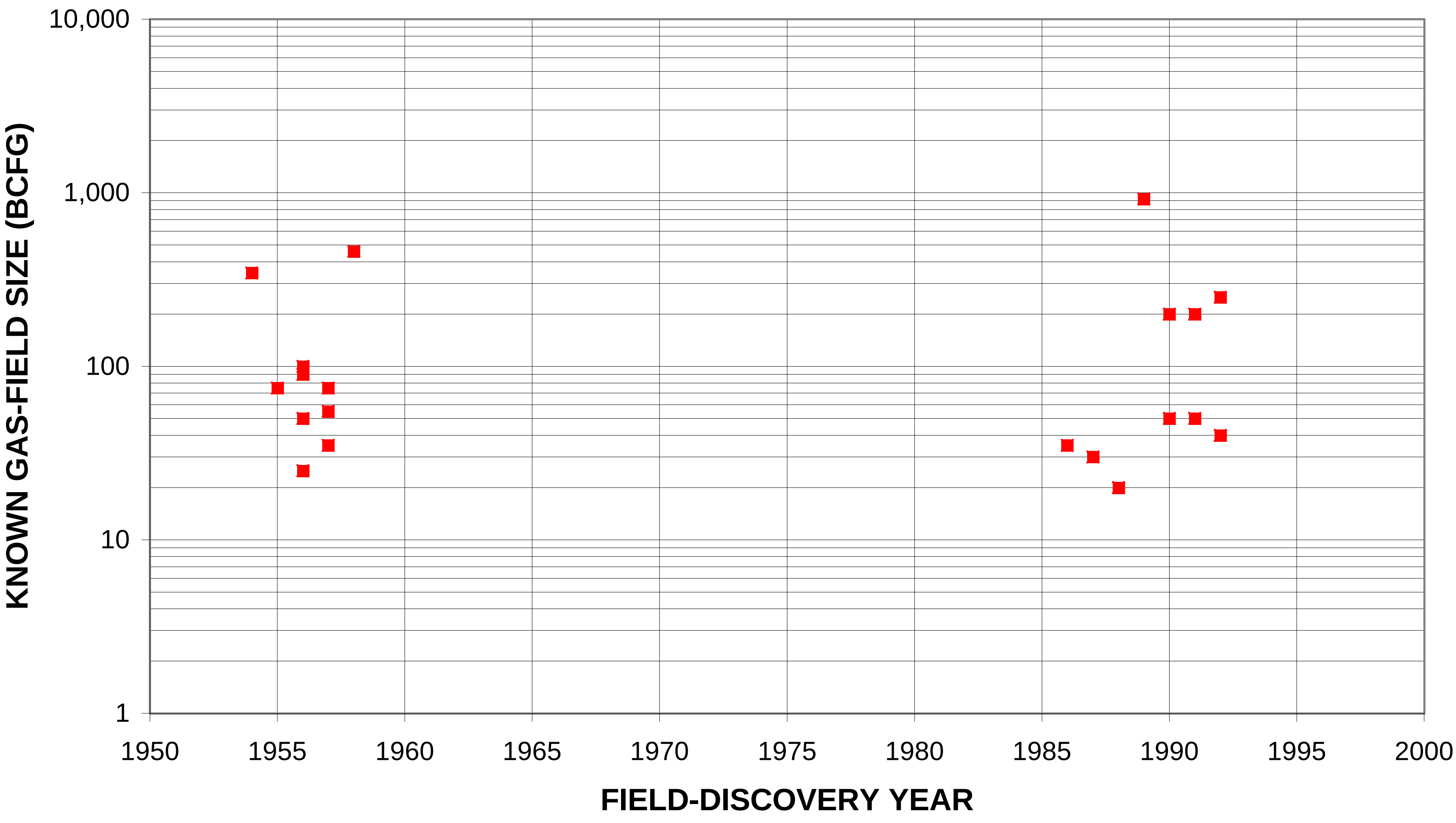
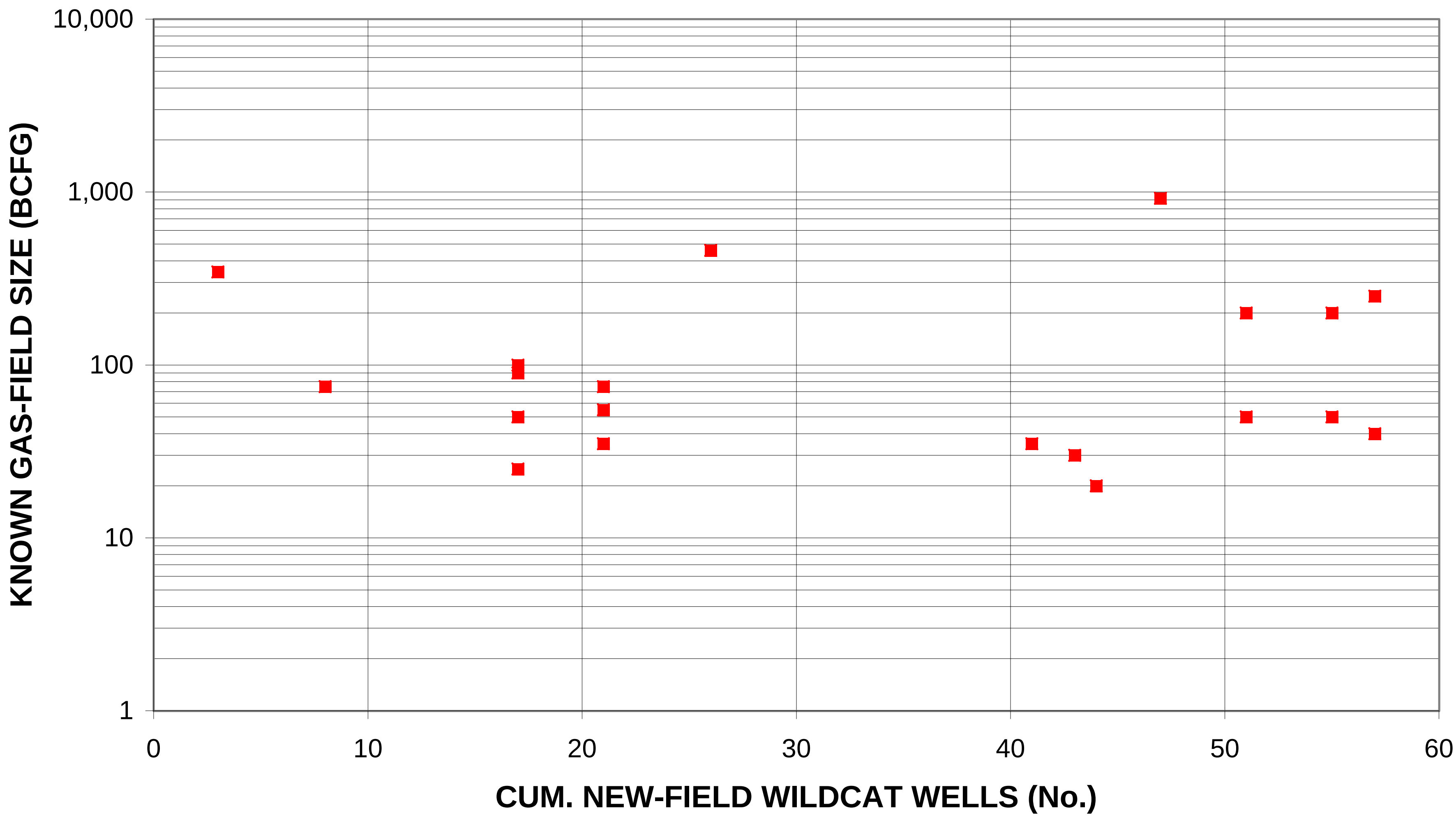
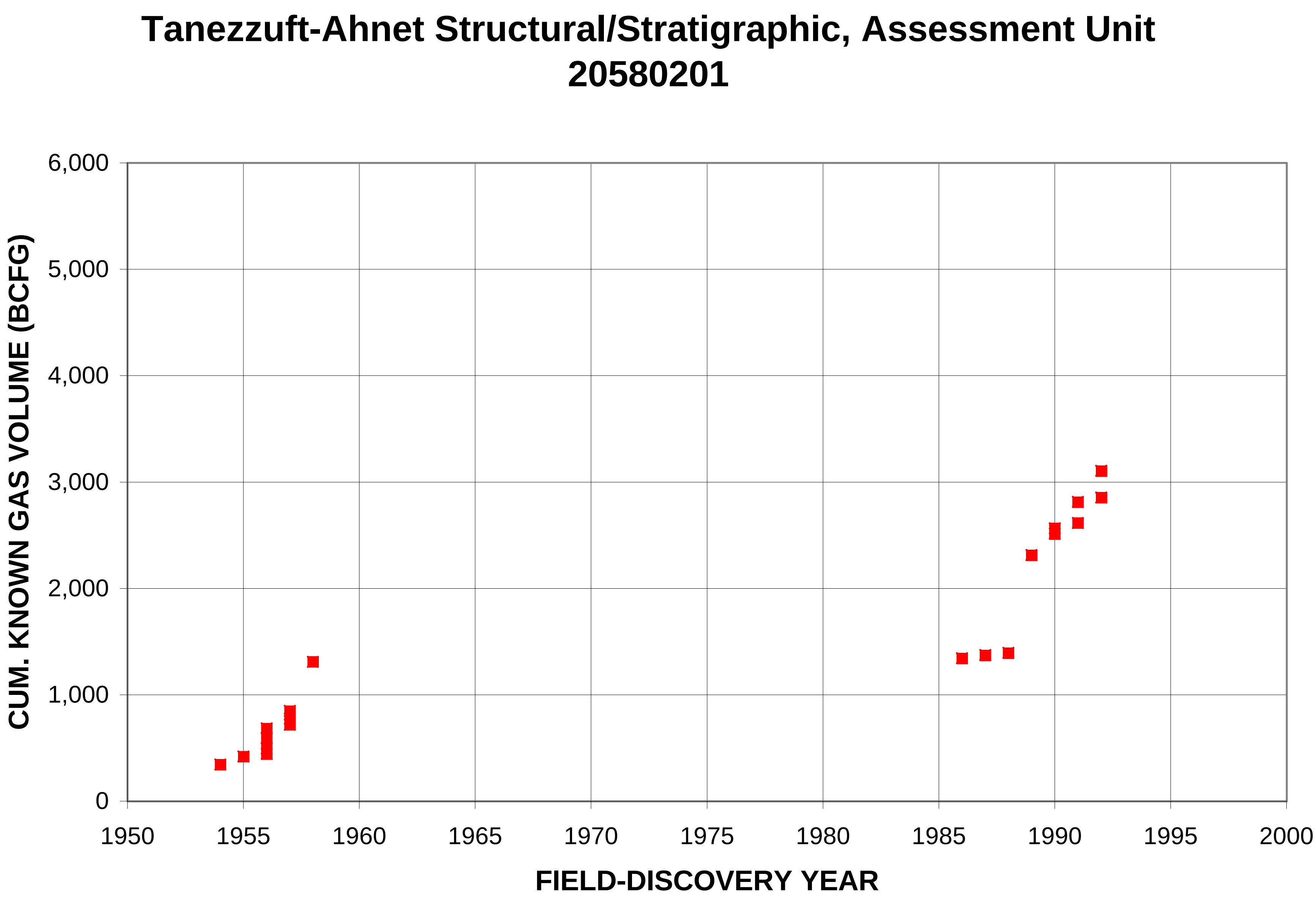
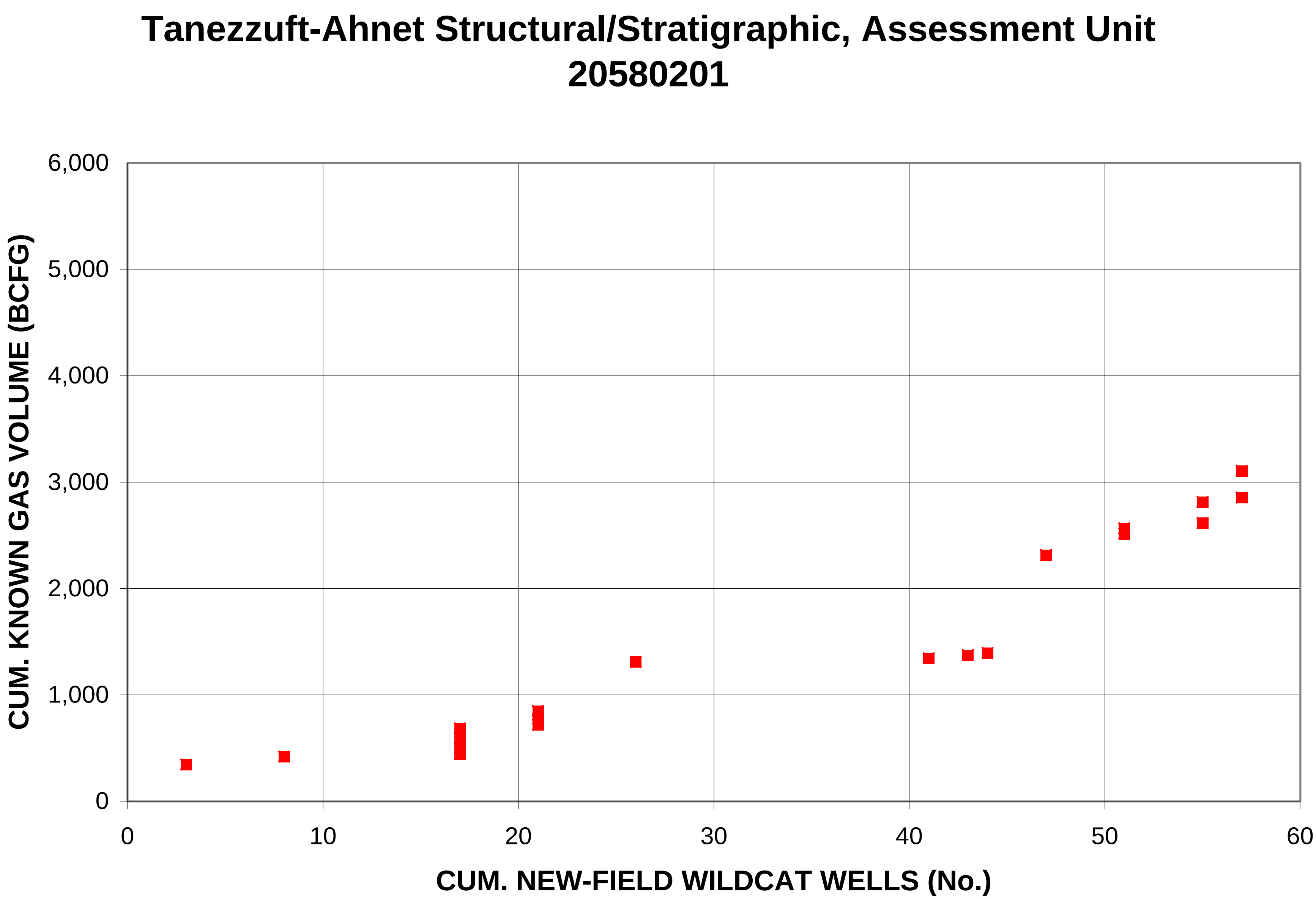


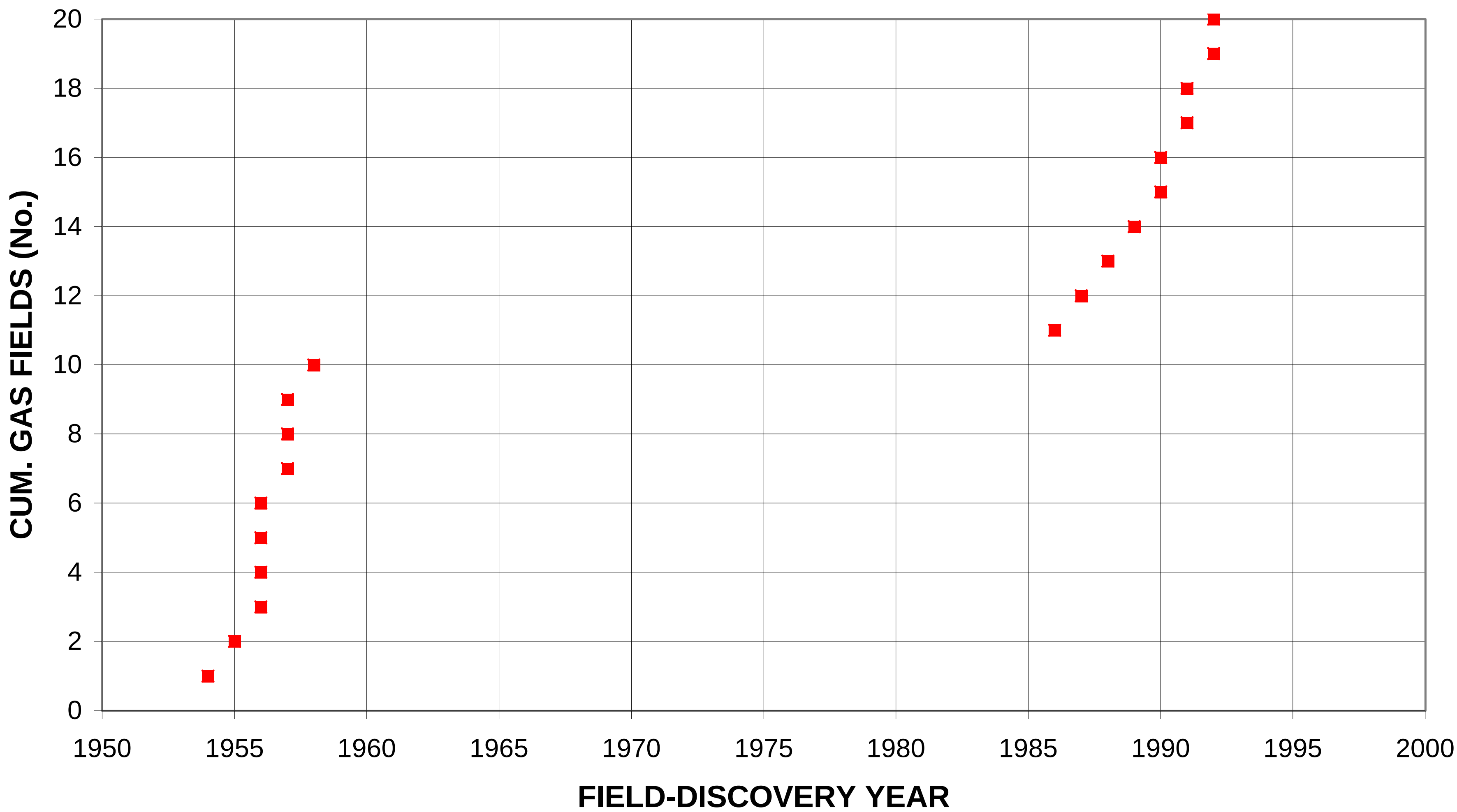
Tanezzuft-Ahnet Structural/Stratigraphic, Assessment Unit 20580201



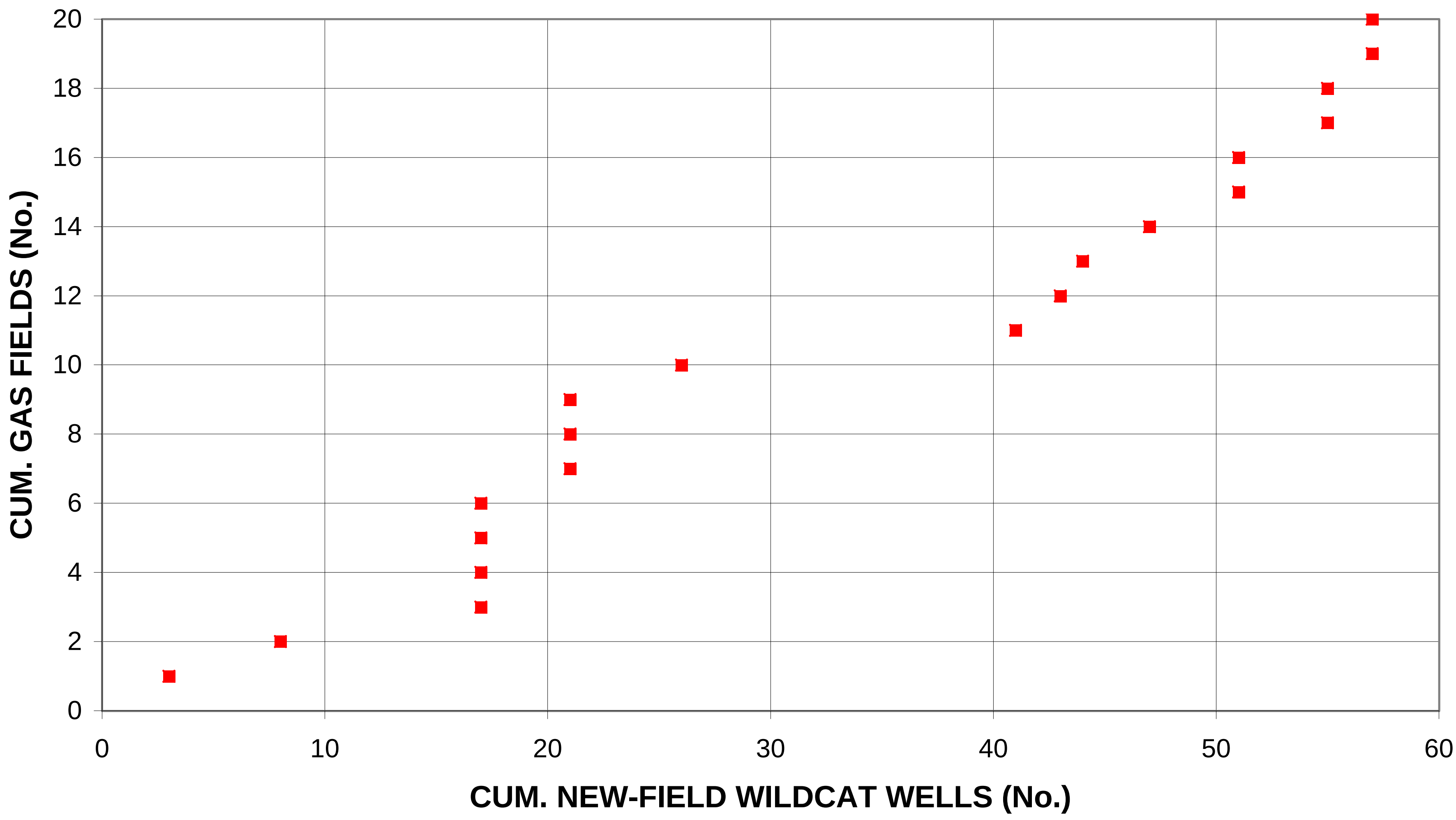

Tanezzuft-Ahnet Structural/Stratigraphic, Assessment Unit 20580201
CUM. KNOWN GAS VOLUME (BCFG)
0
1,000
2,000
3,000
4,000
5,000
6,000
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
FIELD-DISCOVERY YEAR


Tanezzuft-Ahnet Structural/Stratigraphic, Assessment Unit 20580201
CUM. KNOWN GAS VOLUME (BCFG)
6,000
5,000
4,000
3,000
2,000
1,000
0
0
10
20
30
40
50
60
CUM. NEW-FIELD WILDCAT WELLS (No.)

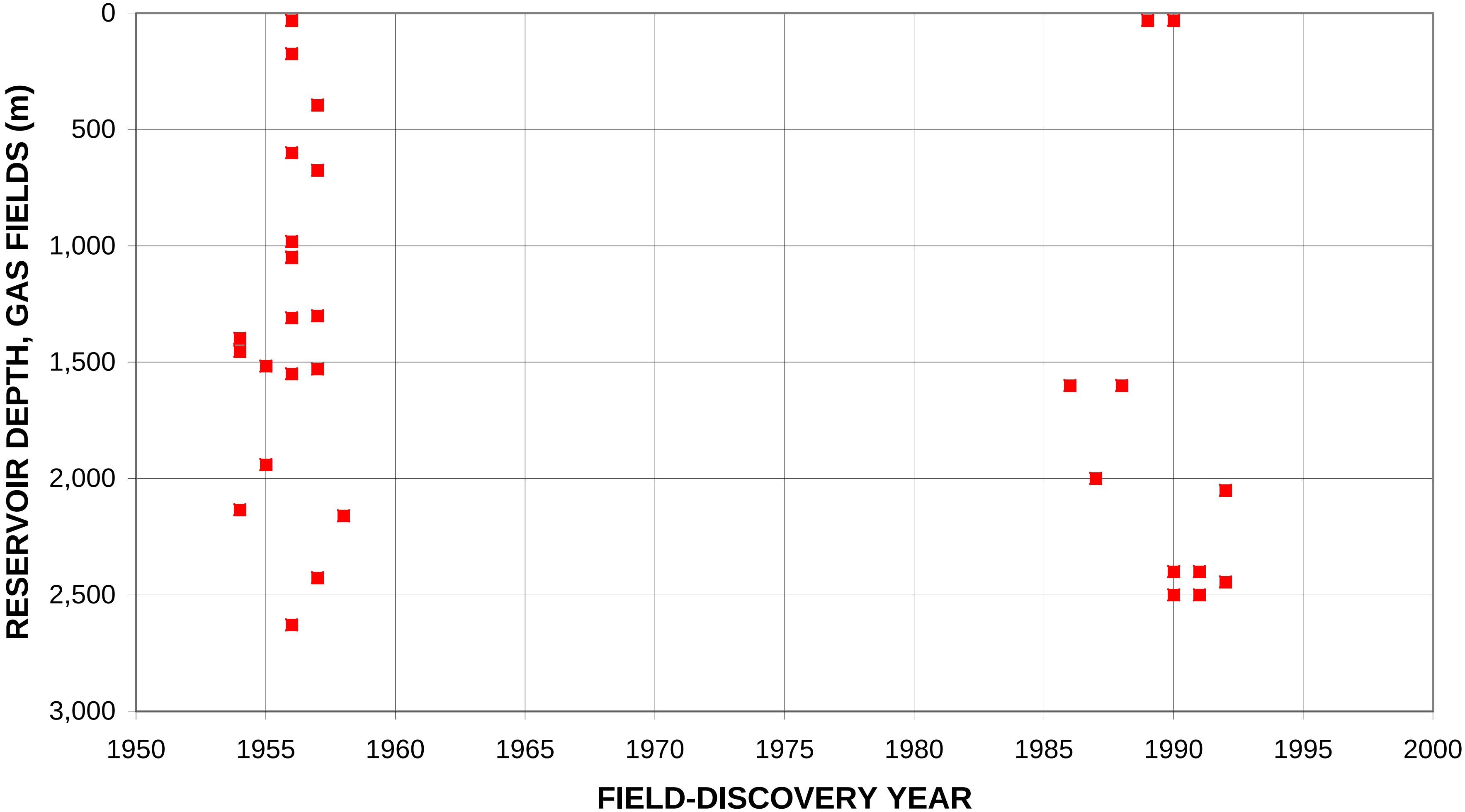
Tanezzuft-Ahnet Structural/Stratigraphic, Assessment Unit 20580201



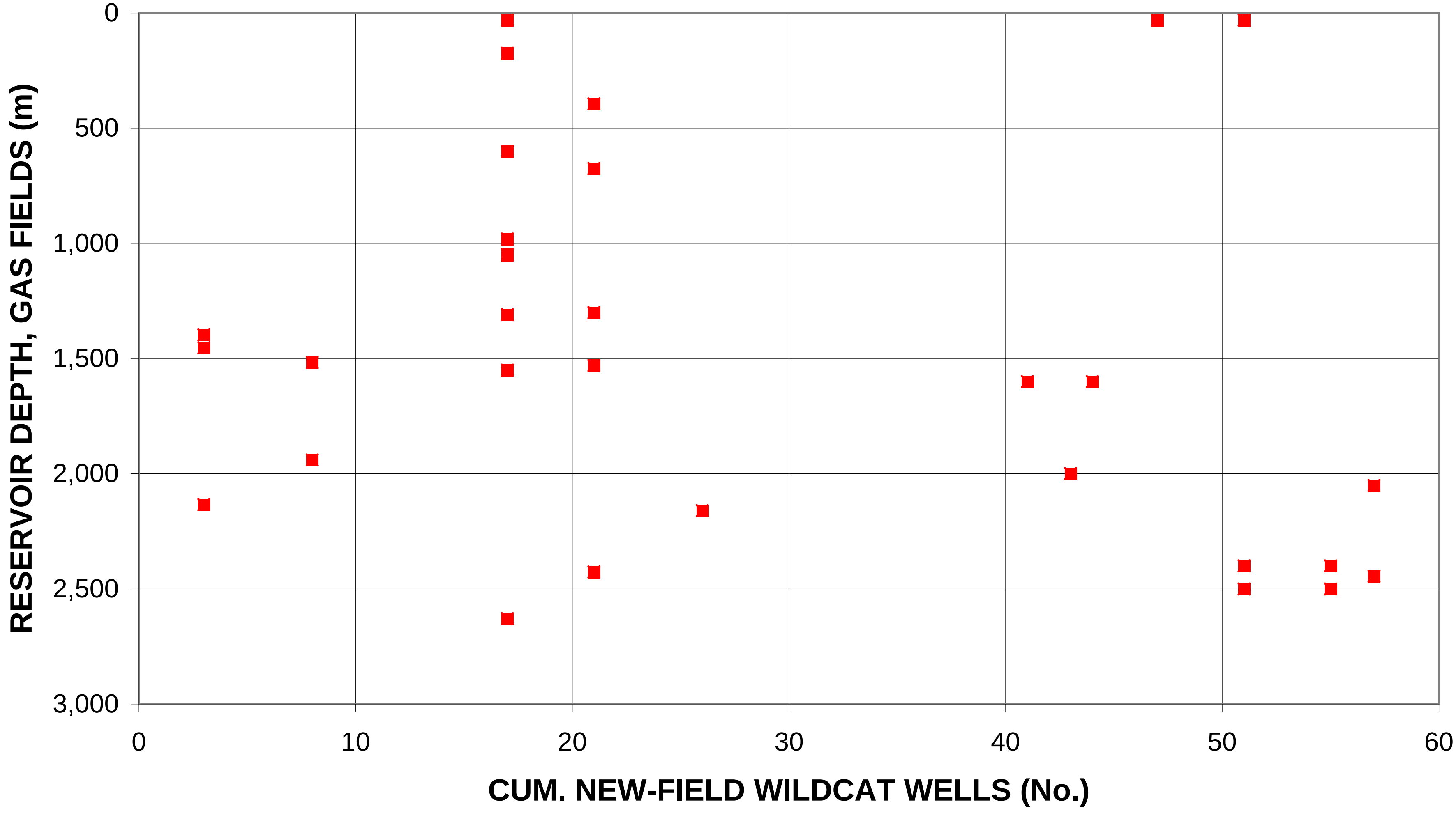
Tanezzuft-Ahnet Structural/Stratigraphic, Assessment Unit 20580201



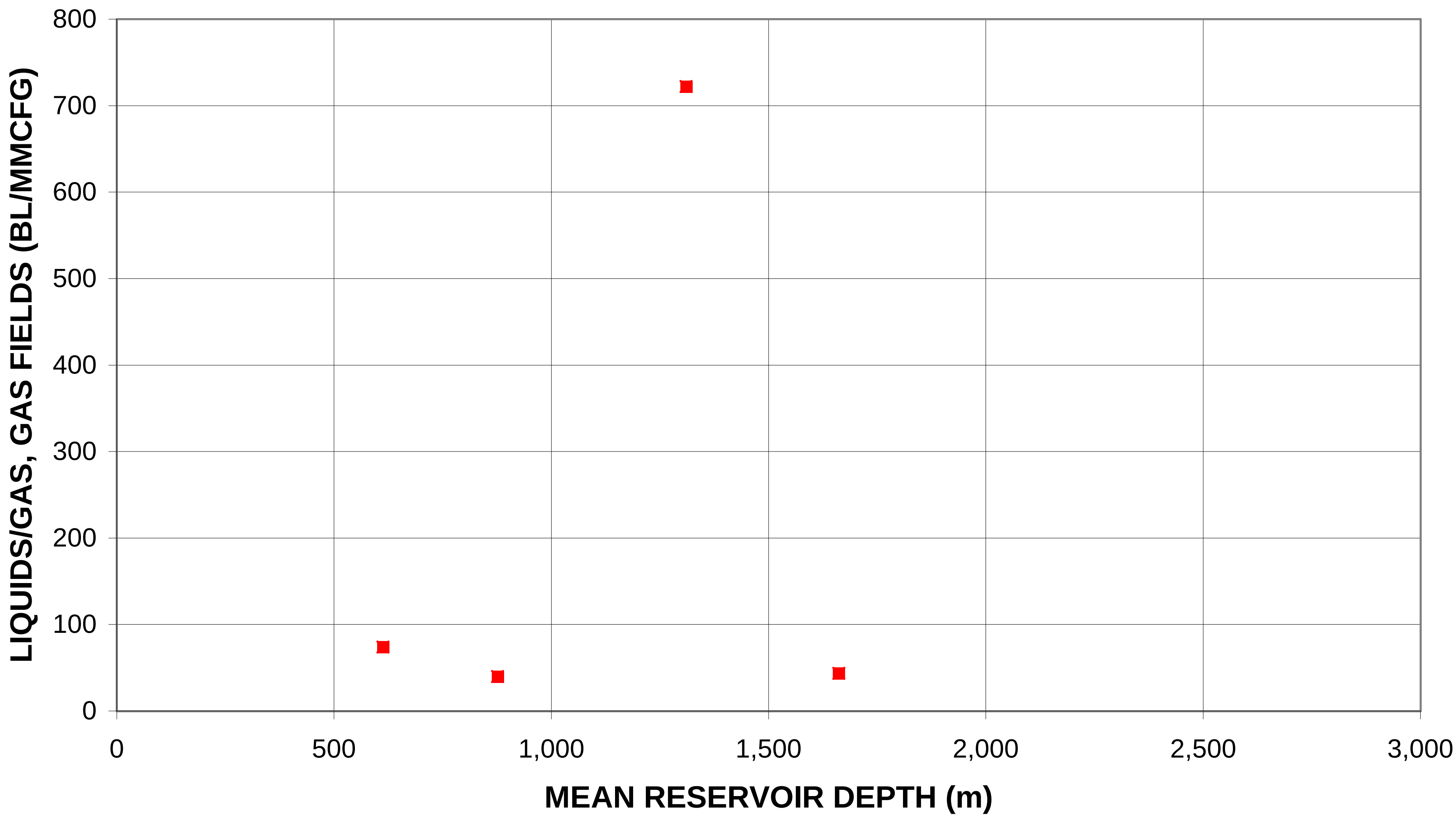
Tanezzuft-Ahnet Structural/Stratigraphic, Assessment Unit 20580201



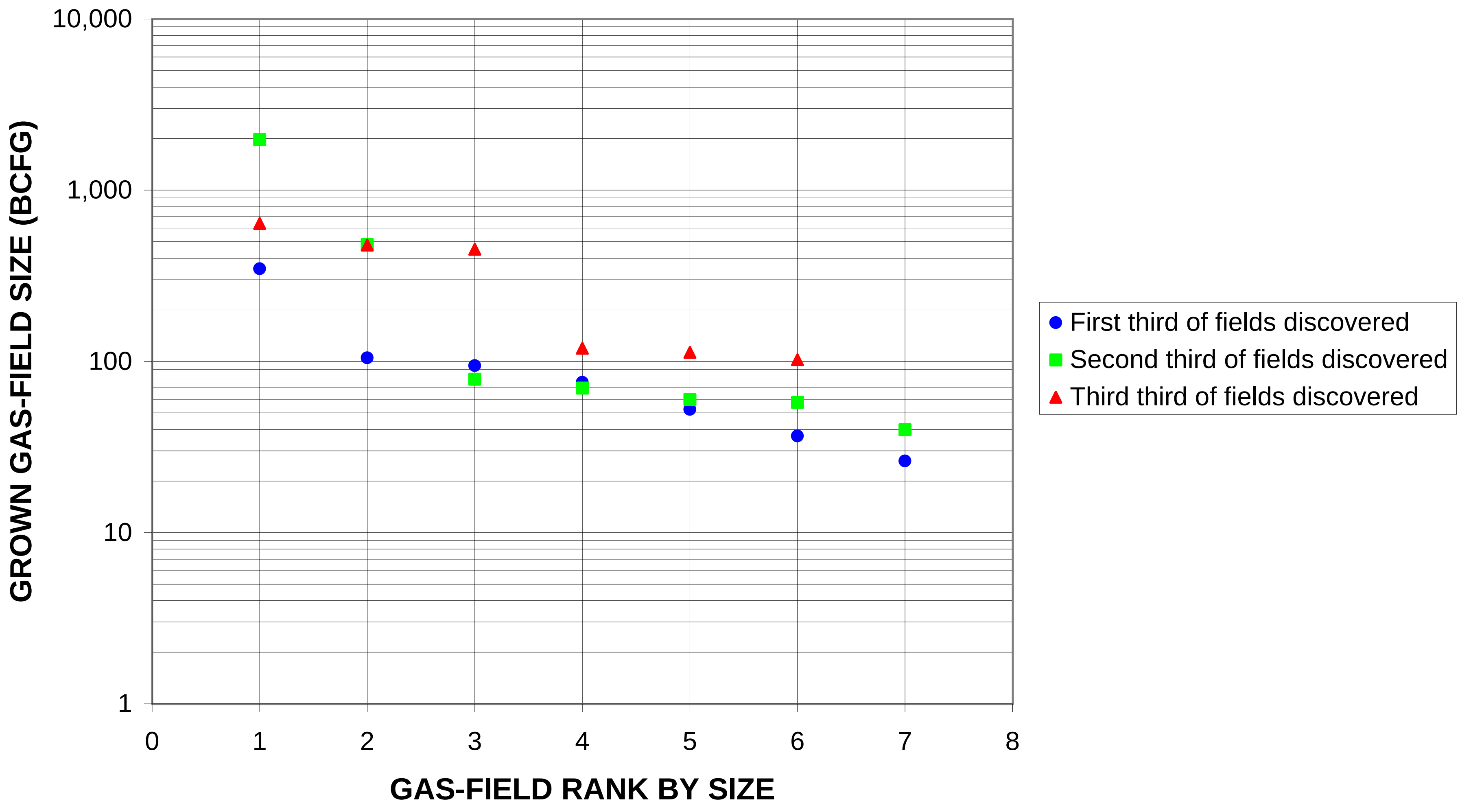
Tanezzuft-Ahnet Structural/Stratigraphic, Assessment Unit 20580201



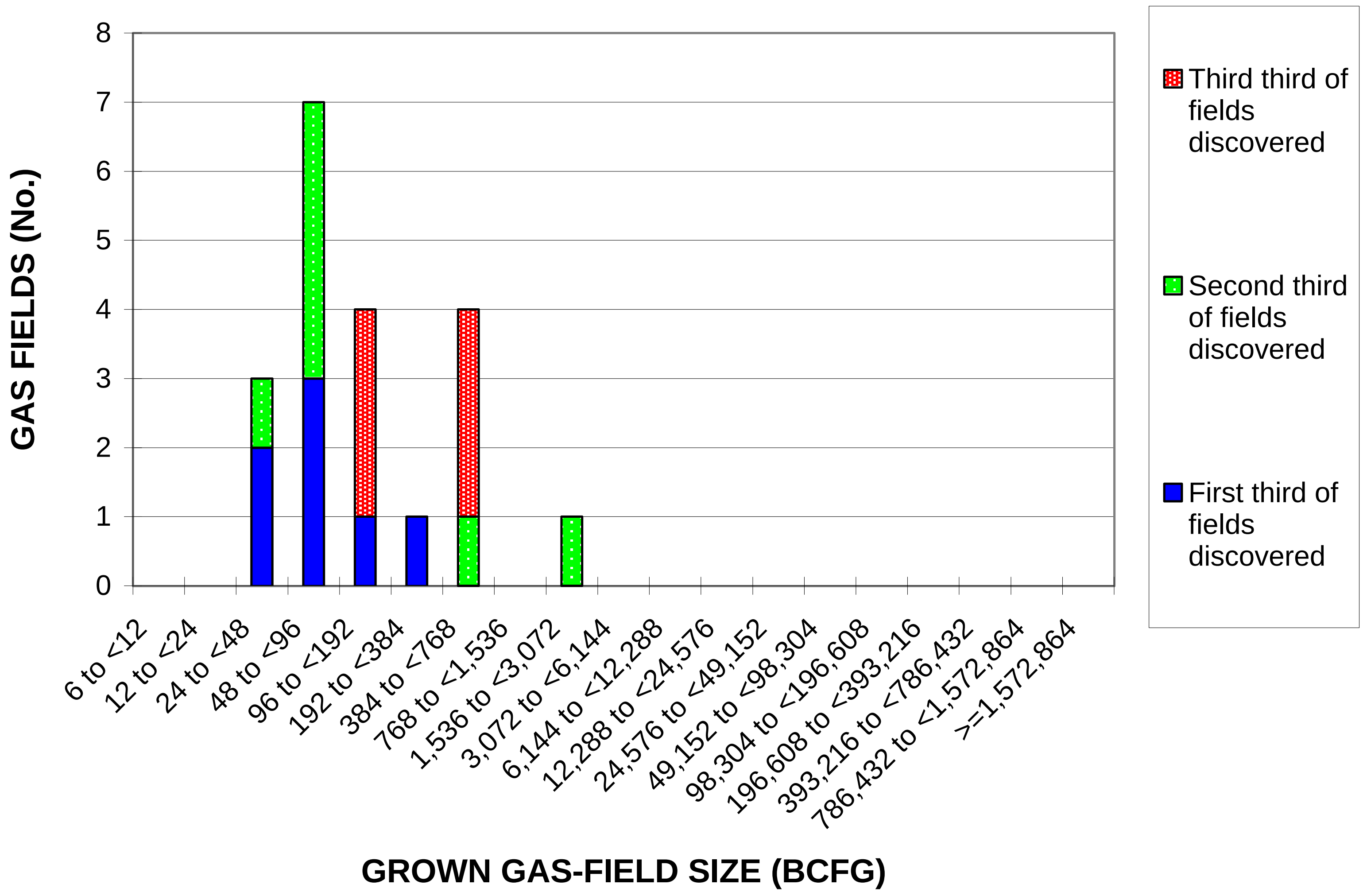
Tanezzuft-Ahnet Structural/Stratigraphic, Assessment Unit 20580201



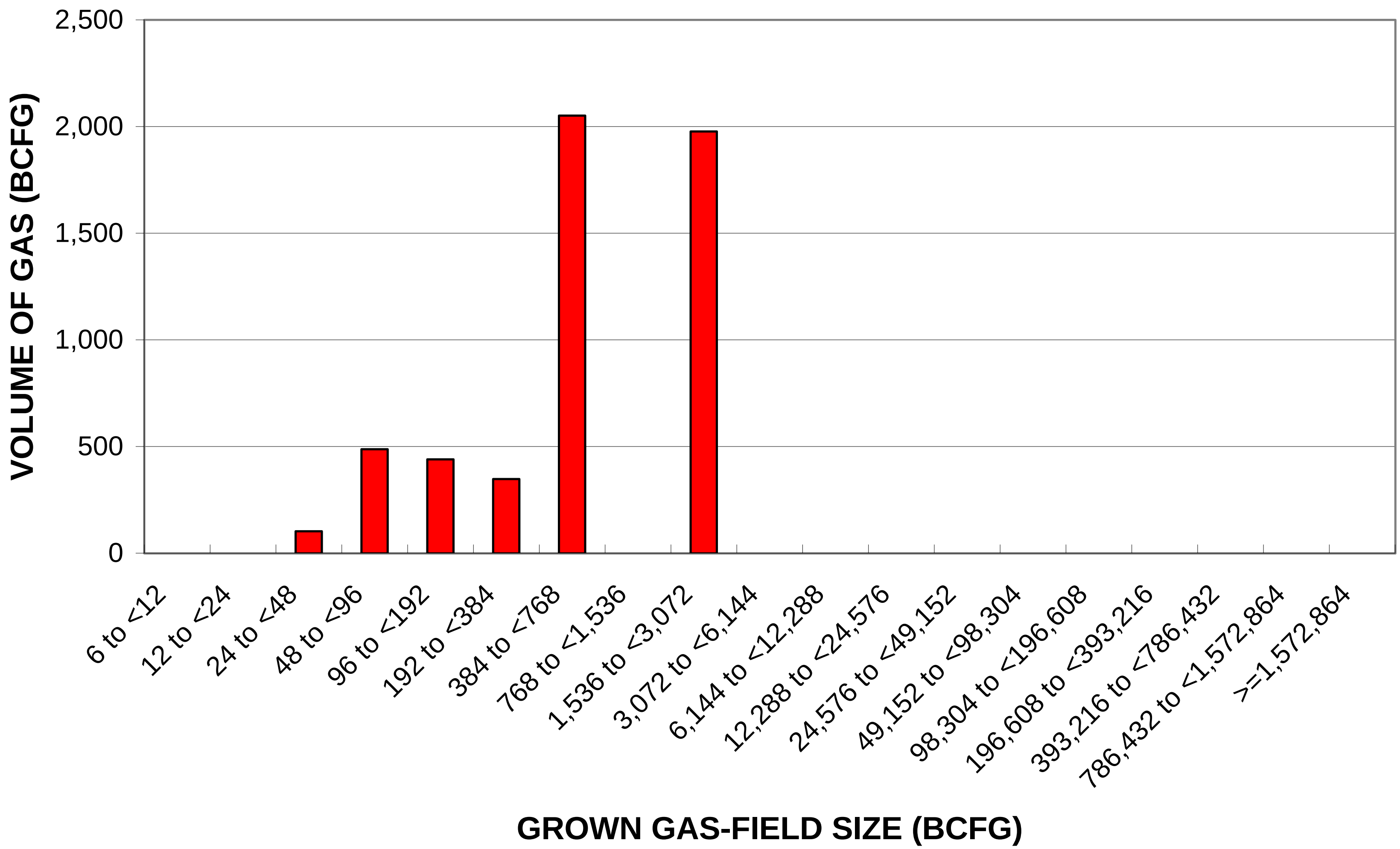
Tanezzuft-Ahnet Structural/Stratigraphic, Assessment Unit 20580201



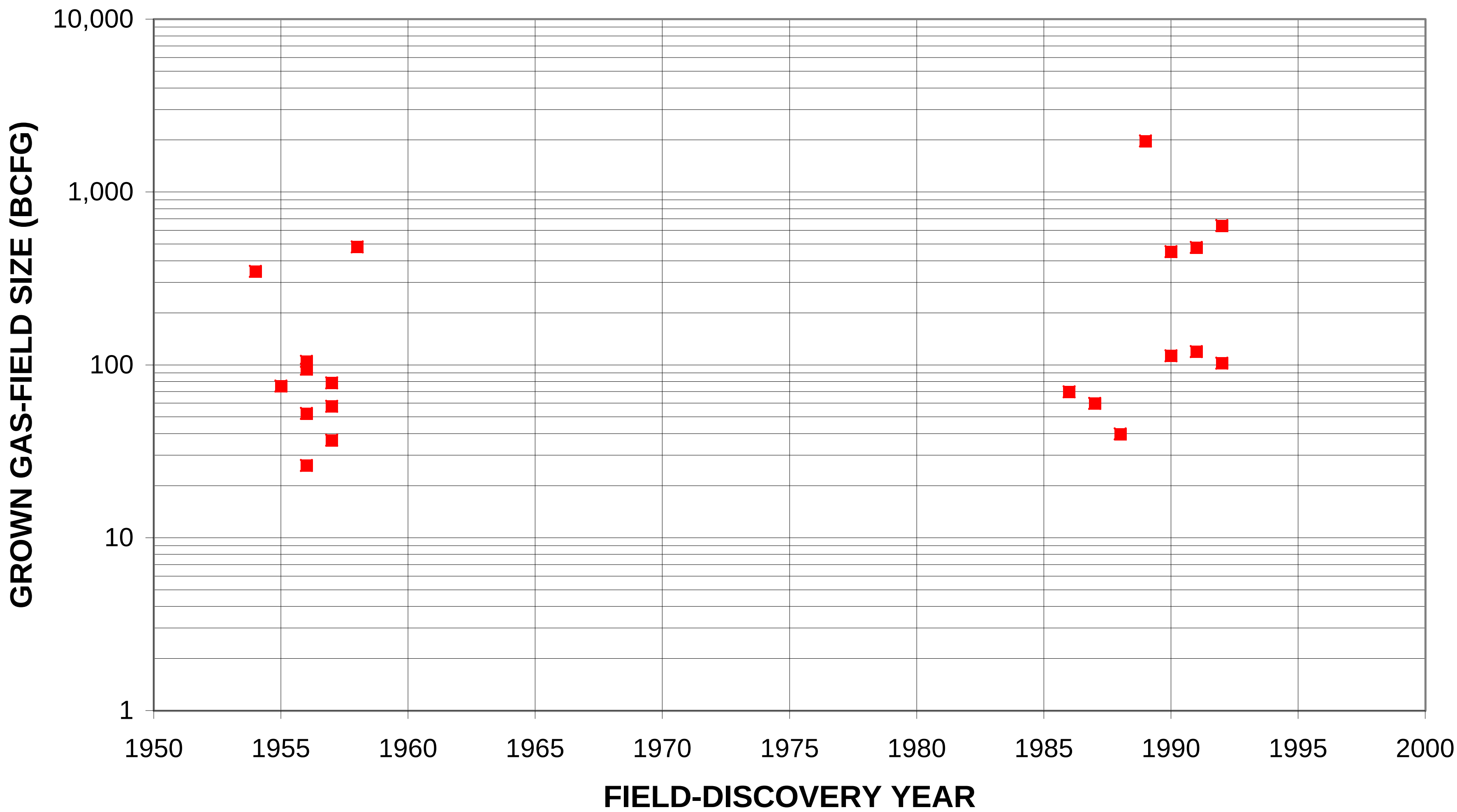
Tanezzuft-Ahnet Structural/Stratigraphic, Assessment Unit 20580201



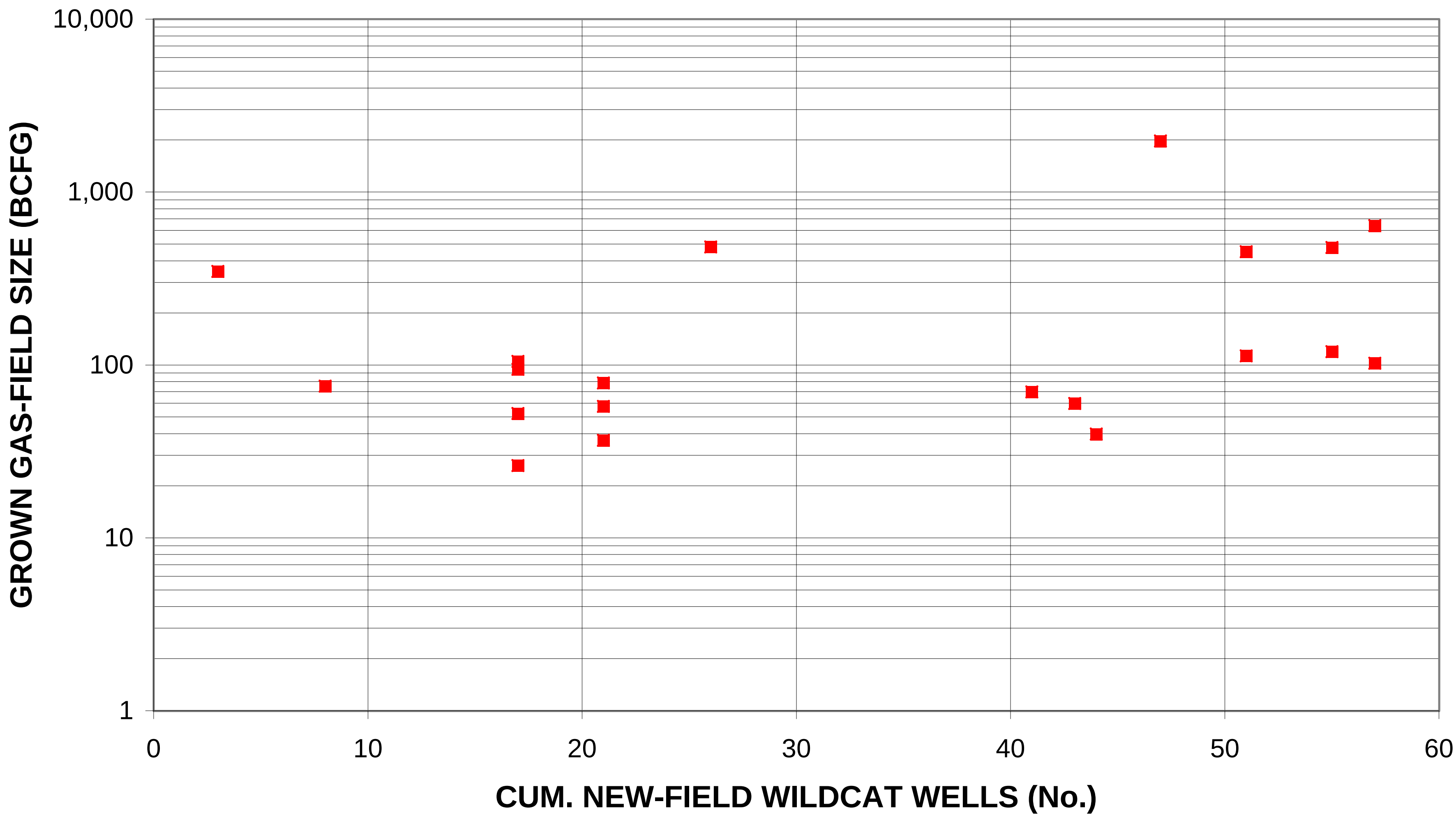
Tanezzuft-Ahnet Structural/Stratigraphic, Assessment Unit 20580201



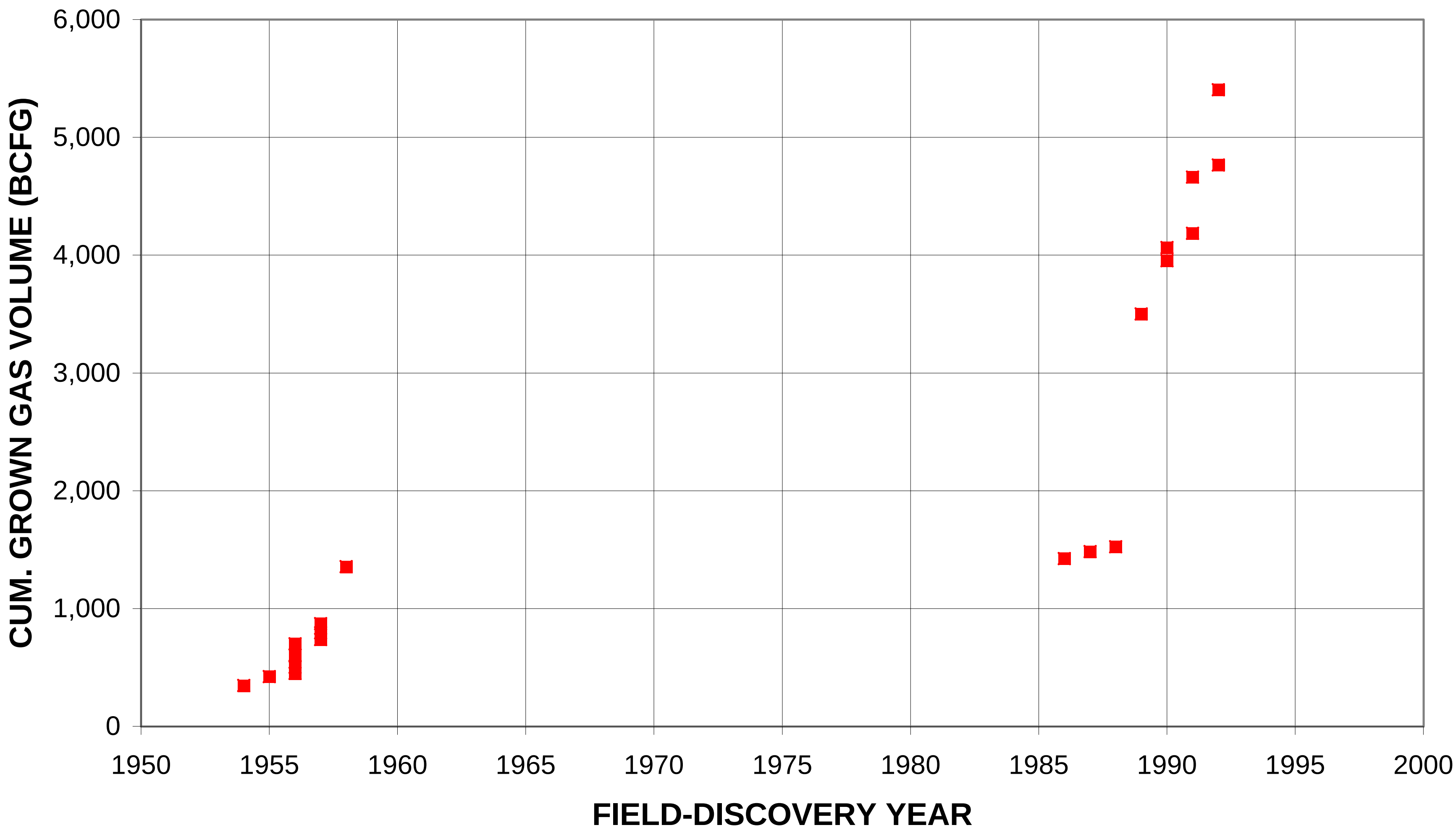
Tanezzuft-Ahnet Structural/Stratigraphic, Assessment Unit 20580201



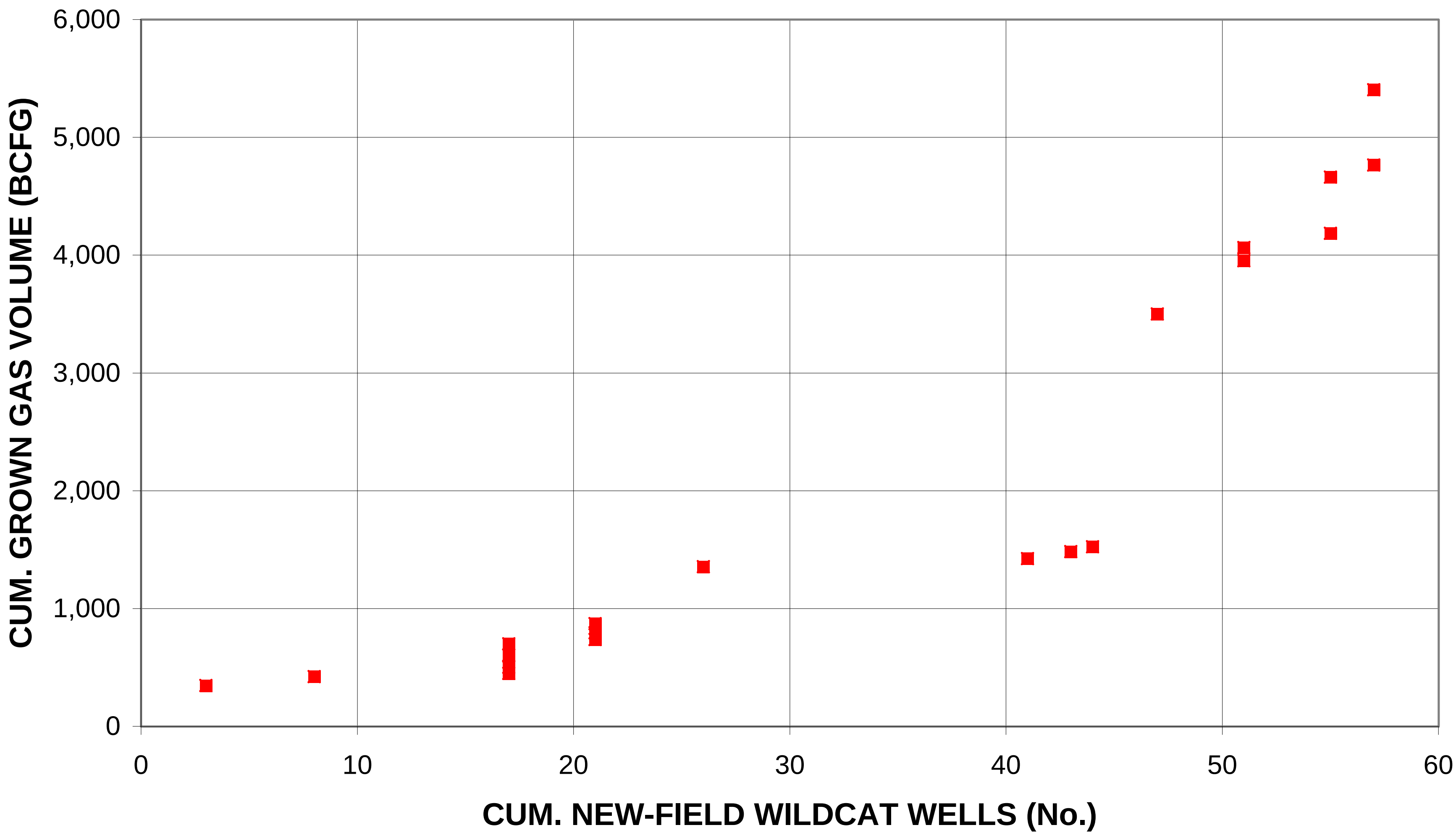
Tanezzuft-Ahnet Structural/Stratigraphic, Assessment Unit 20580201



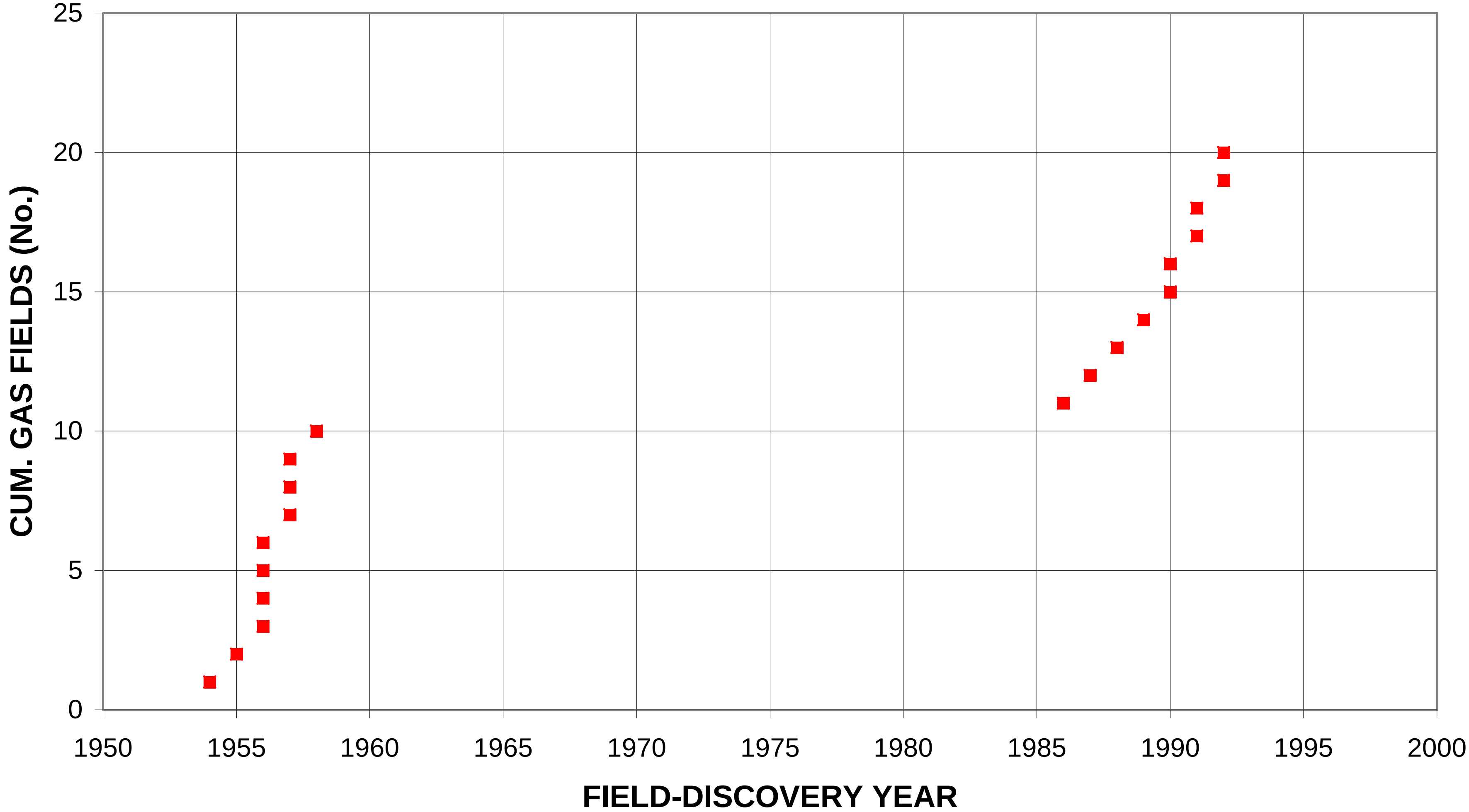
Tanezzuft-Ahnet Structural/Stratigraphic, Assessment Unit 20580201



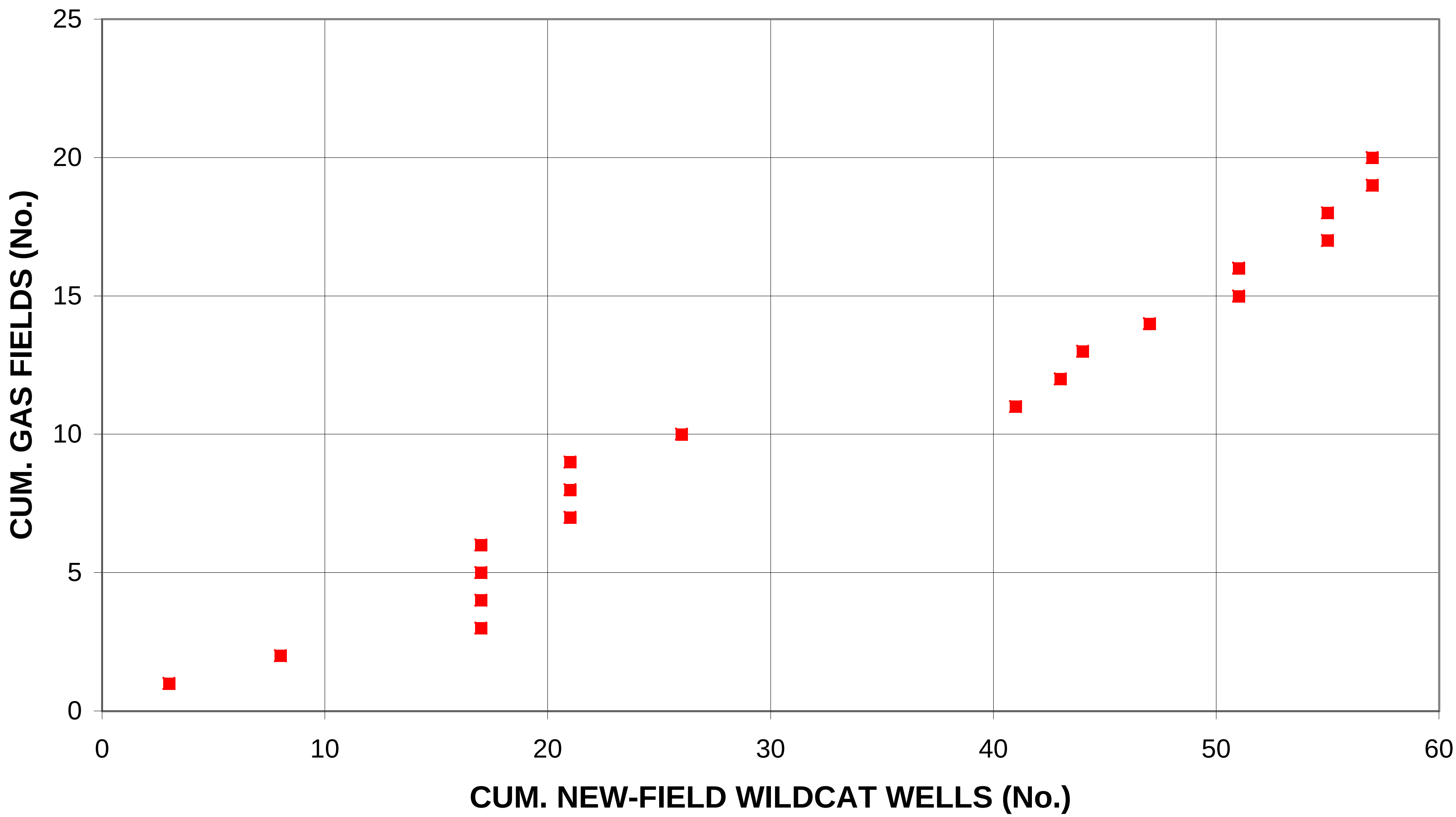
Tanezzuft-Ahnet Structural/Stratigraphic, Assessment Unit 20580201



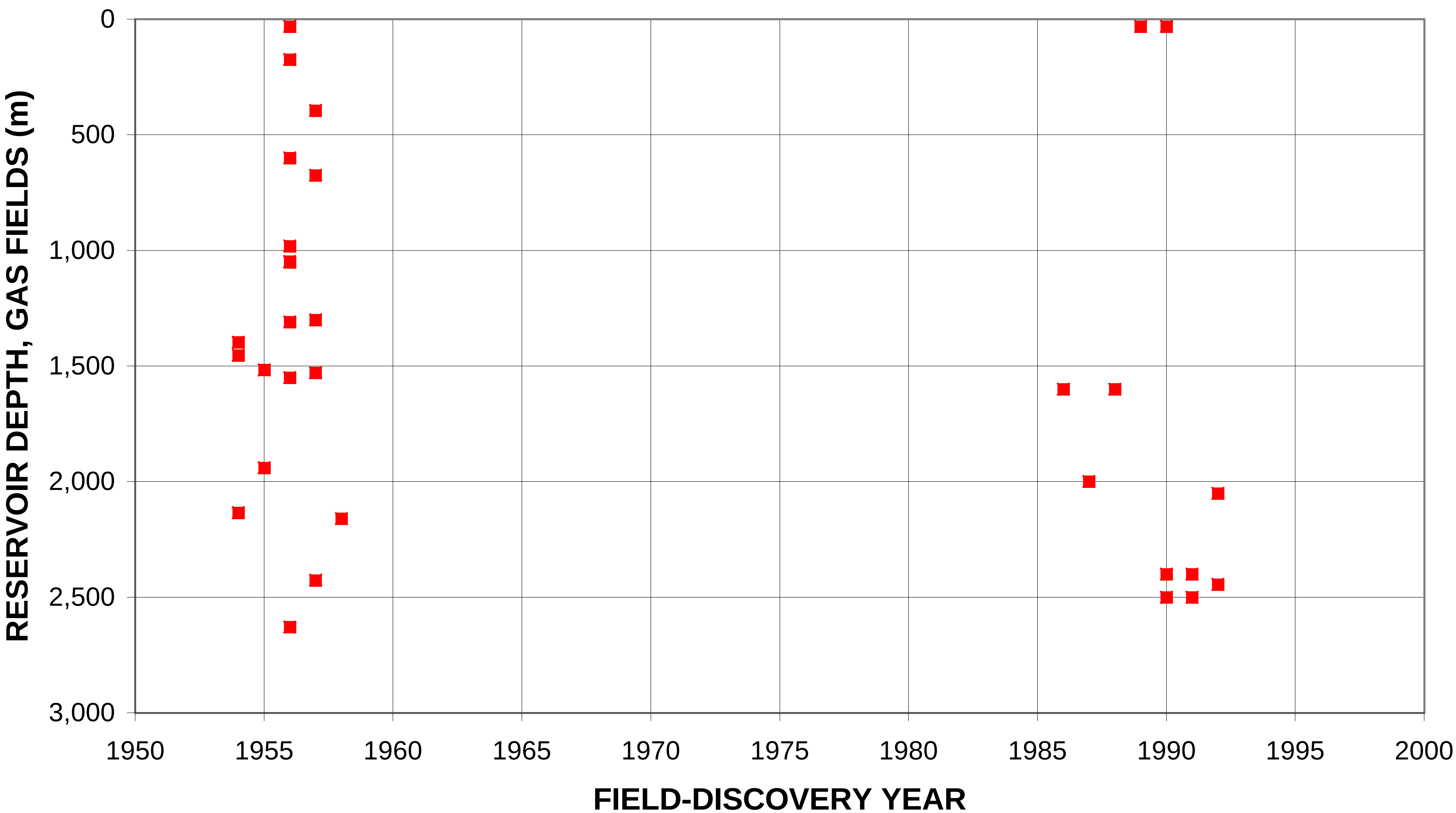
Tanezzuft-Ahnet Structural/Stratigraphic, Assessment Unit 20580201



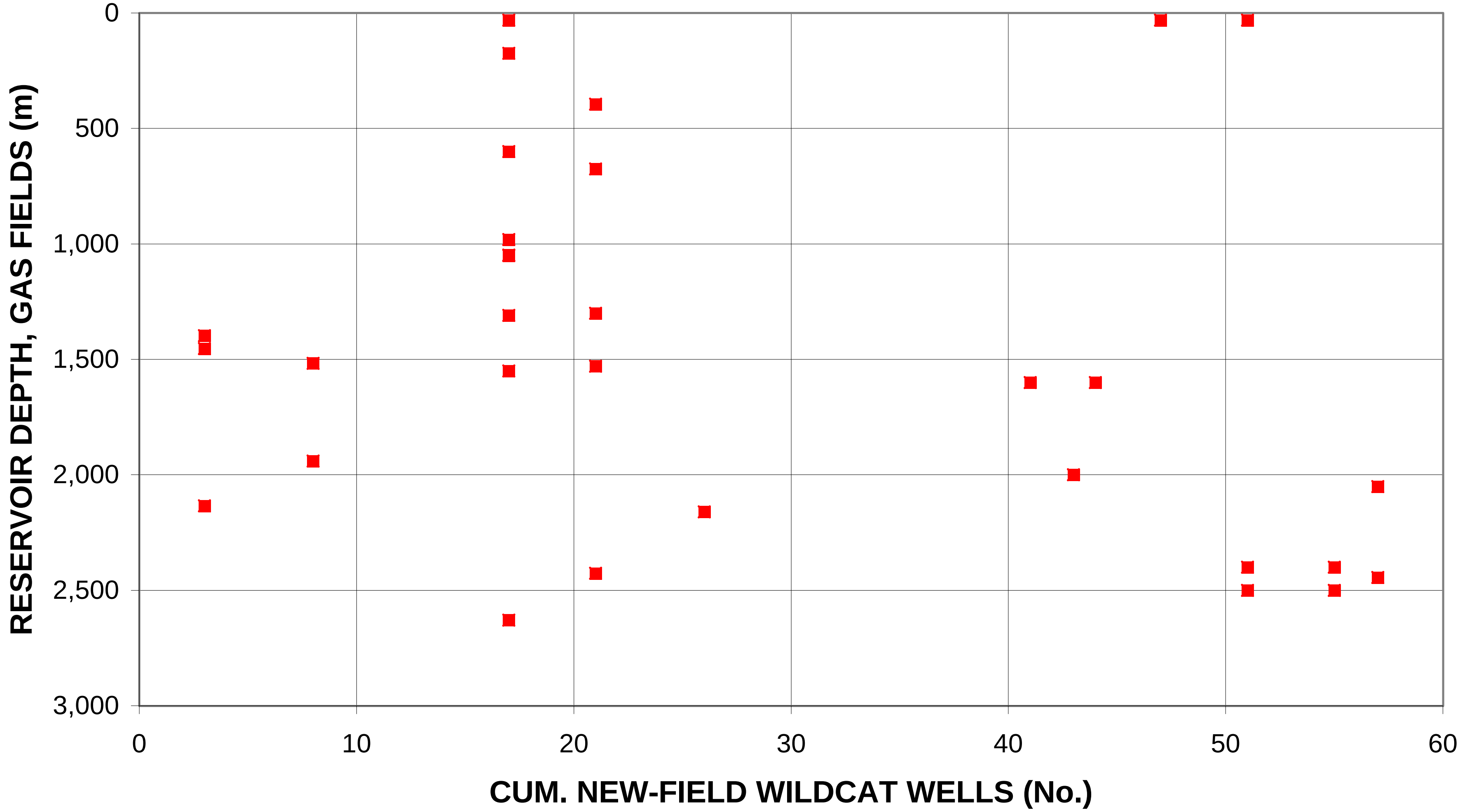
Tanezzuft-Ahnet Structural/Stratigraphic, Assessment Unit 20580201

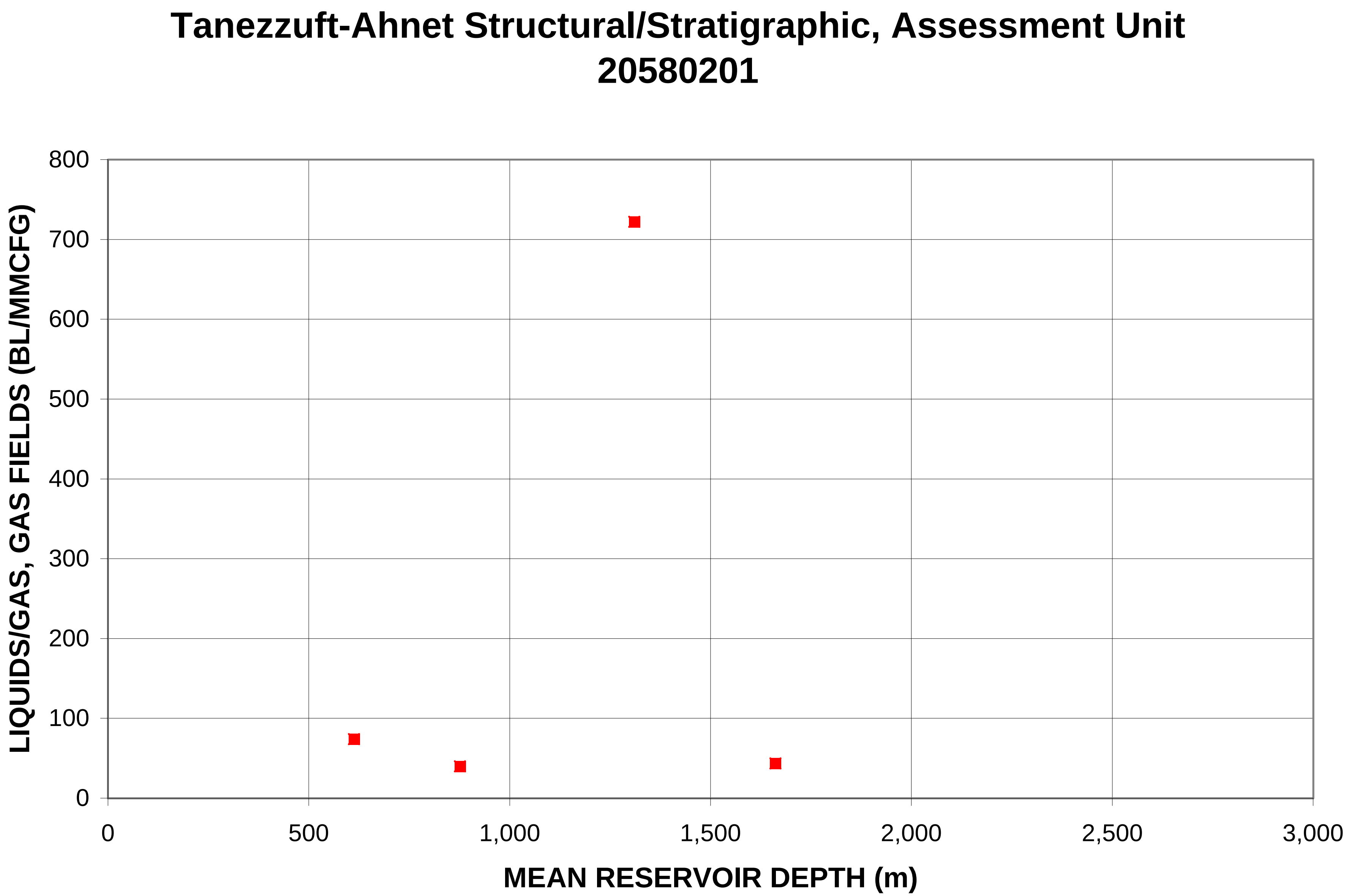


Tanezzuft-Ahnet Structural/Stratigraphic, Assessment Unit 20580201



Tanezzuft-Ahnet Structural/Stratigraphic, Assessment Unit 20580201

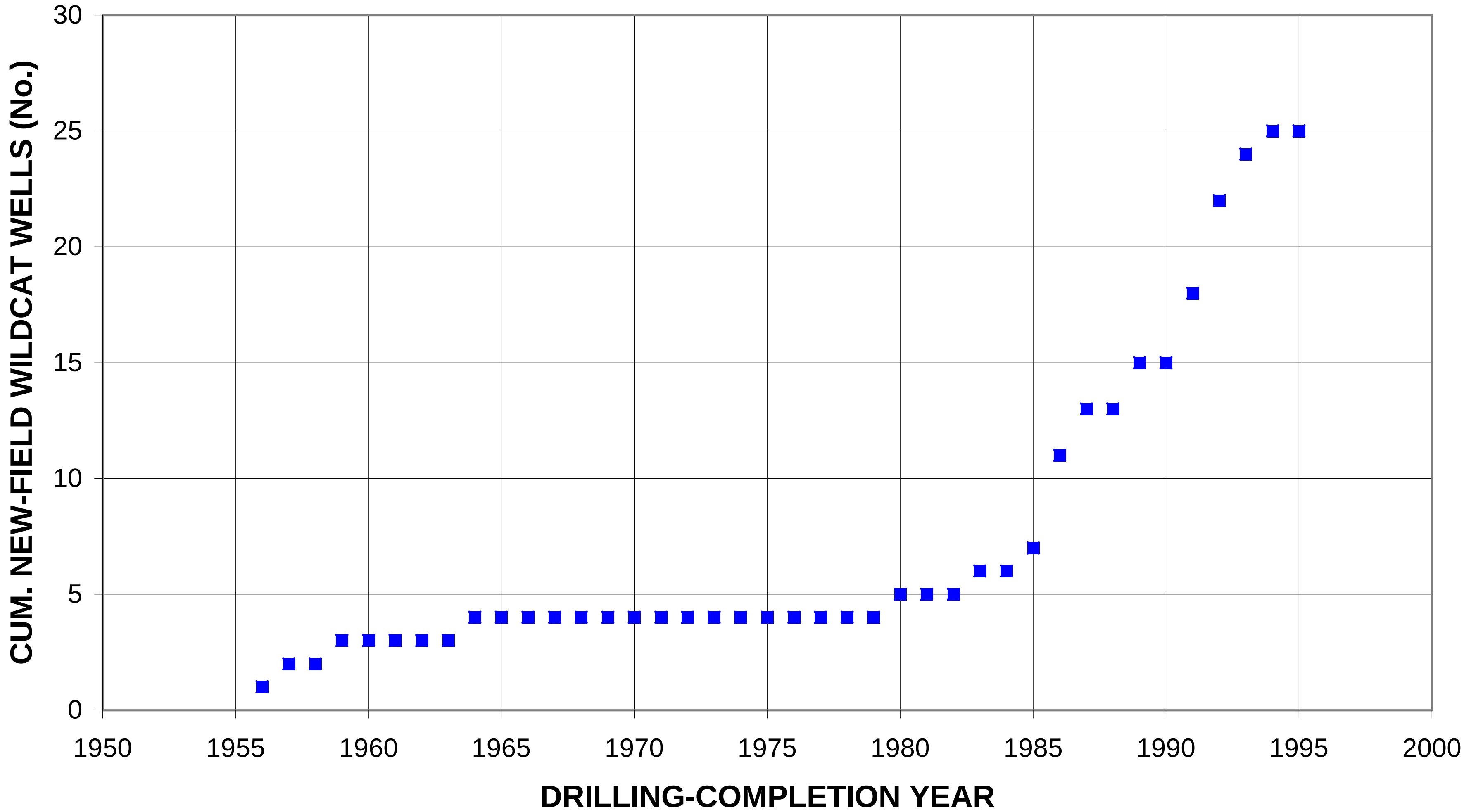




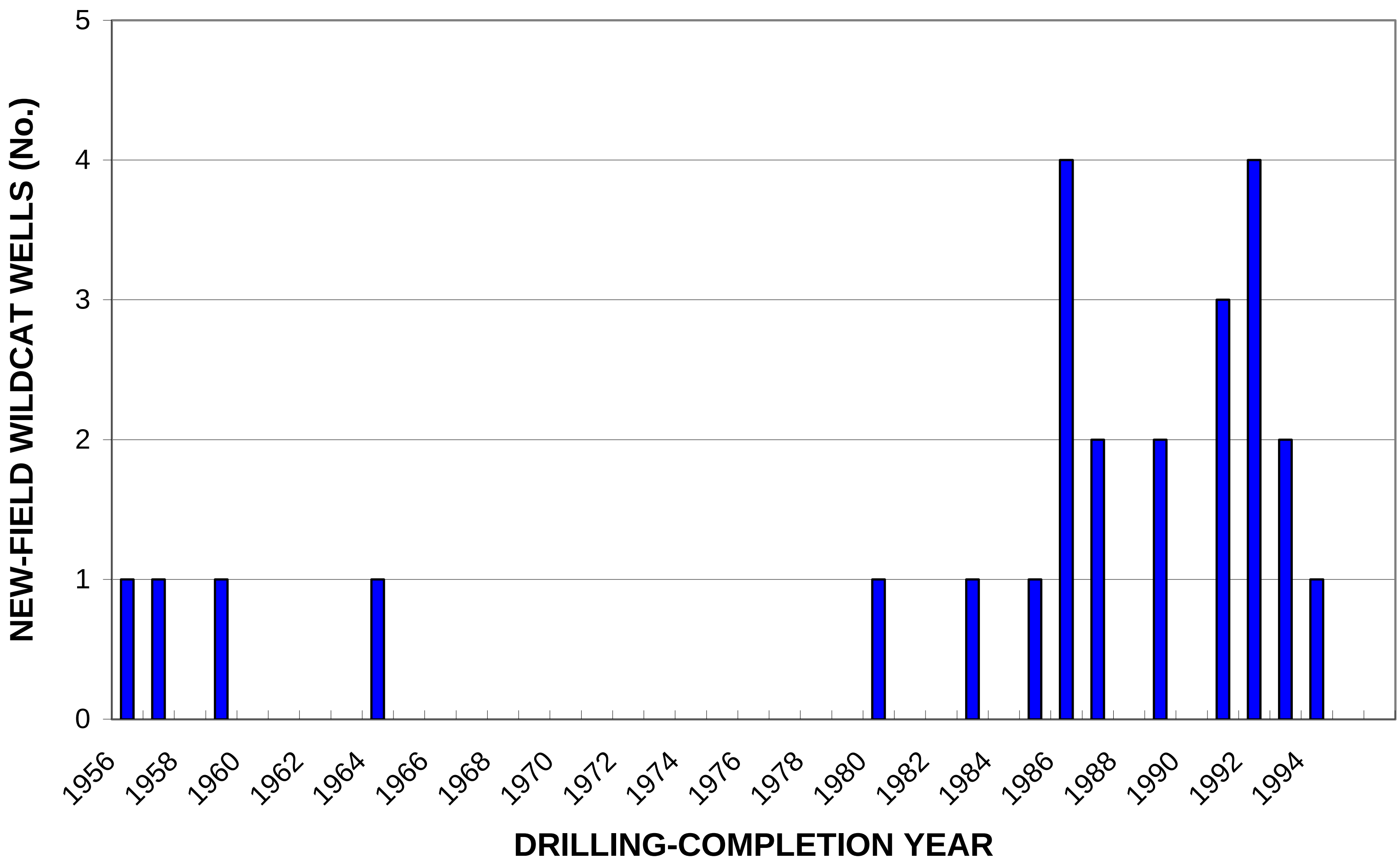
Tanezzuft-Ahnet Structural/Stratigraphic, Assessment Unit 20580201
LIQUIDS/GAS, GAS FIELDS (BL/MMCFG)
800
700
600
500
400
300
200
100
0
0
500
1,000
1,500
2,000
2,500
3,000
MEAN RESERVOIR DEPTH (m)

Appendix 3. Exploration-activity and discovery-history plots for the Tanezzuft-Sbaa Structural/Stratigraphic Assessment Unit.

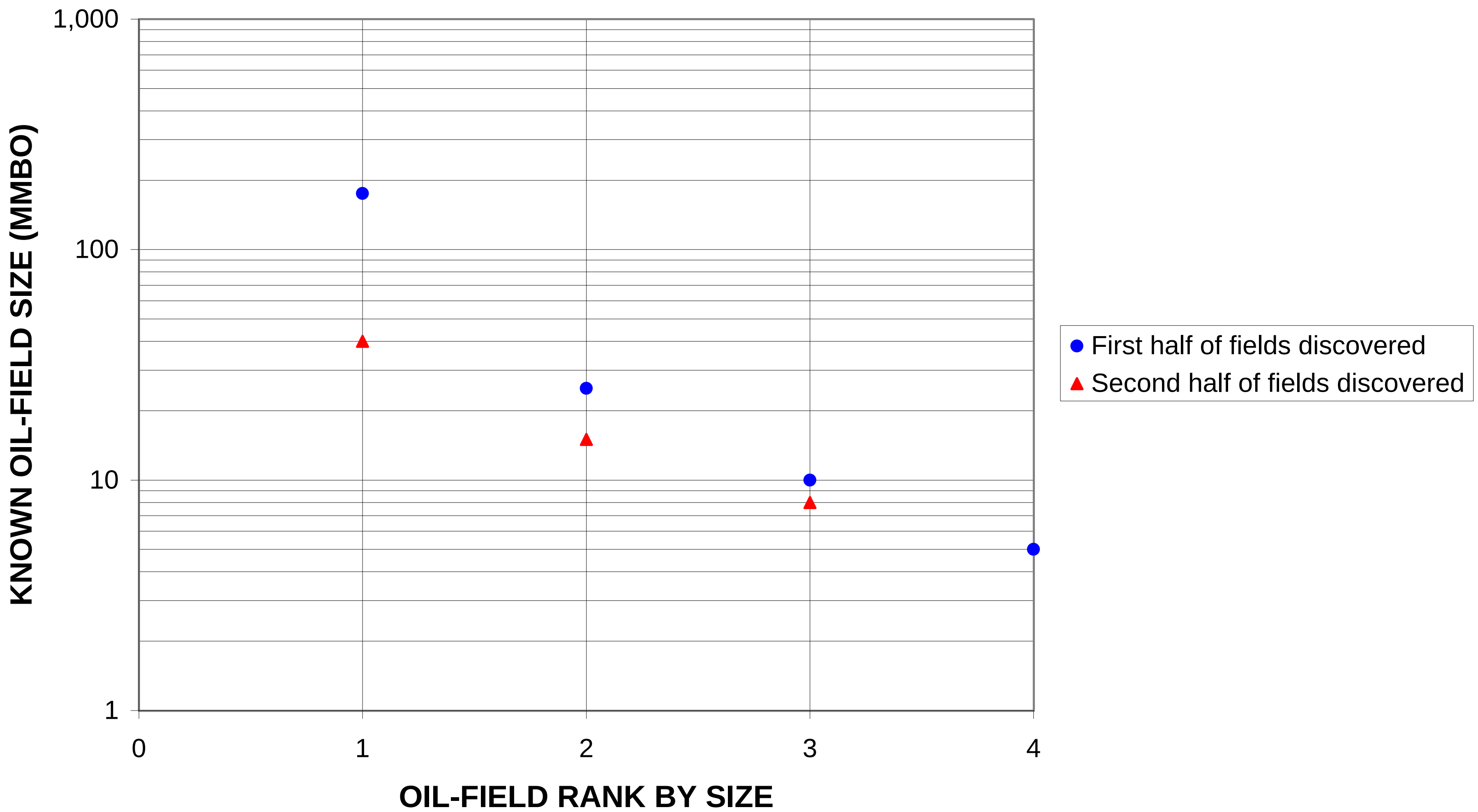
Tanezzuft-Sbaa Structural/Stratigraphic, Assessment Unit 20580301



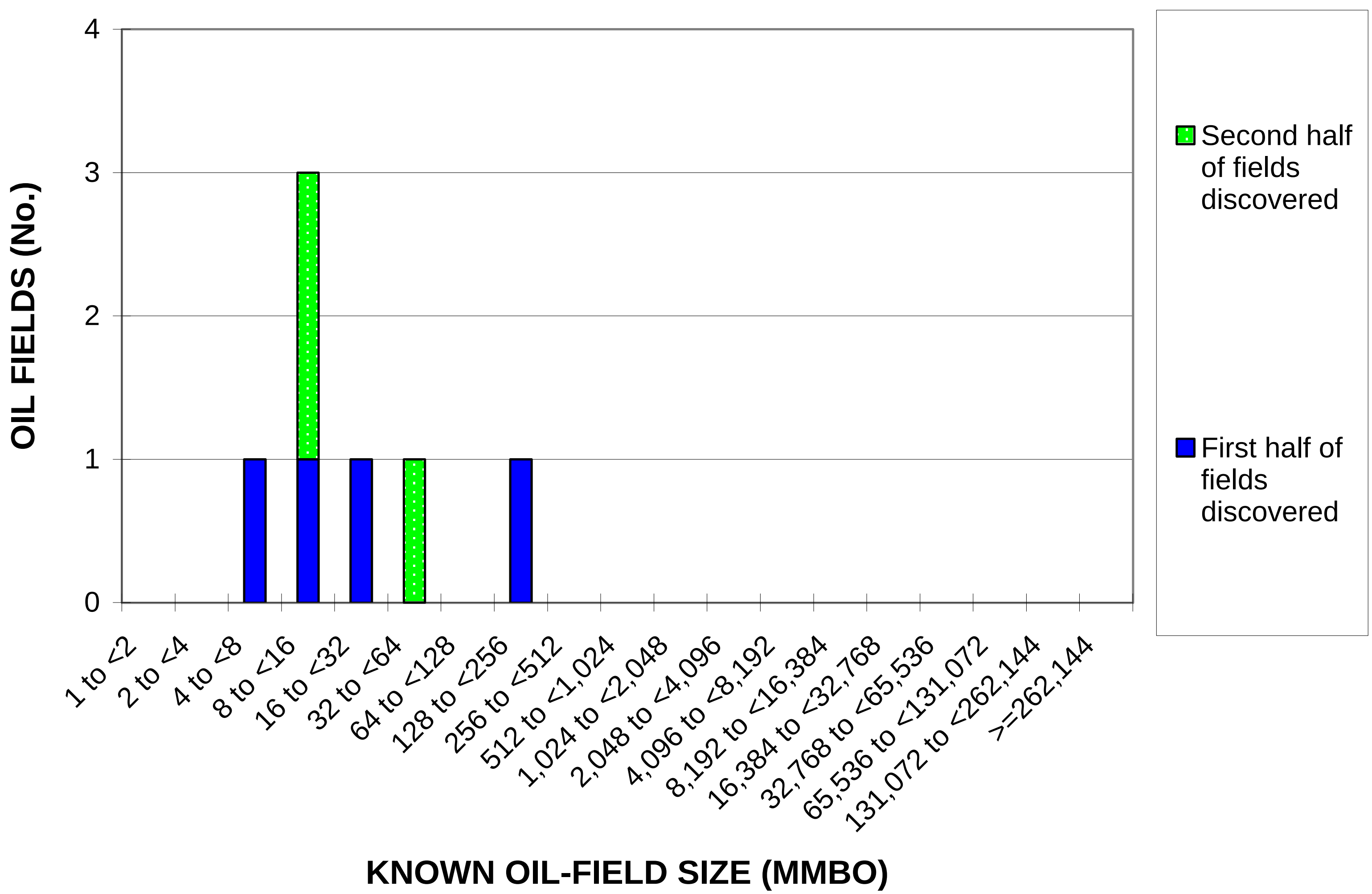
Tanezzuft-Sbaa Structural/Stratigraphic, Assessment Unit 20580301



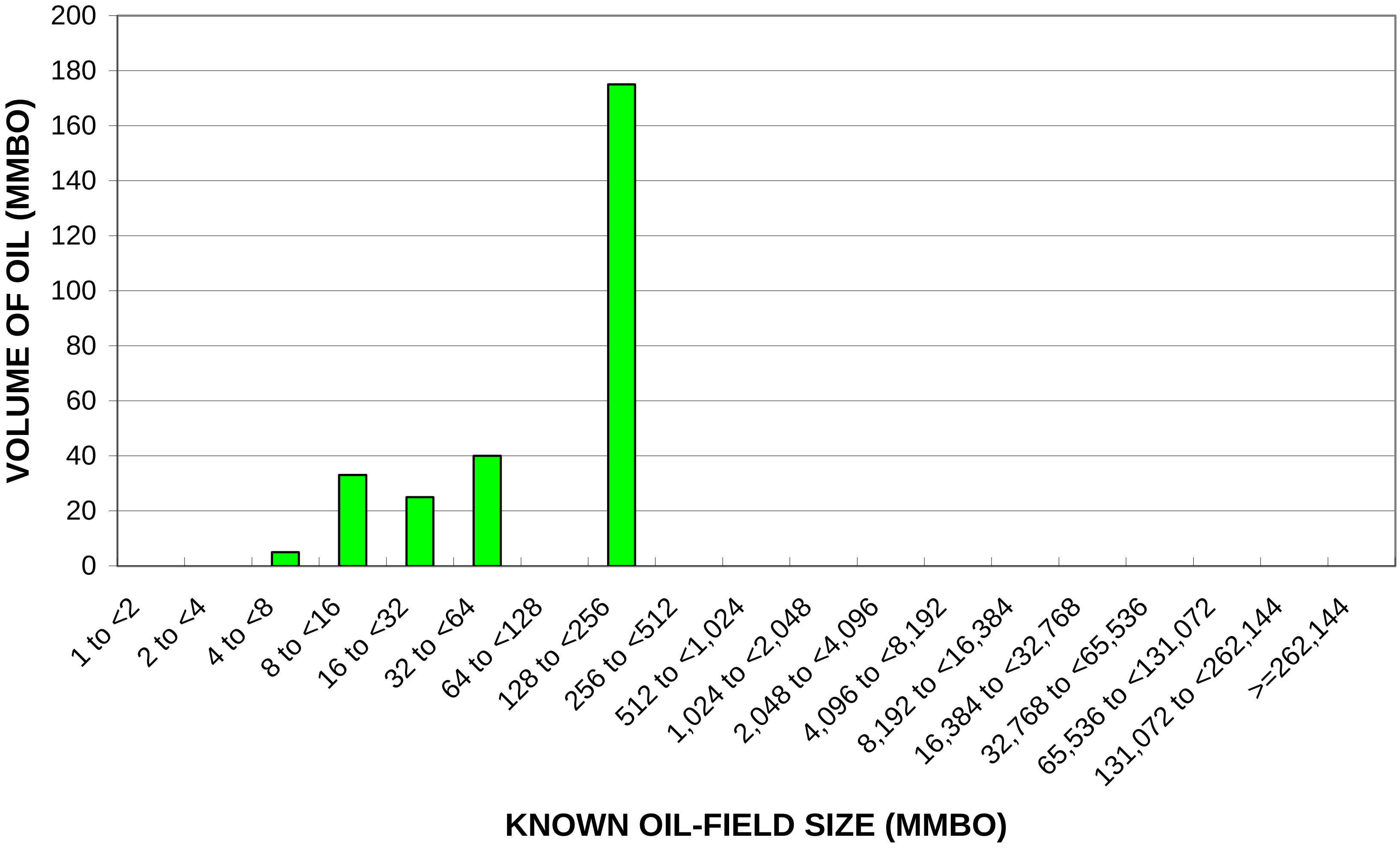
Tanezzuft-Sbaa Structural/Stratigraphic, Assessment Unit 20580301



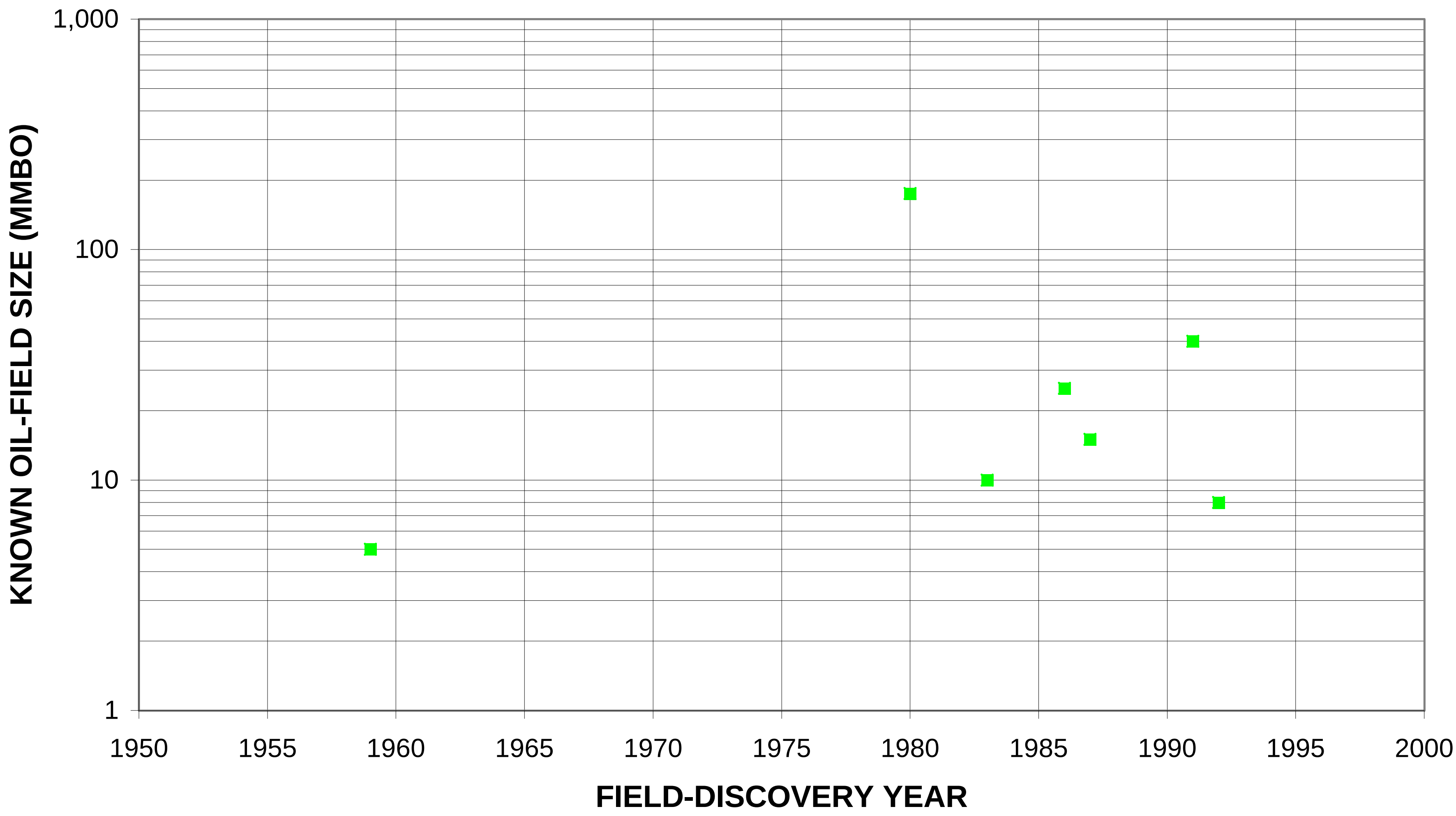
Tanezzuft-Sbaa Structural/Stratigraphic, Assessment Unit 20580301



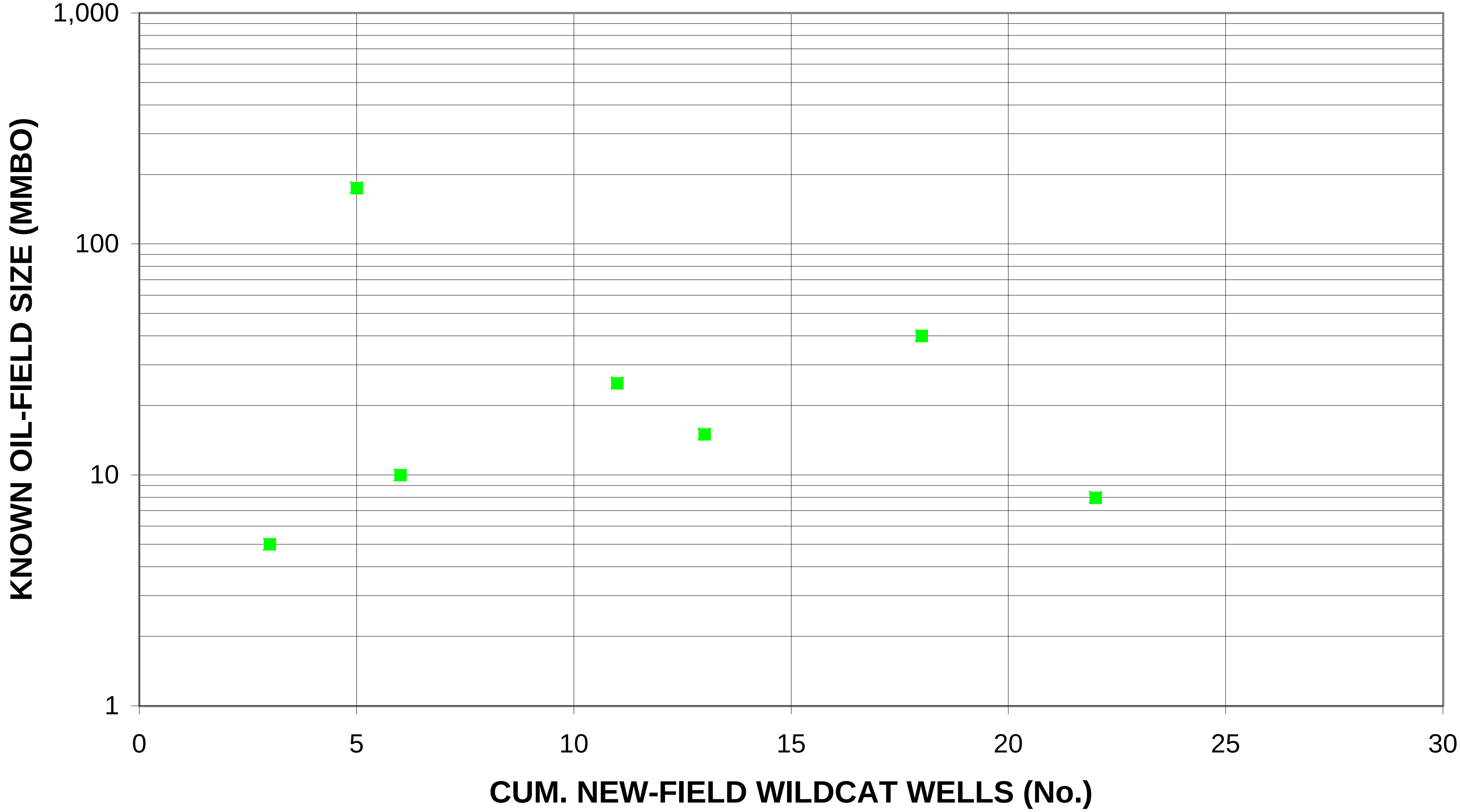
Tanezzuft-Sbaa Structural/Stratigraphic, Assessment Unit 20580301



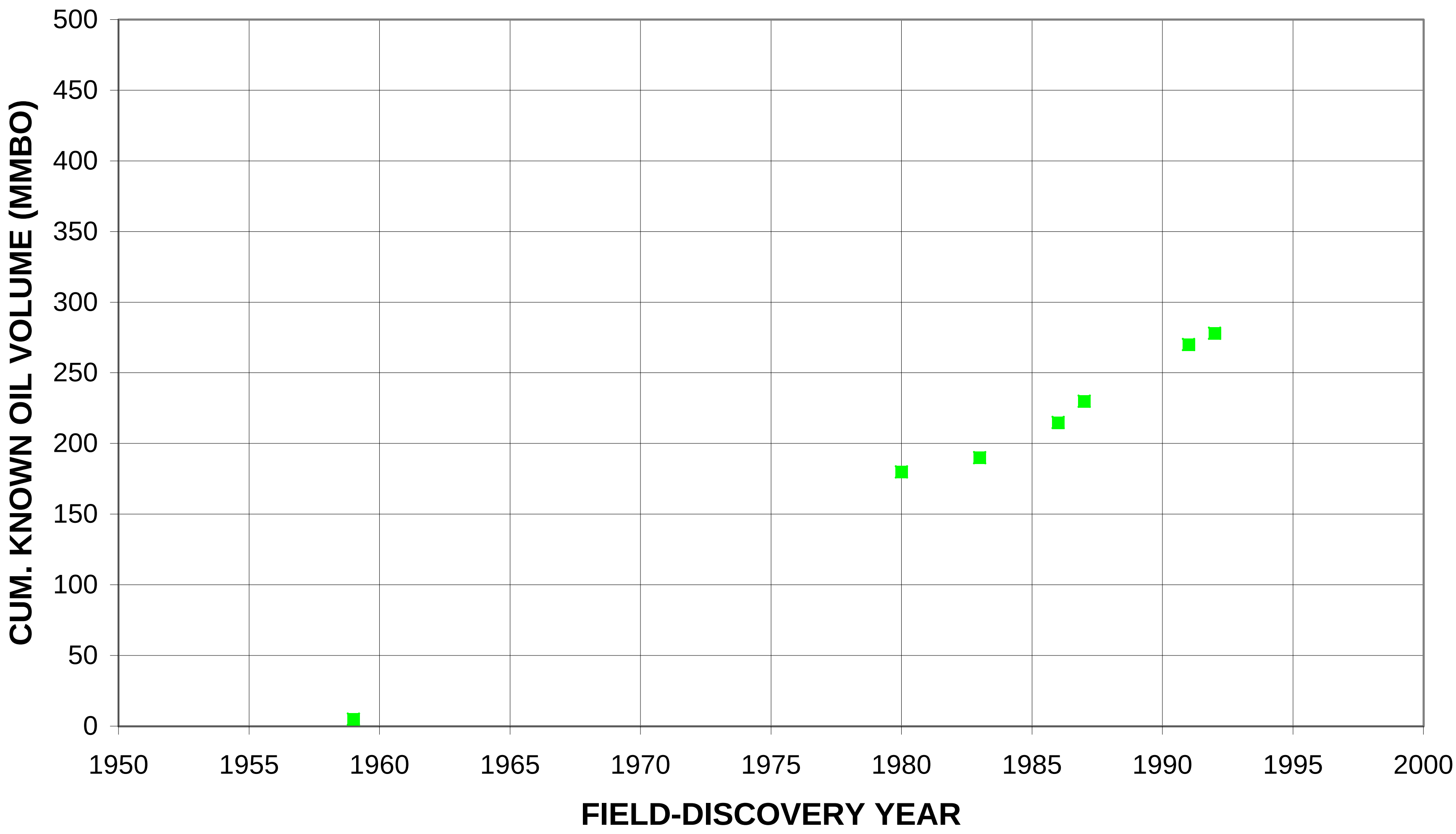
Tanezzuft-Sbaa Structural/Stratigraphic, Assessment Unit 20580301



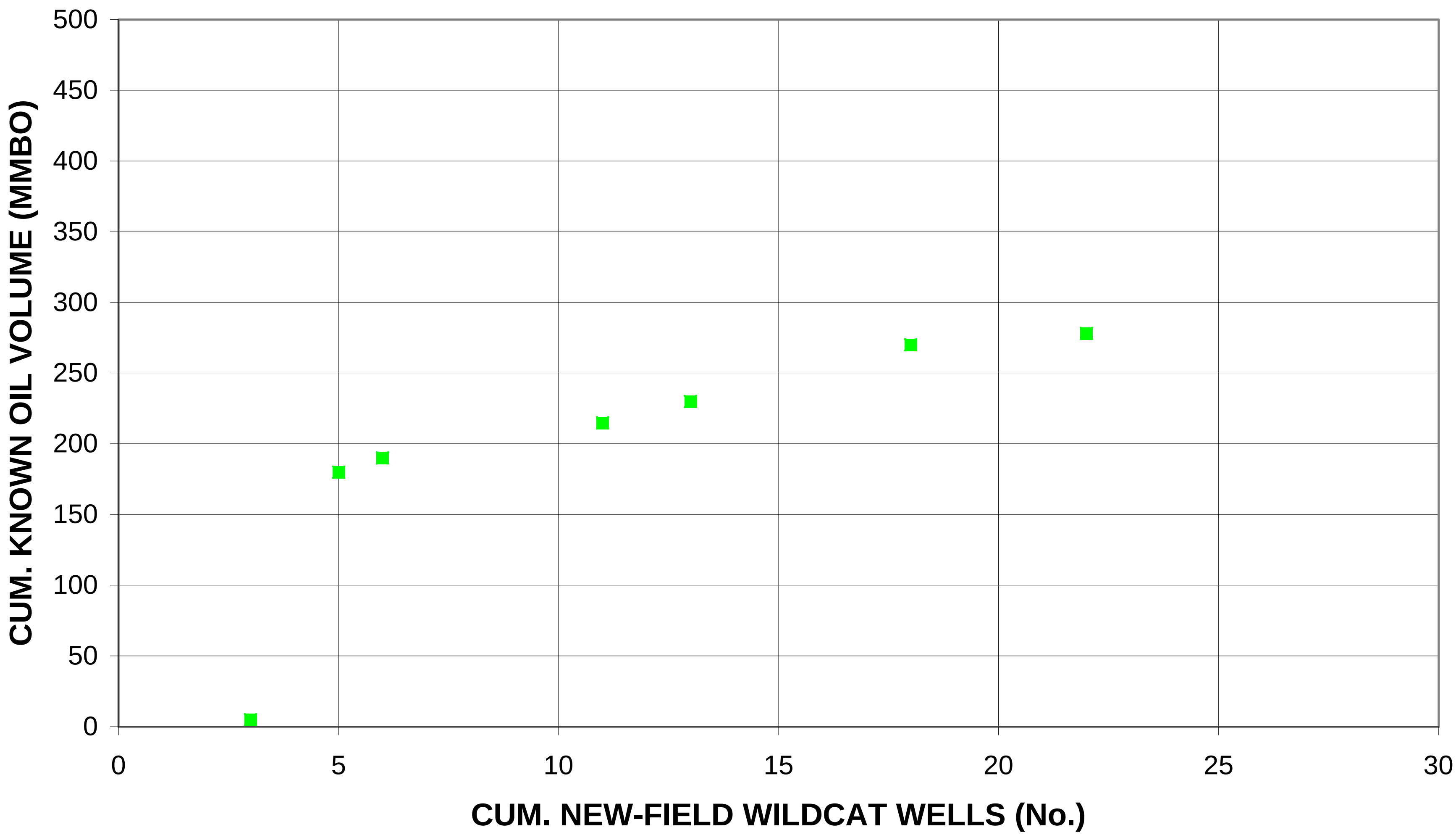
Tanezzuft-Sbaa Structural/Stratigraphic, Assessment Unit 20580301



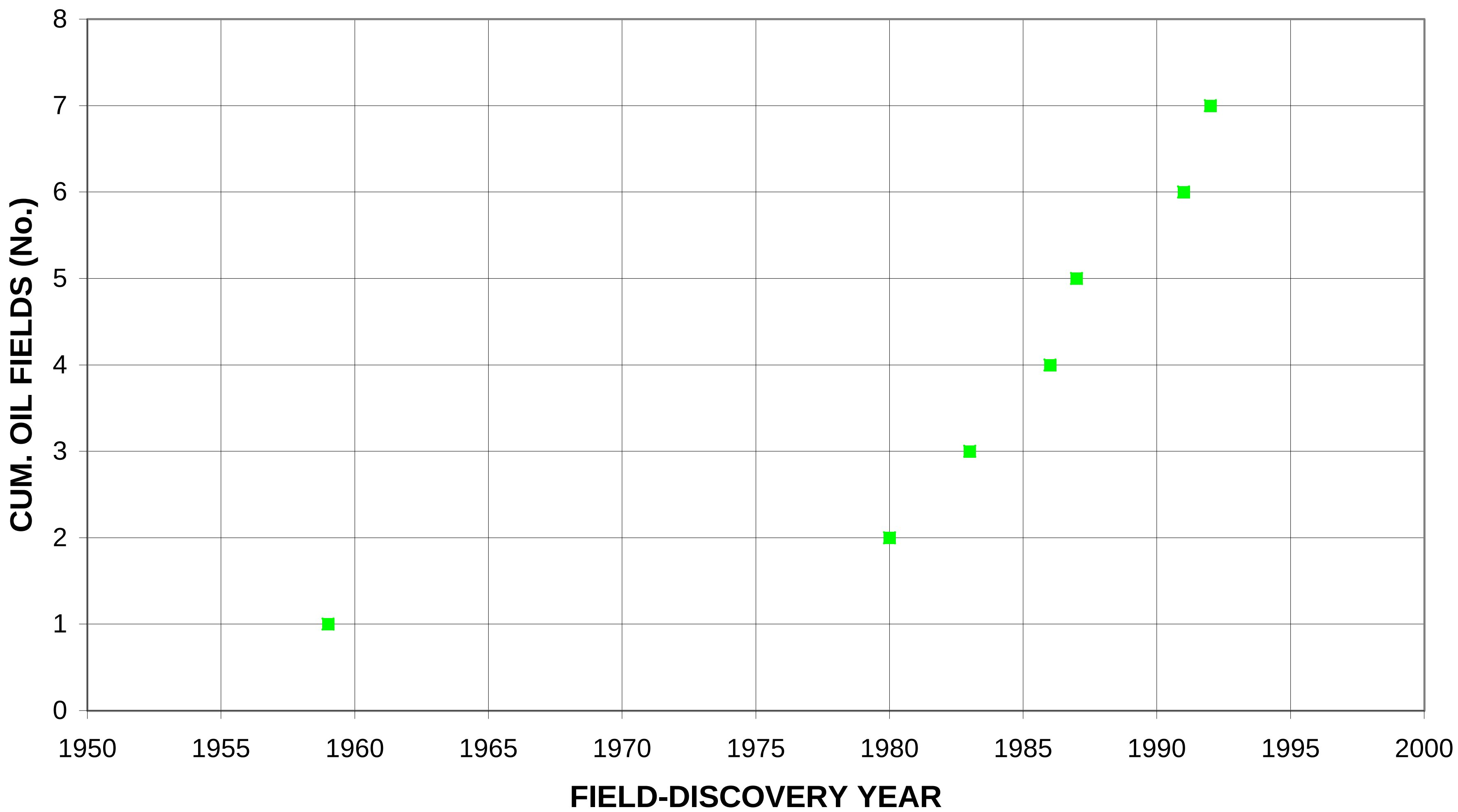
Tanezzuft-Sbaa Structural/Stratigraphic, Assessment Unit 20580301



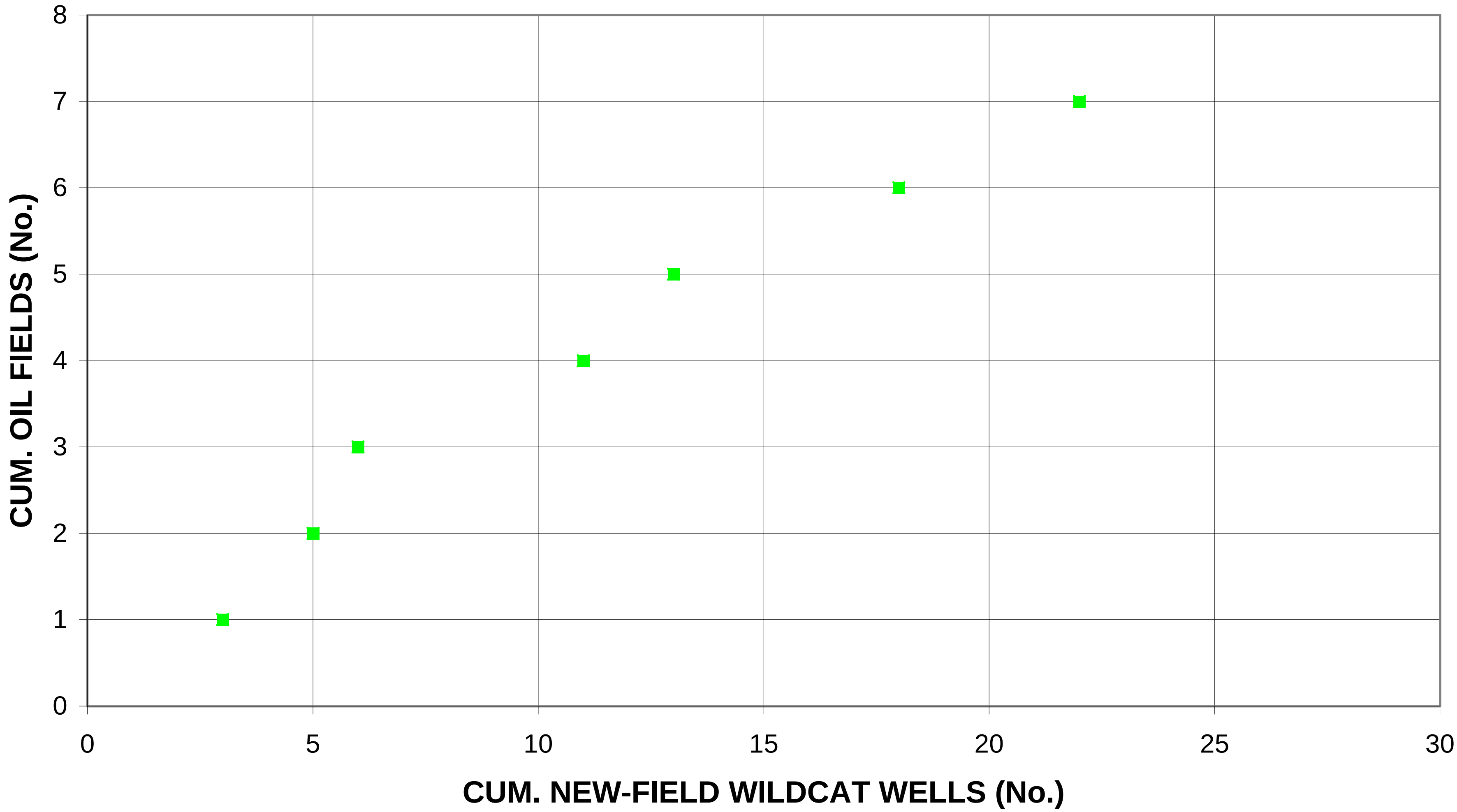
Tanezzuft-Sbaa Structural/Stratigraphic, Assessment Unit 20580301



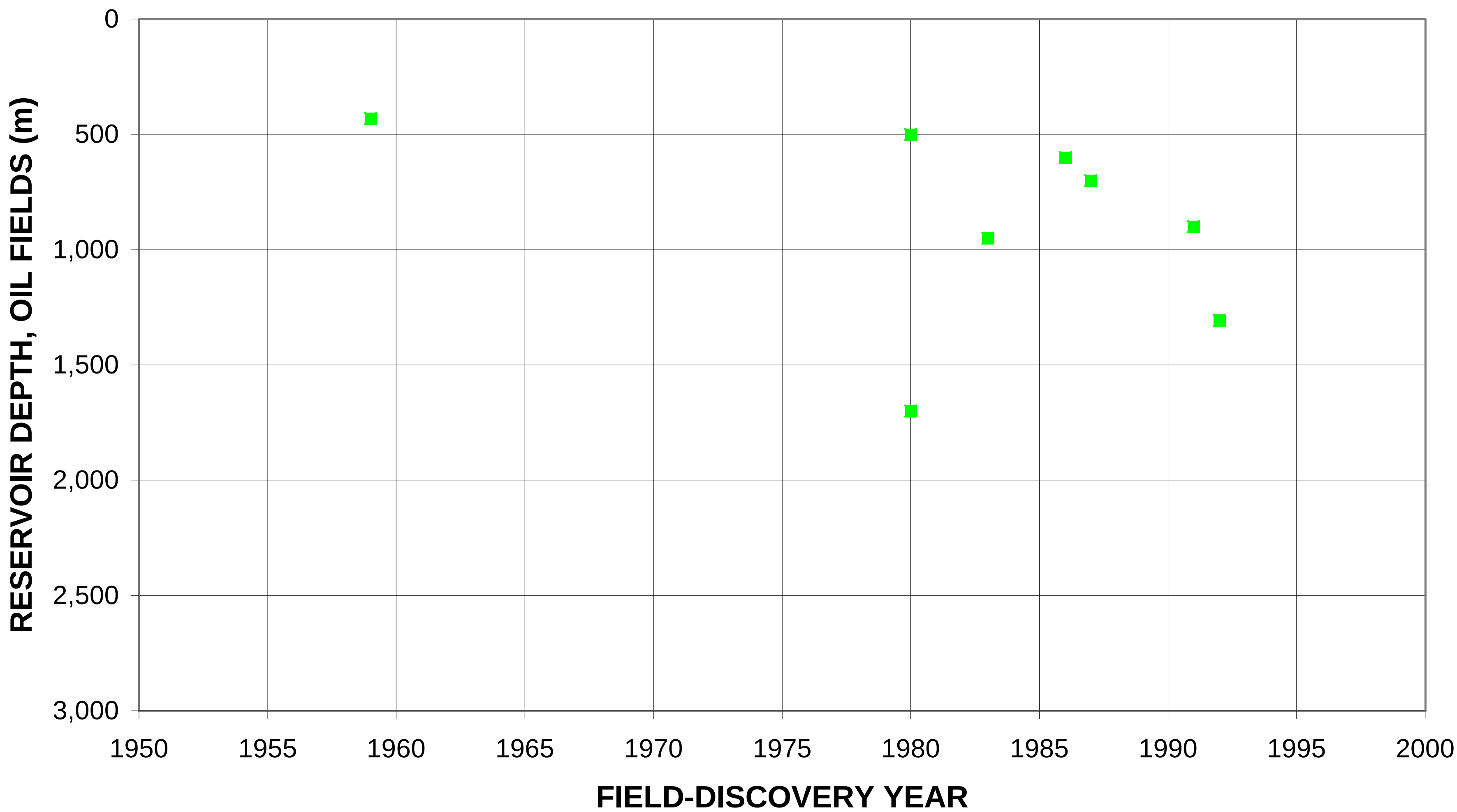
Tanezzuft-Sbaa Structural/Stratigraphic, Assessment Unit 20580301

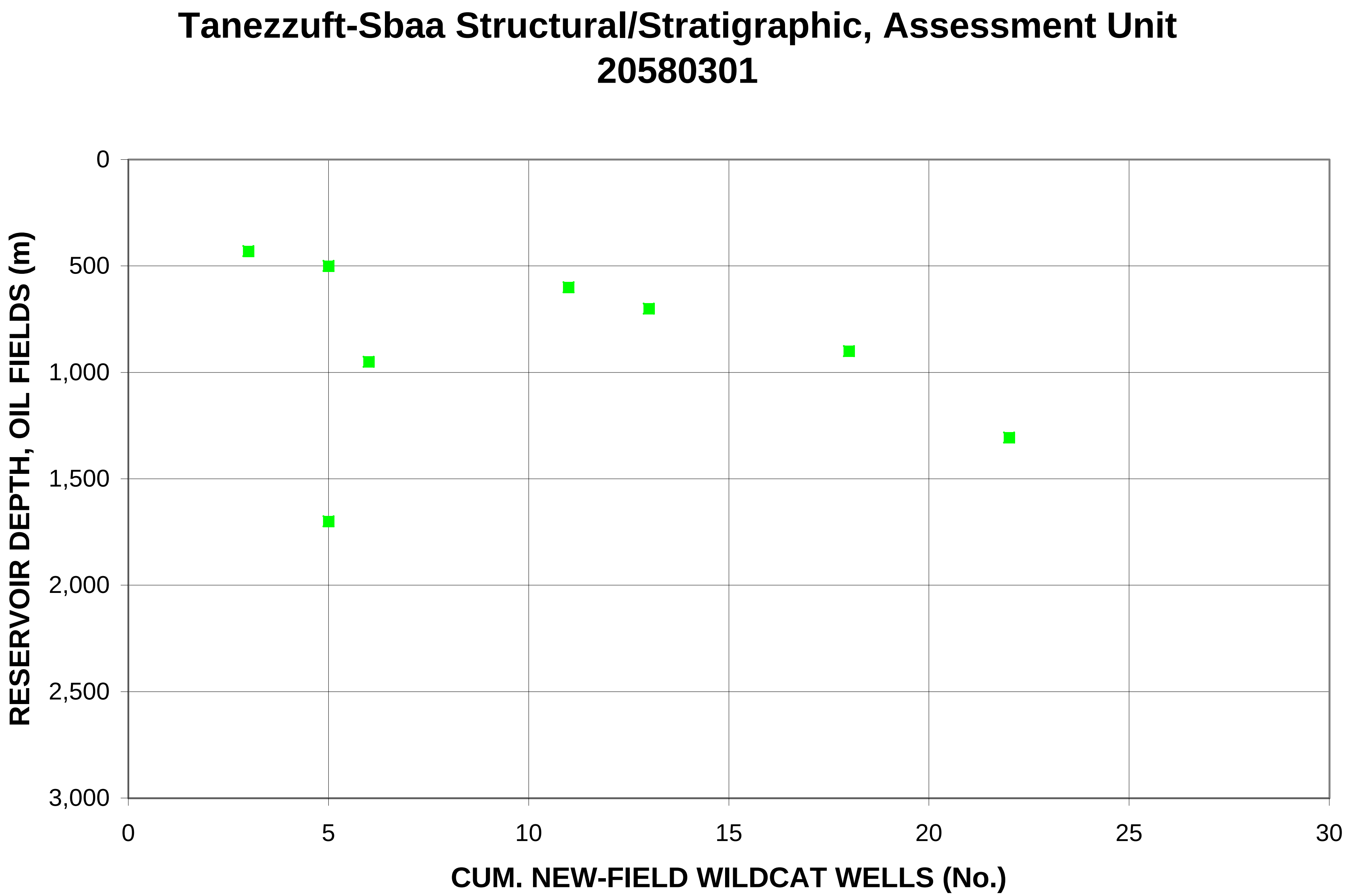


Tanezzuft-Sbaa Structural/Stratigraphic, Assessment Unit 20580301

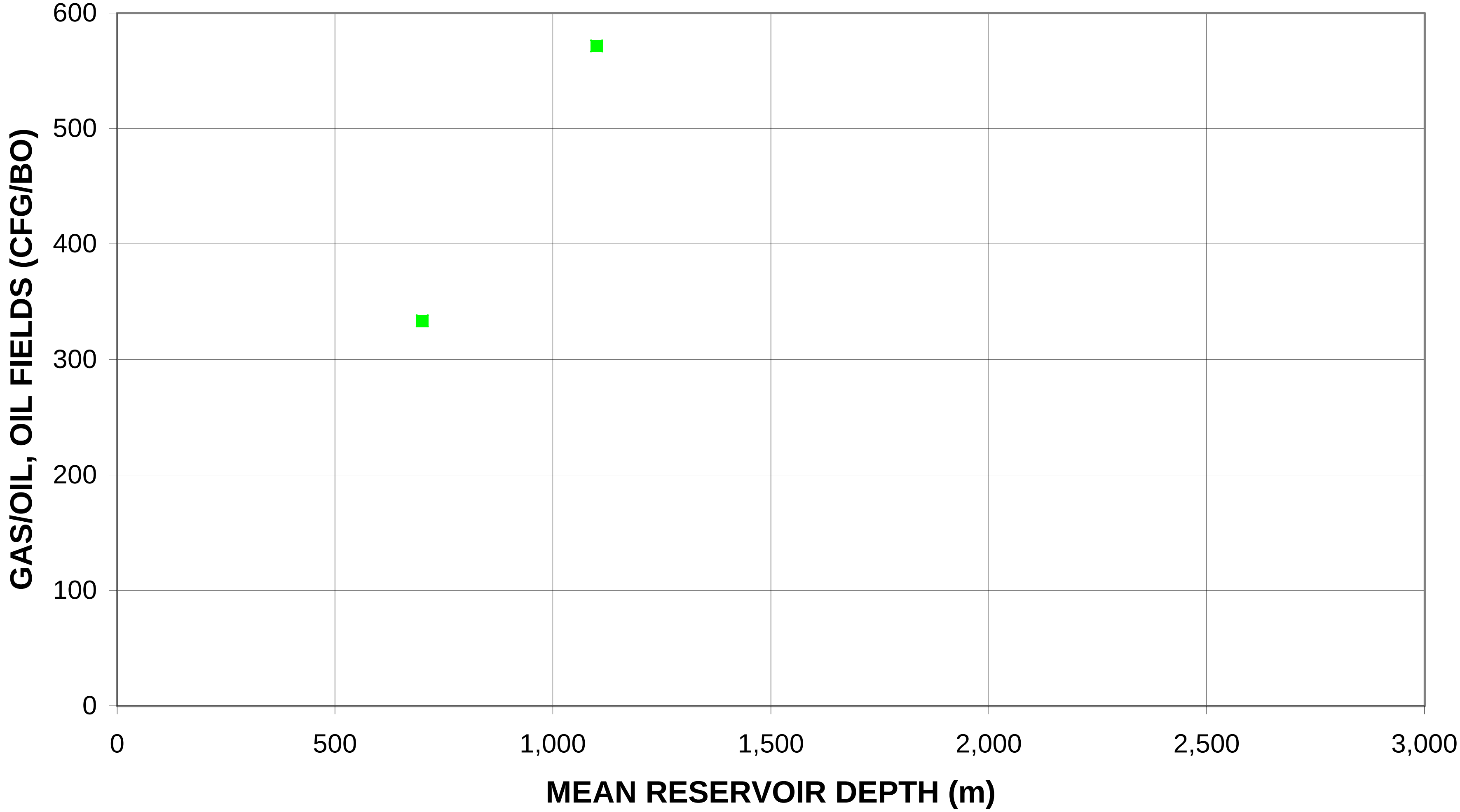


Tanezzuft-Sbaa Structural/Stratigraphic, Assessment Unit 20580301

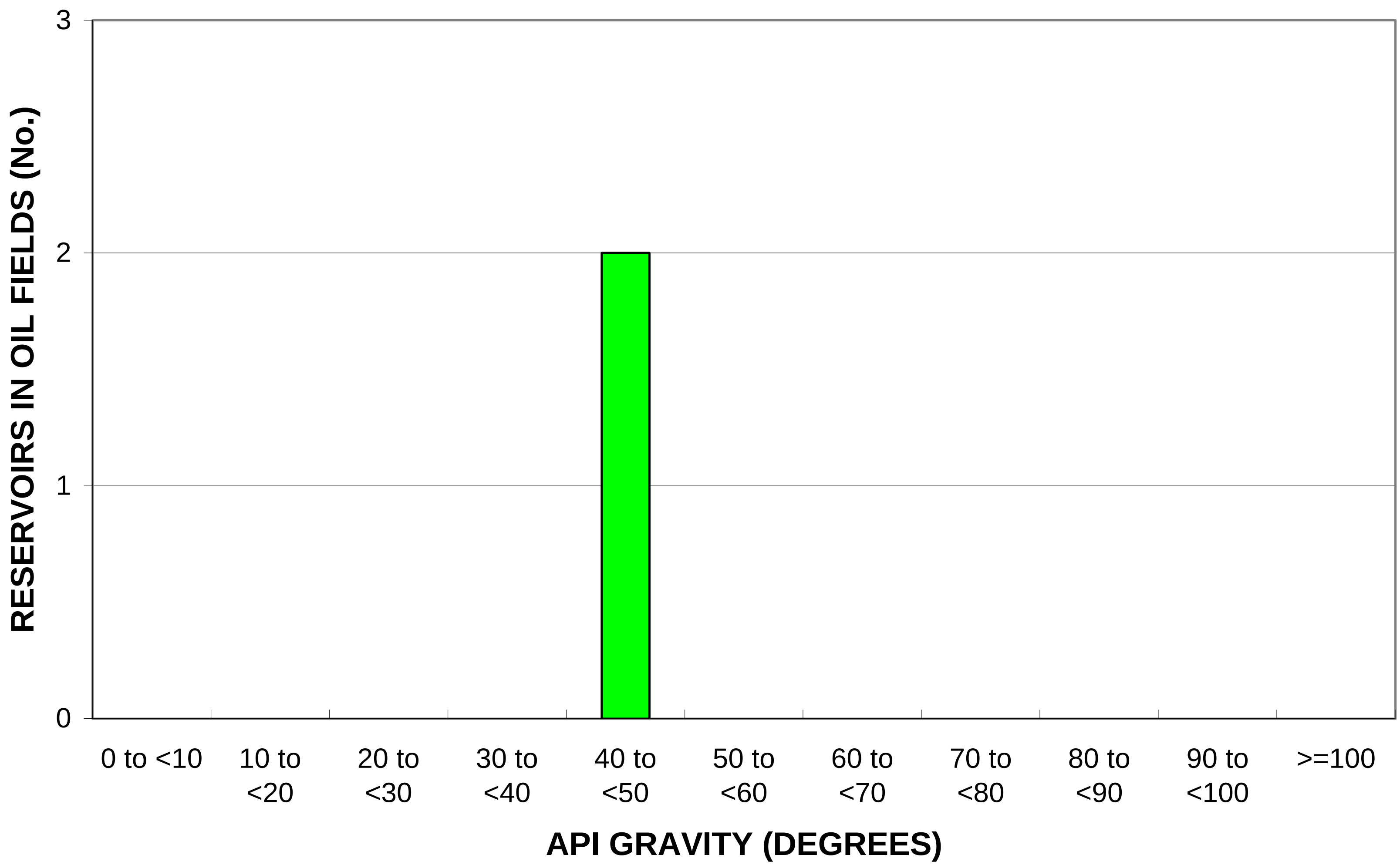



Tanezzuft-Sbaa Structural/Stratigraphic, Assessment Unit 20580301
RESERVOIR DEPTH, OIL FIELDS (m)
0
500
1,000
1,500
2,000
2,500
3,000
0
5
10
15
20
25
30
CUM. NEW-FIELD WILDCAT WELLS (No.)

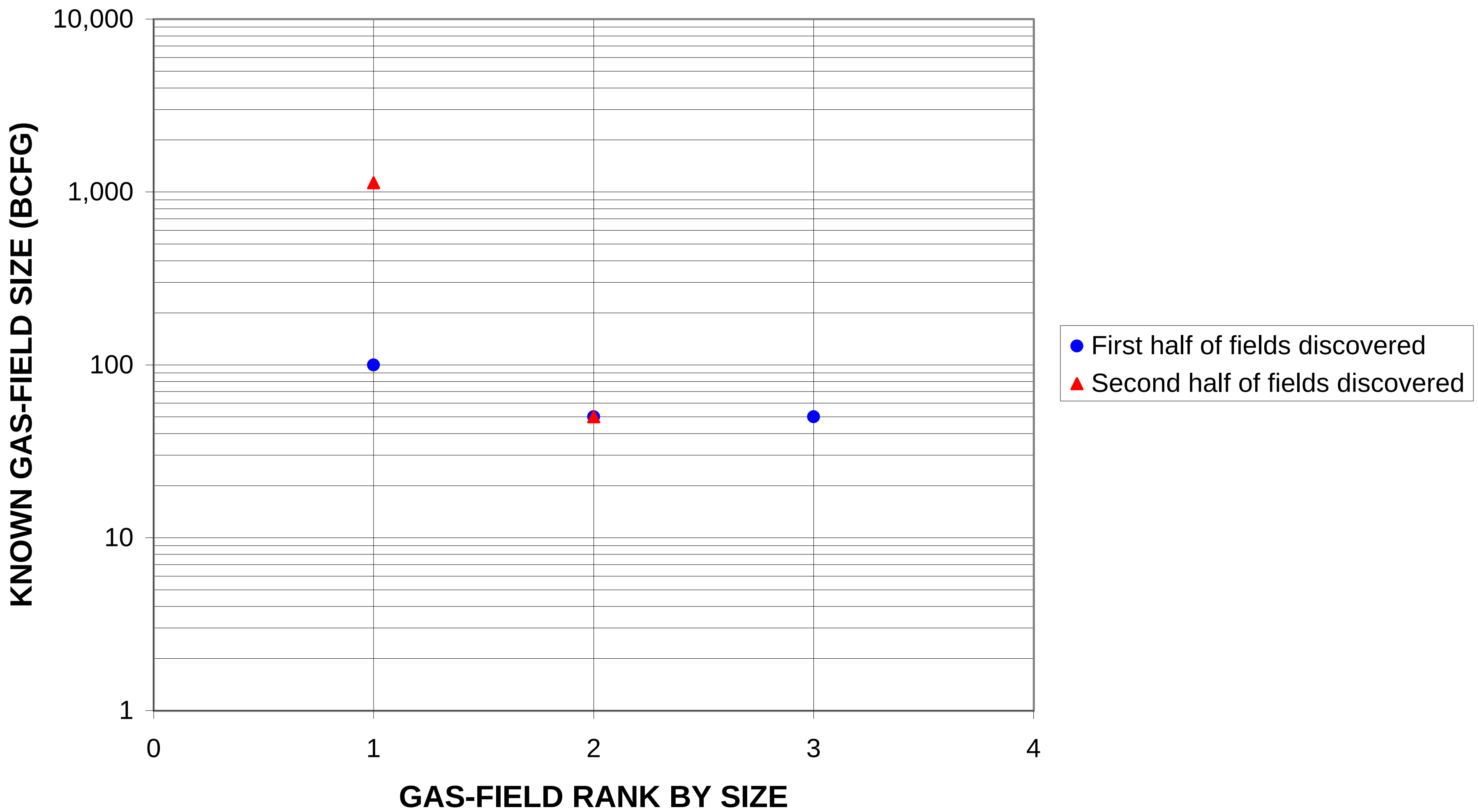
Tanezzuft-Sbaa Structural/Stratigraphic, Assessment Unit 20580301

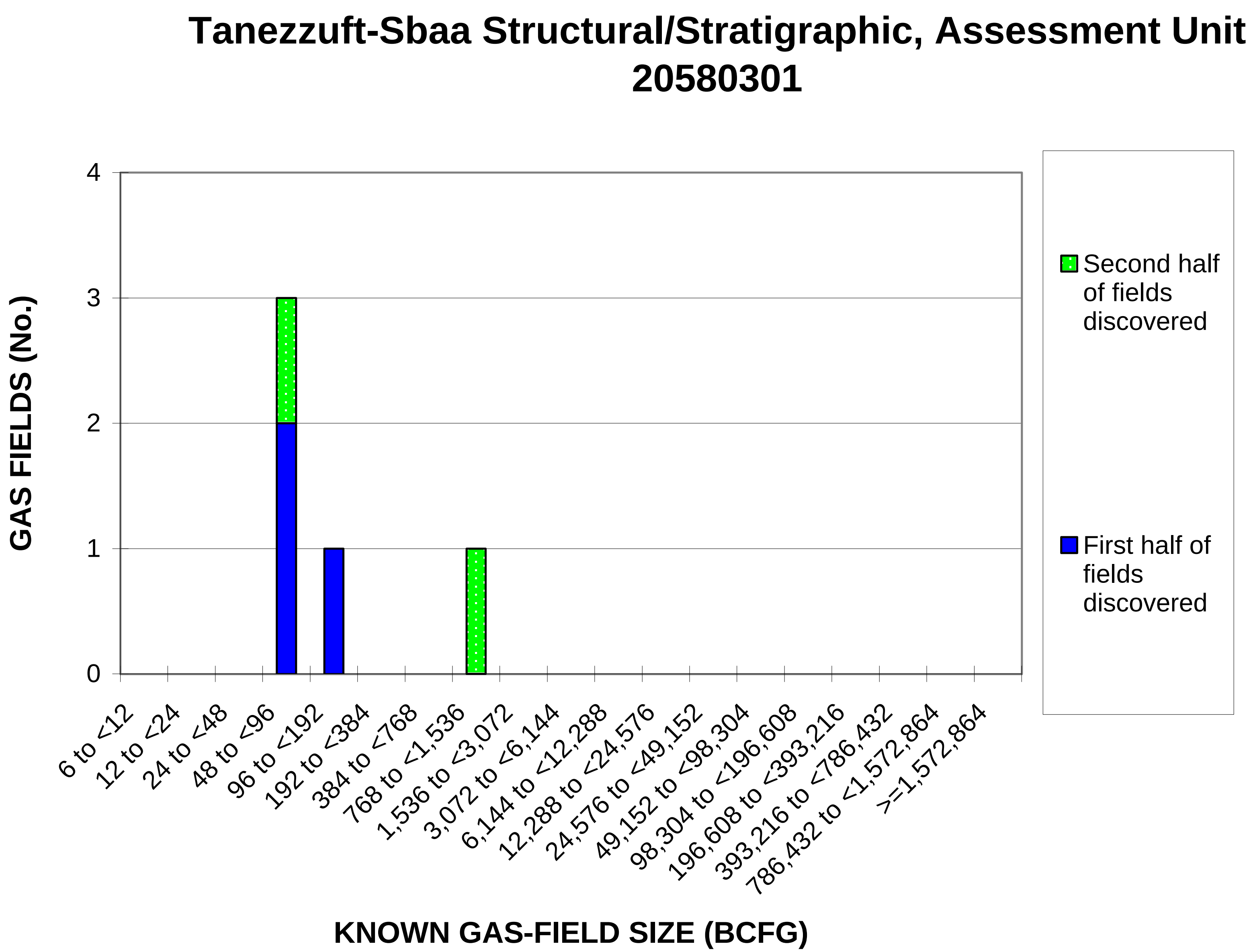


Tanezzuft-Sbaa Structural/Stratigraphic, Assessment Unit 20580301

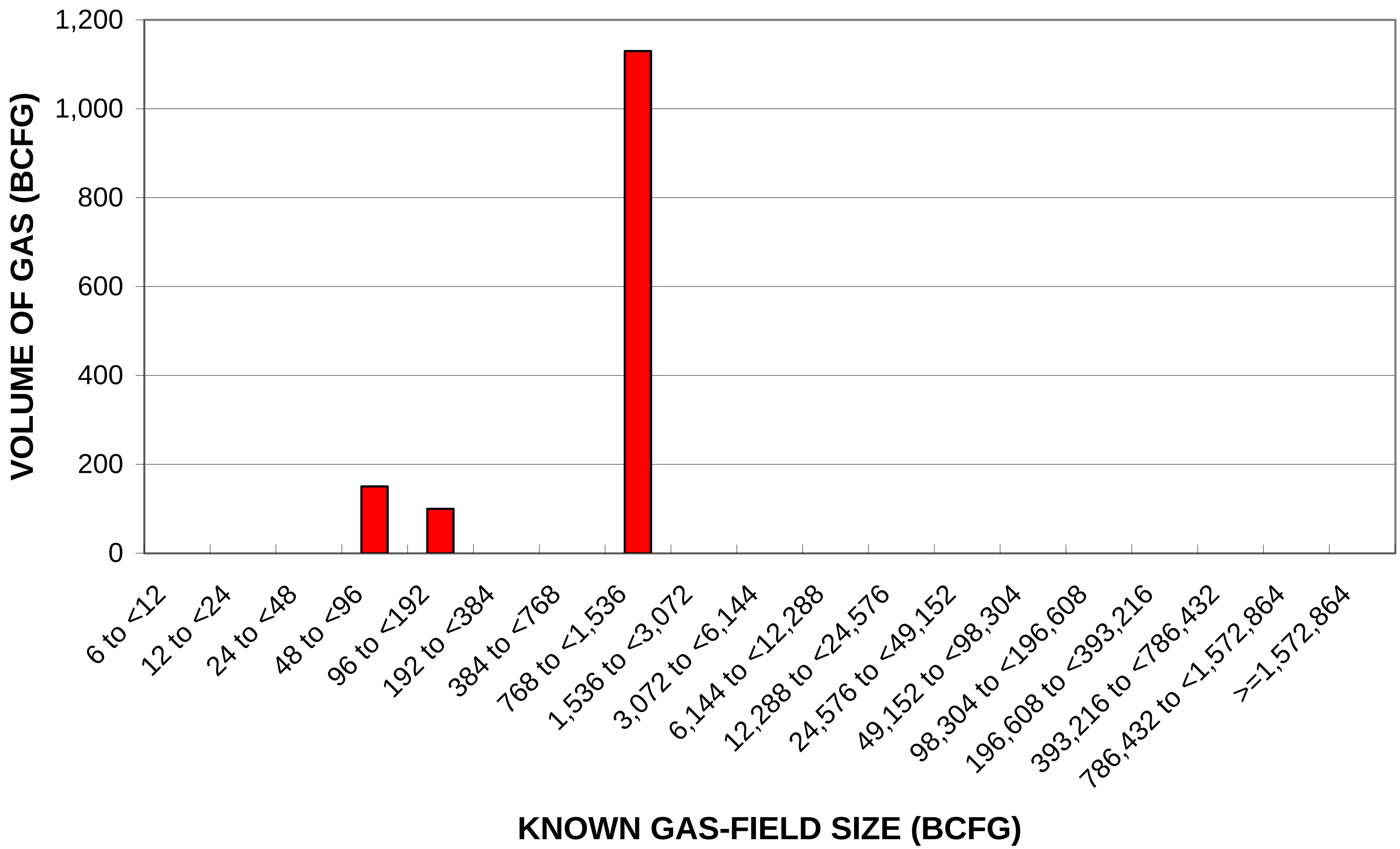


Tanezzuft-Sbaa Structural/Stratigraphic, Assessment Unit 20580301

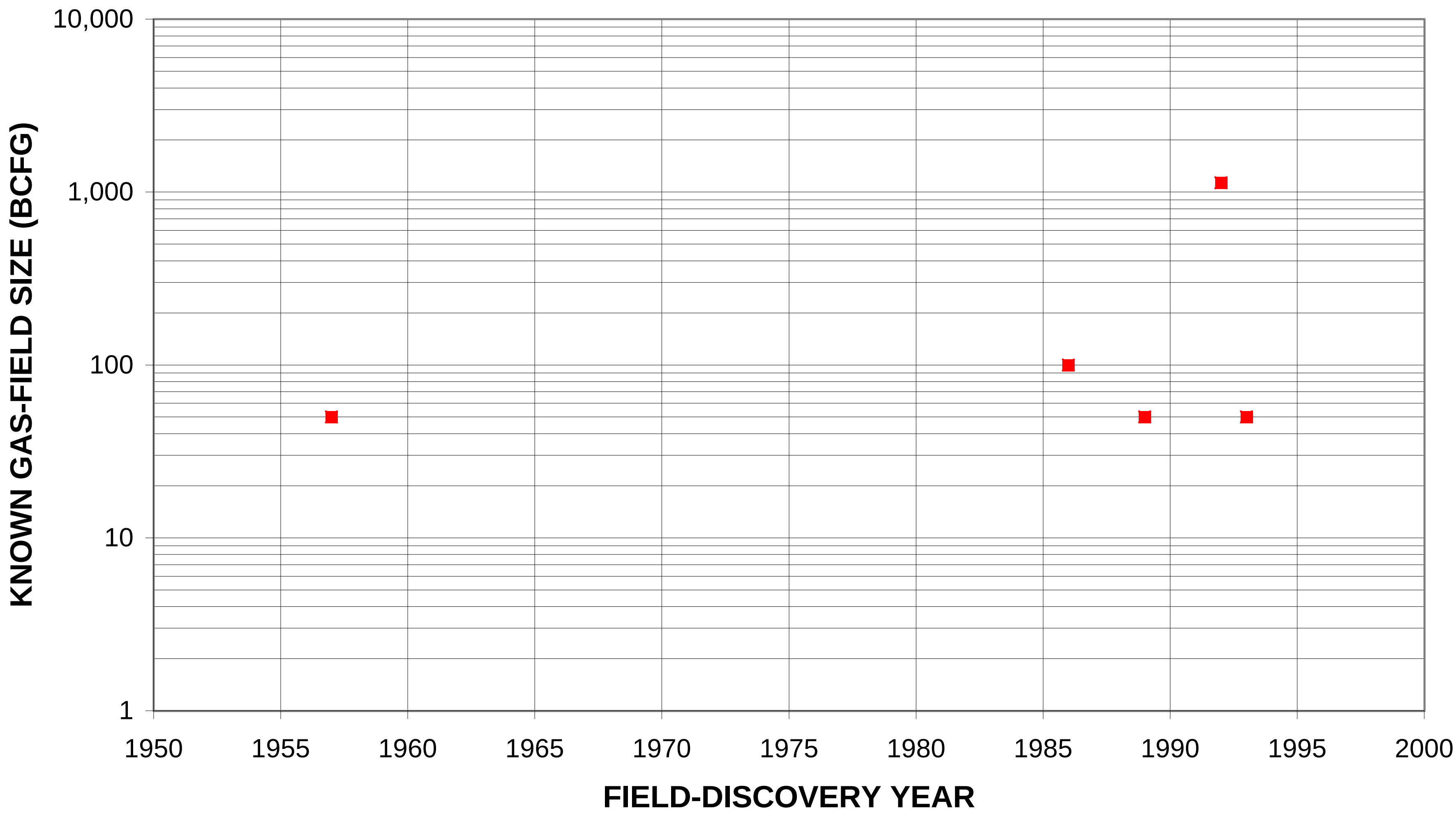



Tanezzuft-Sbaa Structural/Stratigraphic, Assessment Unit 20580301
GAS FIELDS (No.)
0
1
2
3
4
6 to <12
12 to <24
24 to <48
48 to <96
96 to <192
192 to <384
384 to <768
768 to <1,536
1,536 to <3,072
3,072 to <6,144
6,144 to <12,288
12,288 to <24,576
24,576 to <49,152
49,152 to <98,304
98,304 to <196,608
196,608 to <393,216
393,216 to <786,432
786,432 to <1,572,864
>=1,572,864
KNOWN GAS-FIELD SIZE (BCFG)
Second half of fields discovered
First half of fields discovered

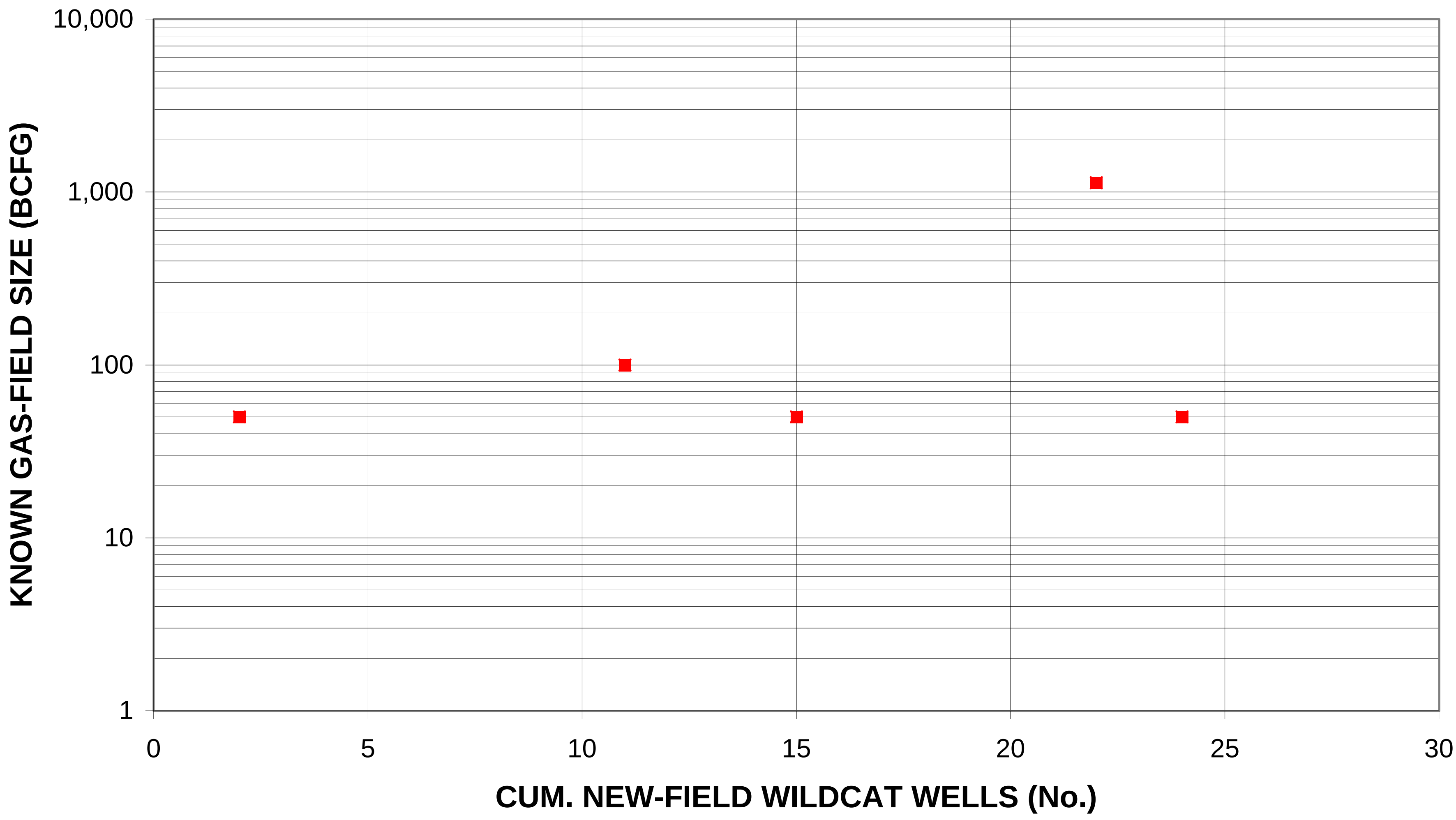
Tanezzuft-Sbaa Structural/Stratigraphic, Assessment Unit 20580301



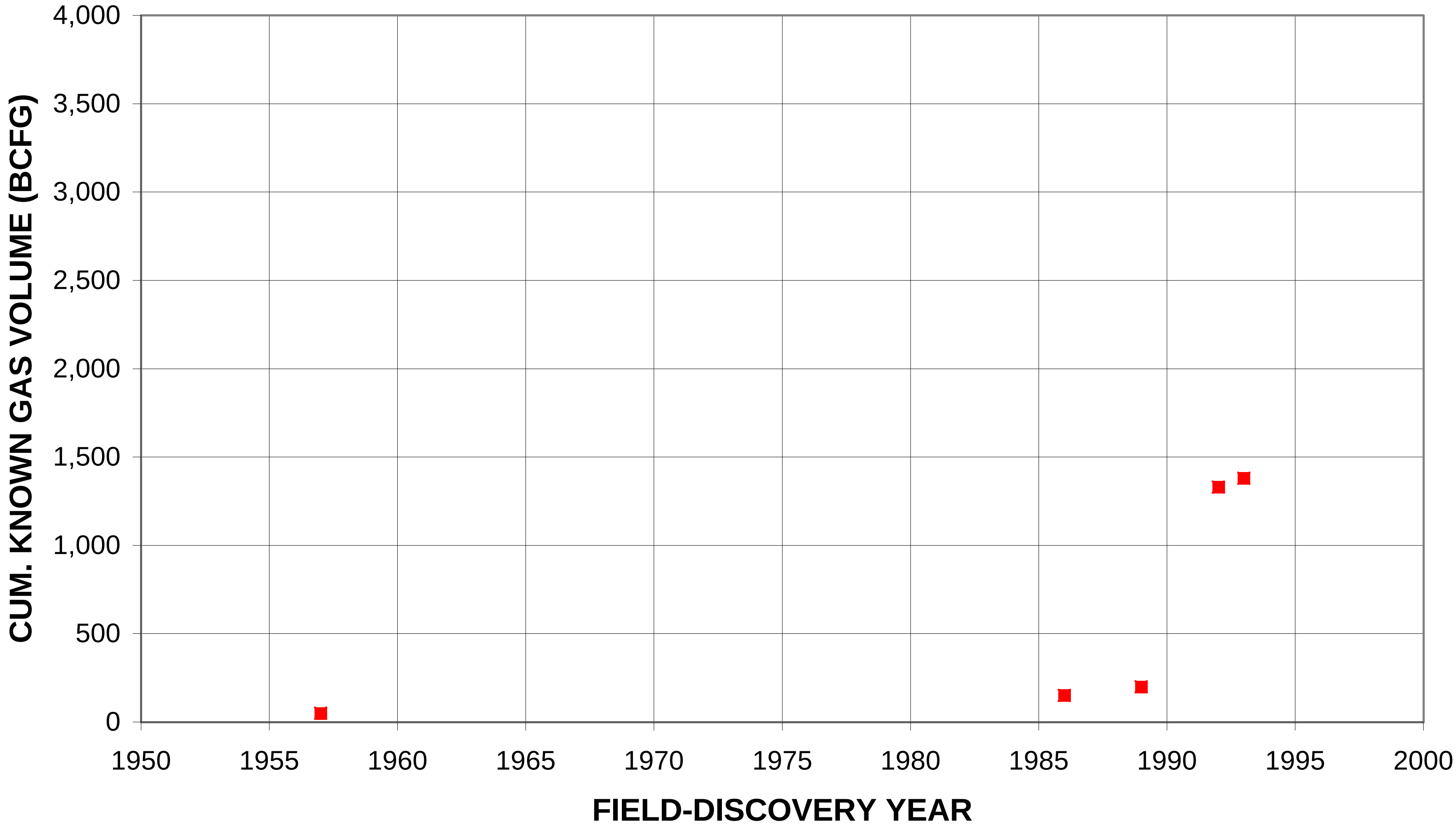
Tanezzuft-Sbaa Structural/Stratigraphic, Assessment Unit 20580301



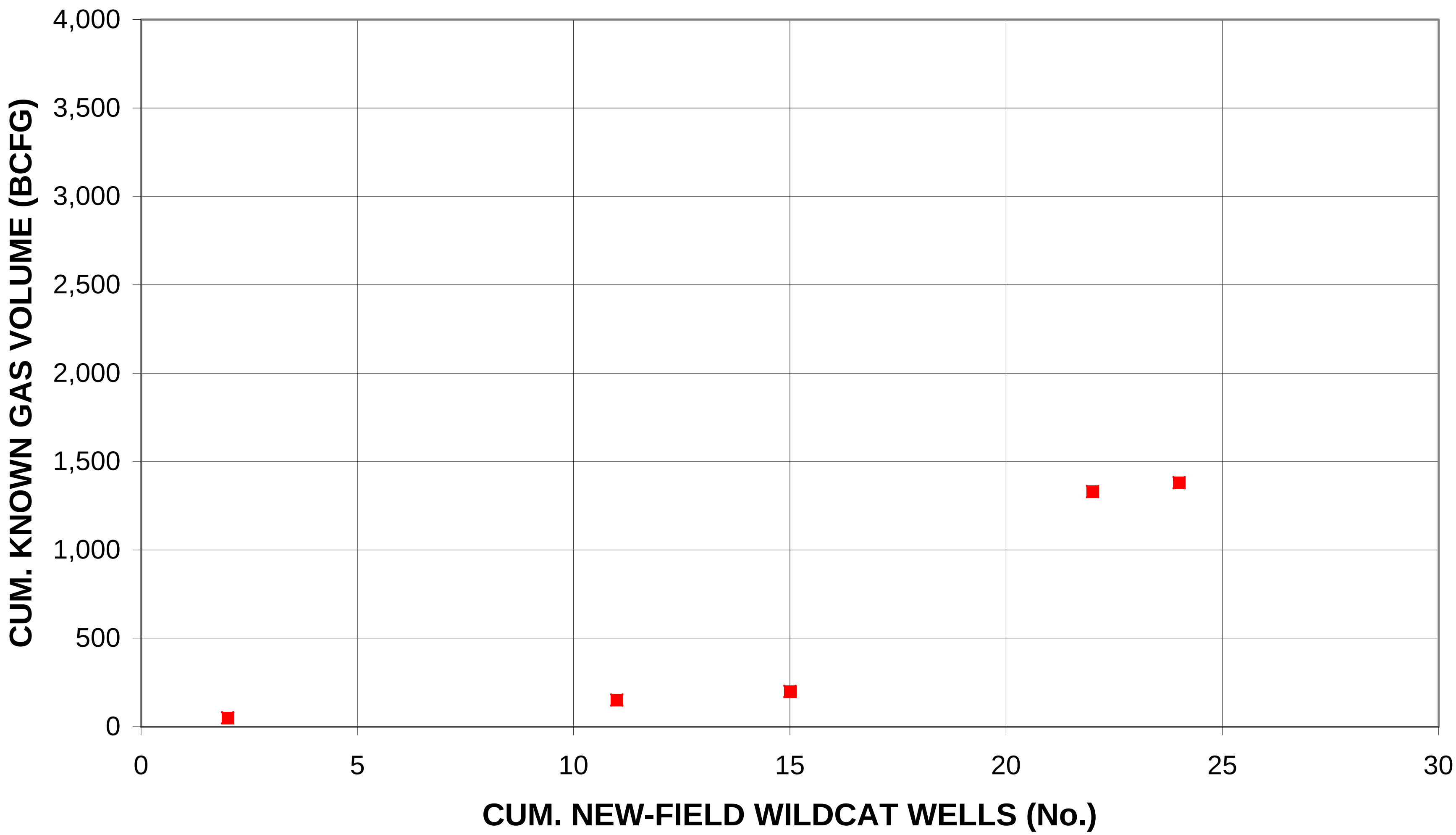
Tanezzuft-Sbaa Structural/Stratigraphic, Assessment Unit 20580301

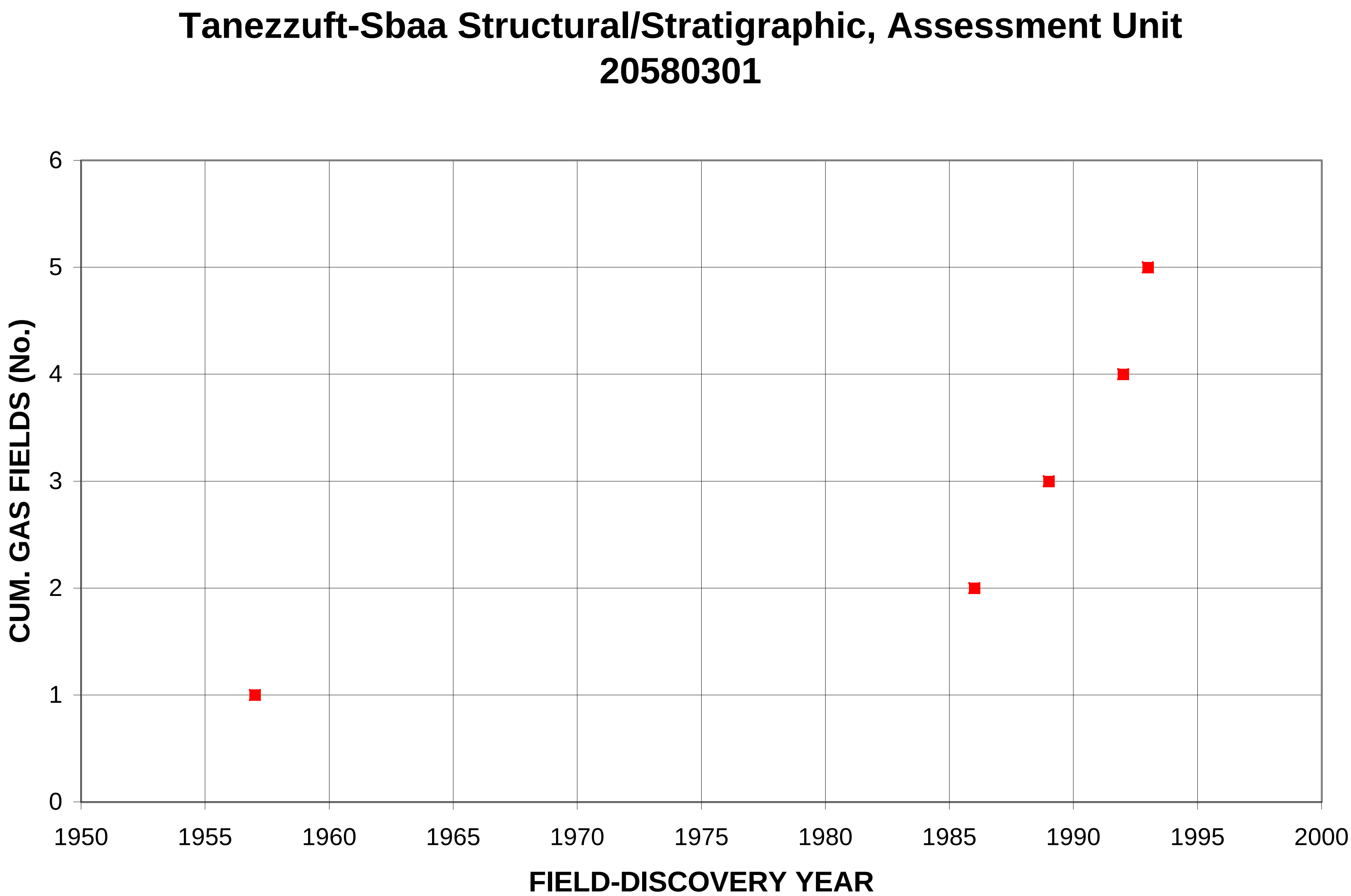


Tanezzuft-Sbaa Structural/Stratigraphic, Assessment Unit 20580301

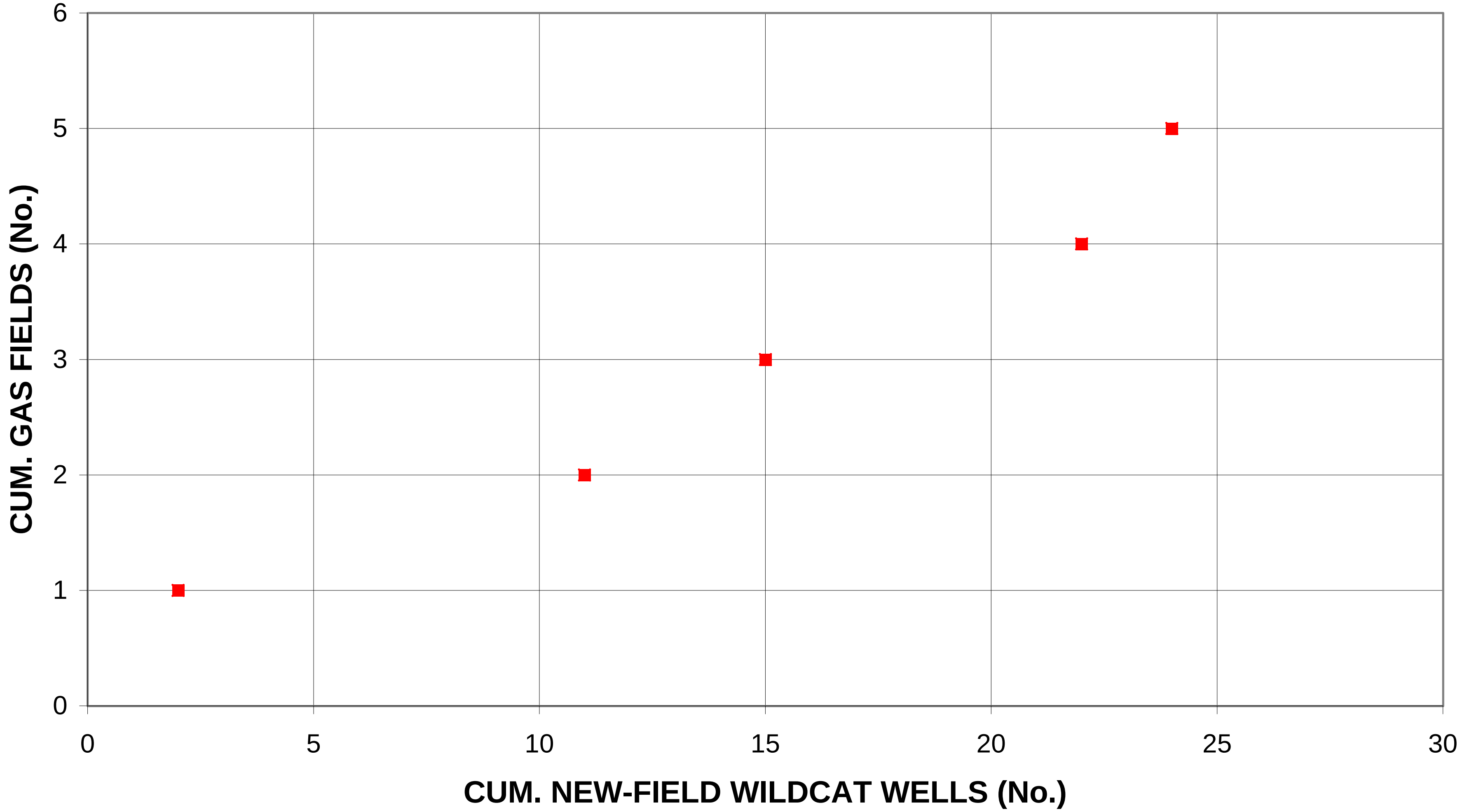


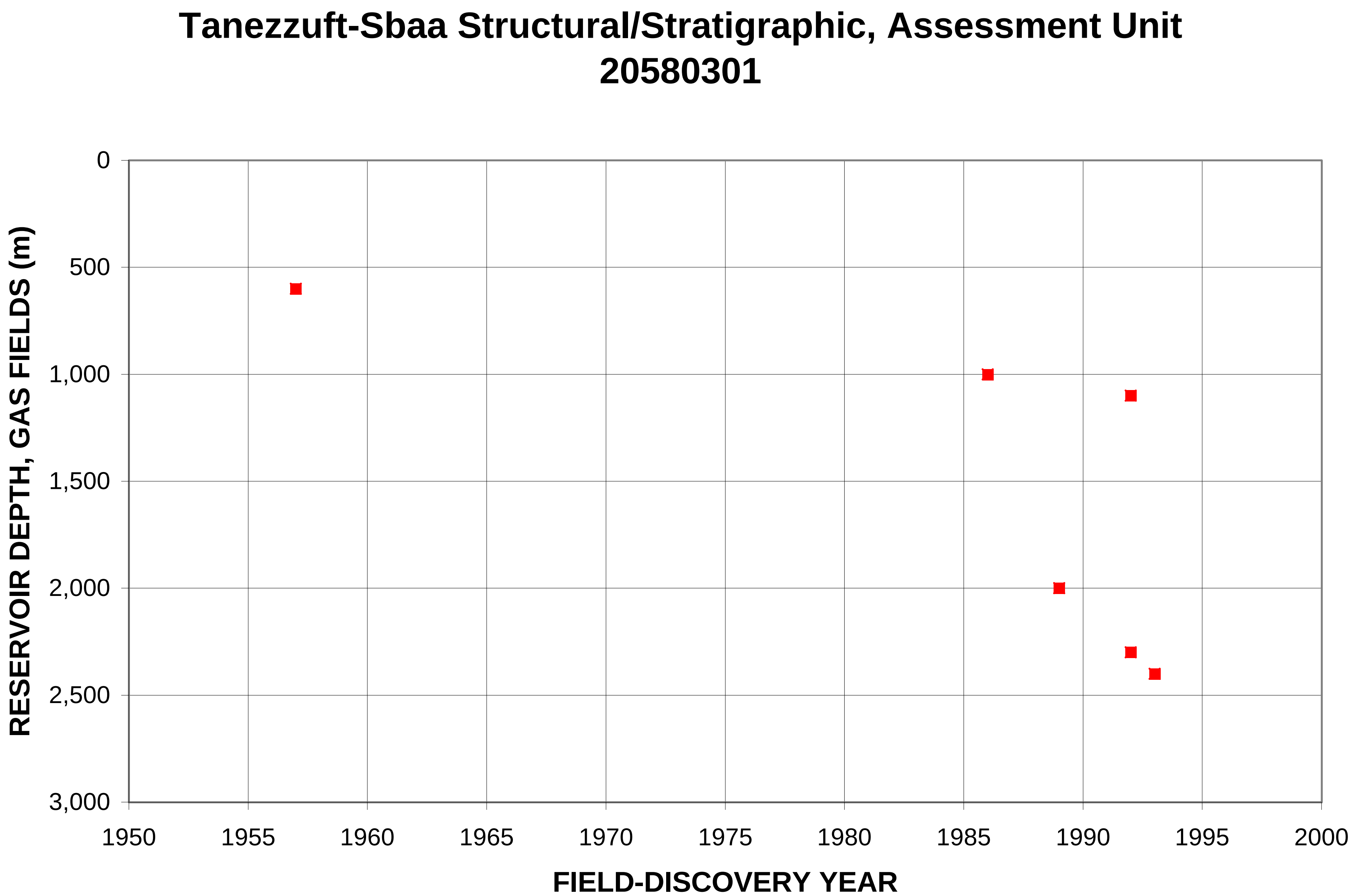
Tanezzuft-Sbaa Structural/Stratigraphic, Assessment Unit 20580301




Tanezzuft-Sbaa Structural/Stratigraphic, Assessment Unit 20580301
CUM. GAS FIELDS (No.)
0
1
2
3
4
5
6
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
FIELD-DISCOVERY YEAR

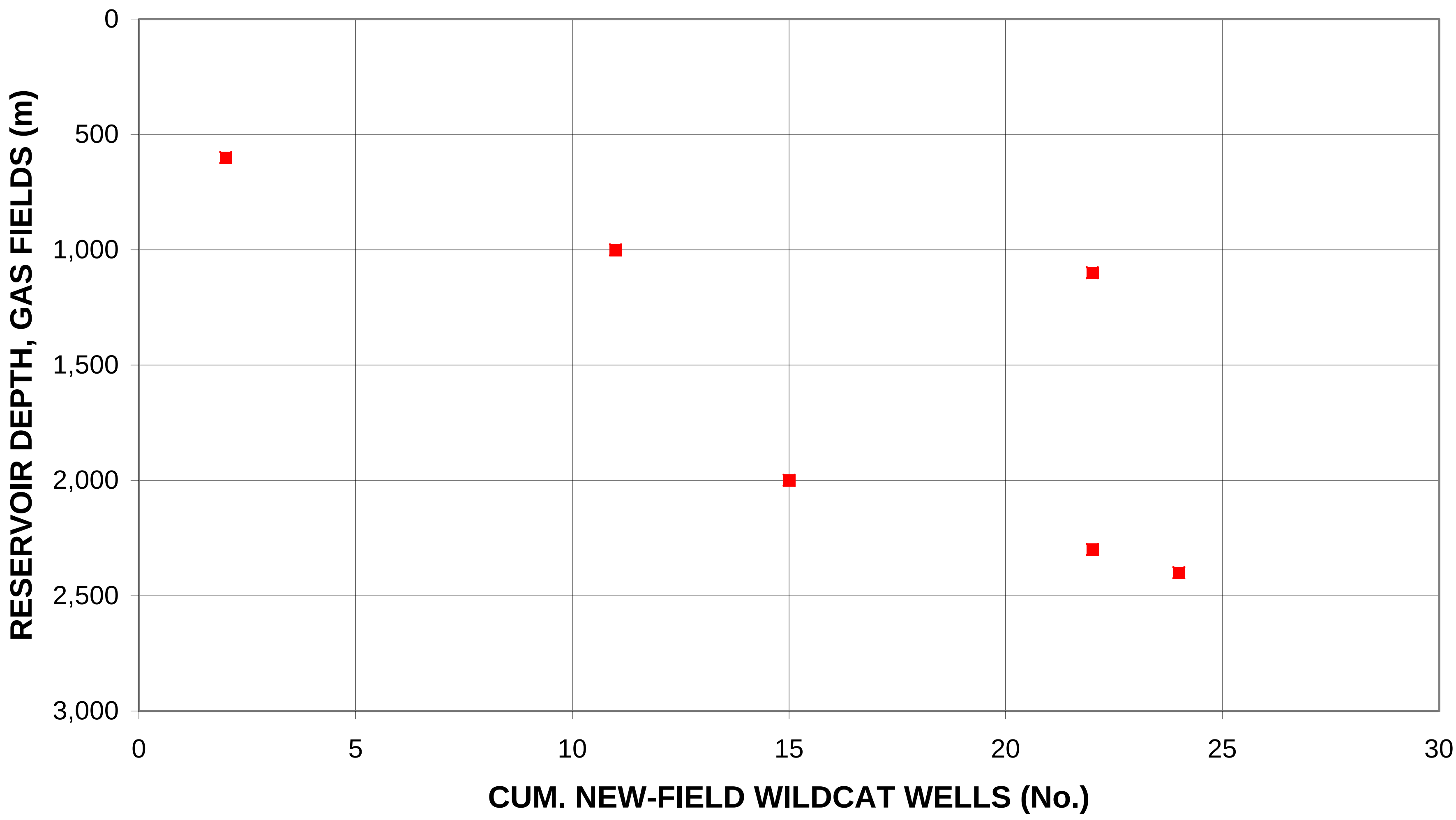
Tanezzuft-Sbaa Structural/Stratigraphic, Assessment Unit 20580301

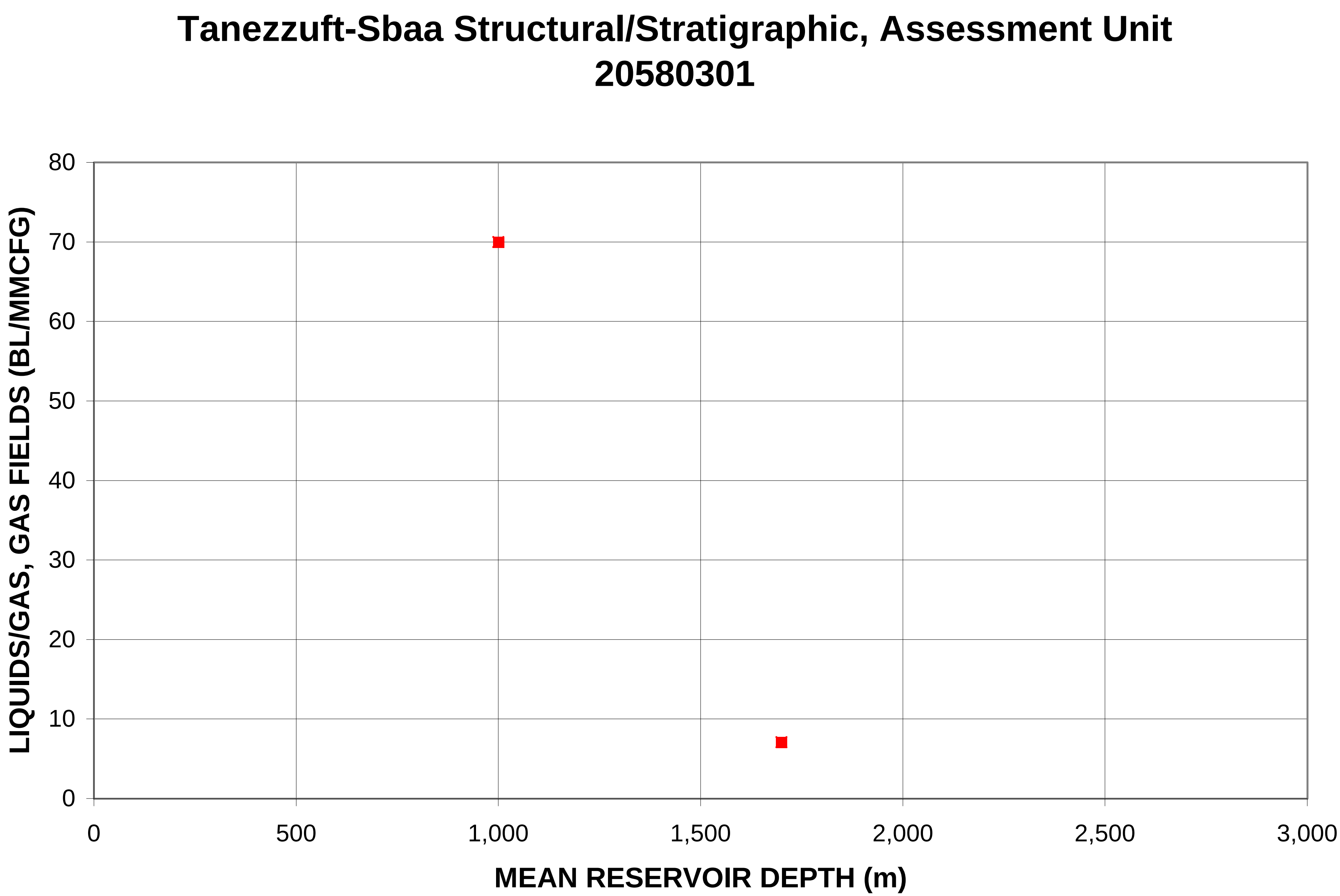




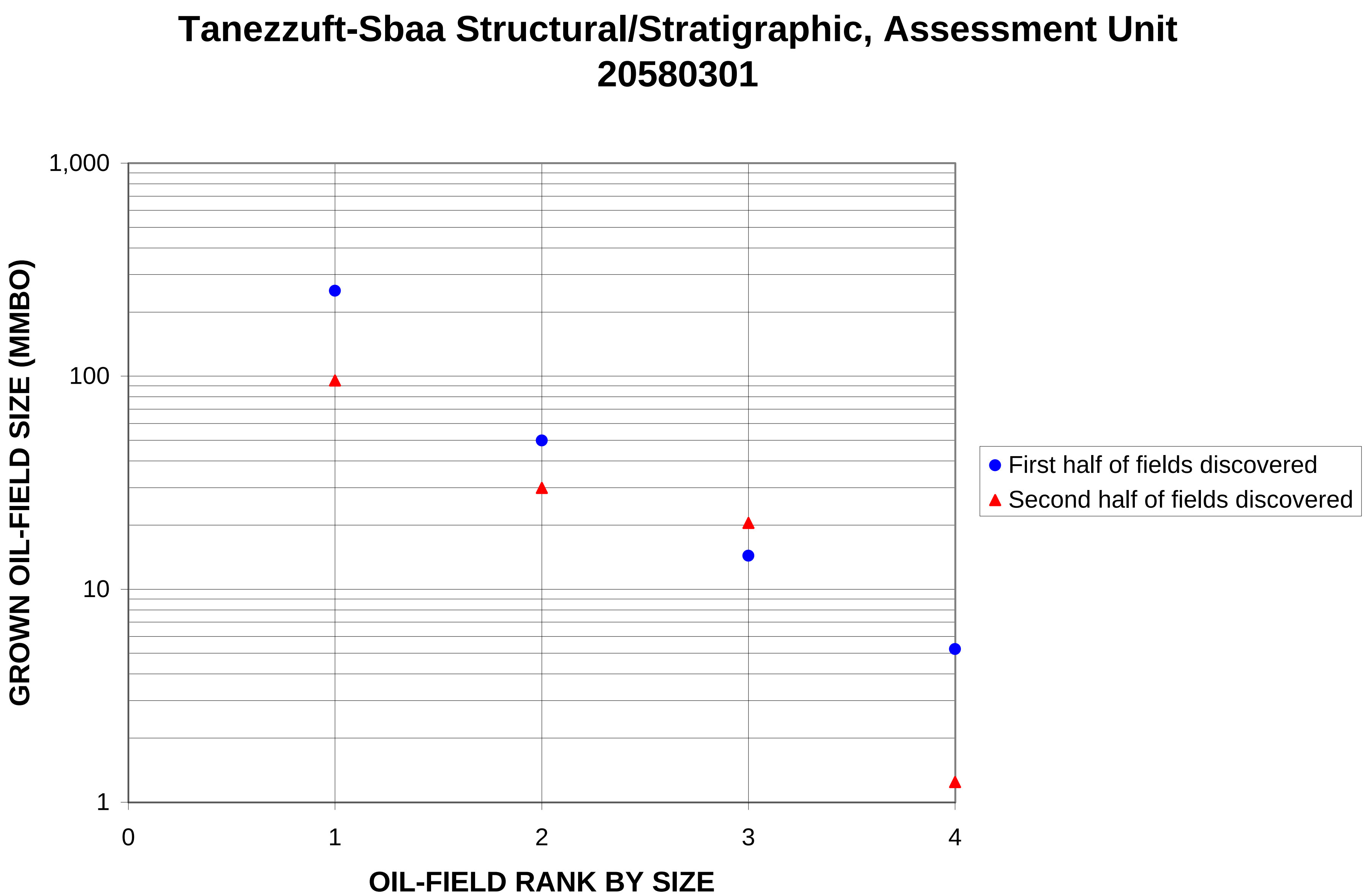
Tanezzuft-Sbaa Structural/Stratigraphic, Assessment Unit 20580301
RESERVOIR DEPTH, GAS FIELDS (m)
0
500
1,000
1,500
2,000
2,500
3,000
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
FIELD-DISCOVERY YEAR

Tanezzuft-Sbaa Structural/Stratigraphic, Assessment Unit 20580301



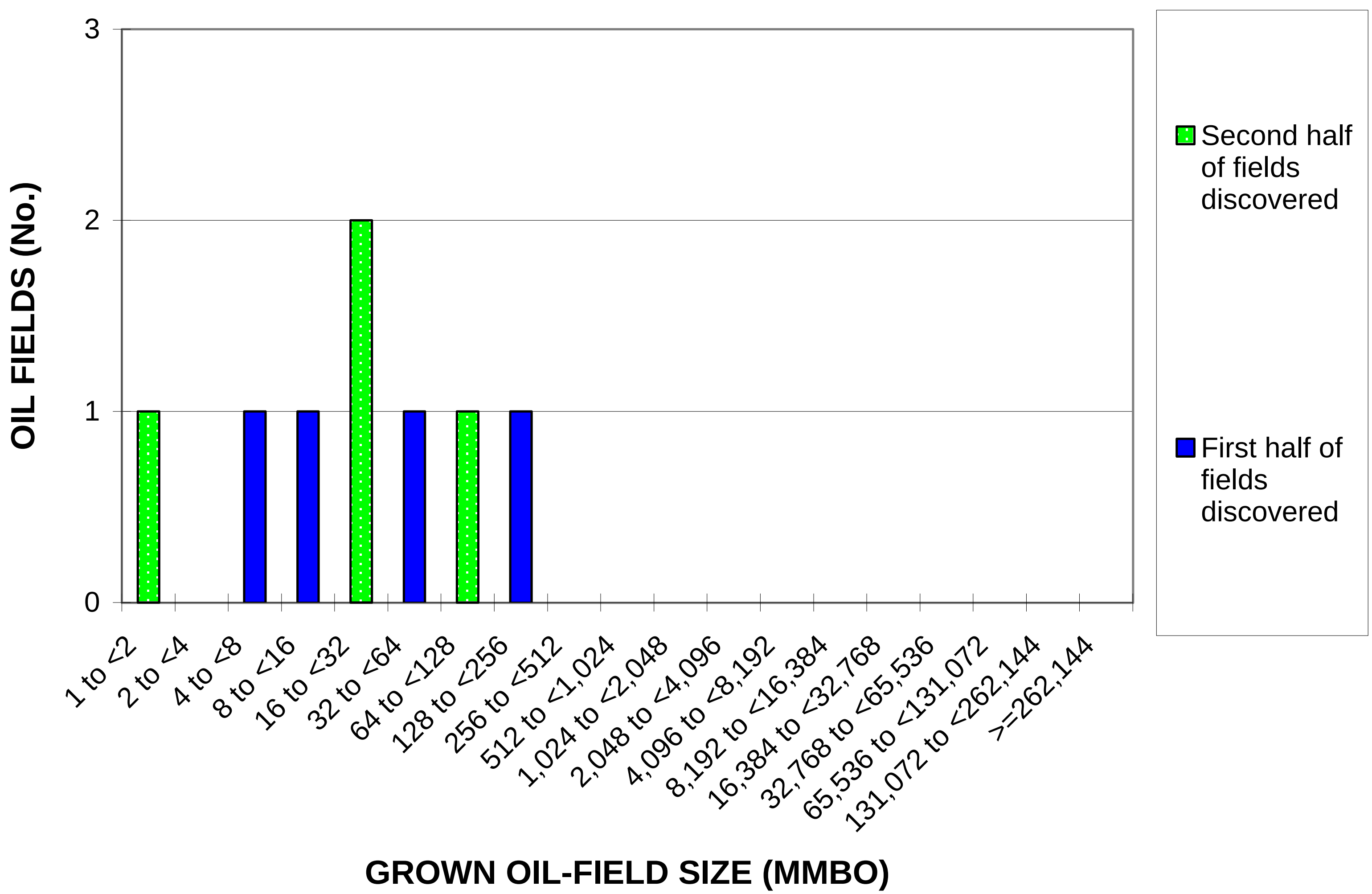


Tanezzuft-Sbaa Structural/Stratigraphic, Assessment Unit 20580301
LIQUIDS/GAS, GAS FIELDS (BL/MMCFG)
0
10
20
30
40
50
60
70
80
0
500
1,000
1,500
2,000
2,500
3,000
MEAN RESERVOIR DEPTH (m)

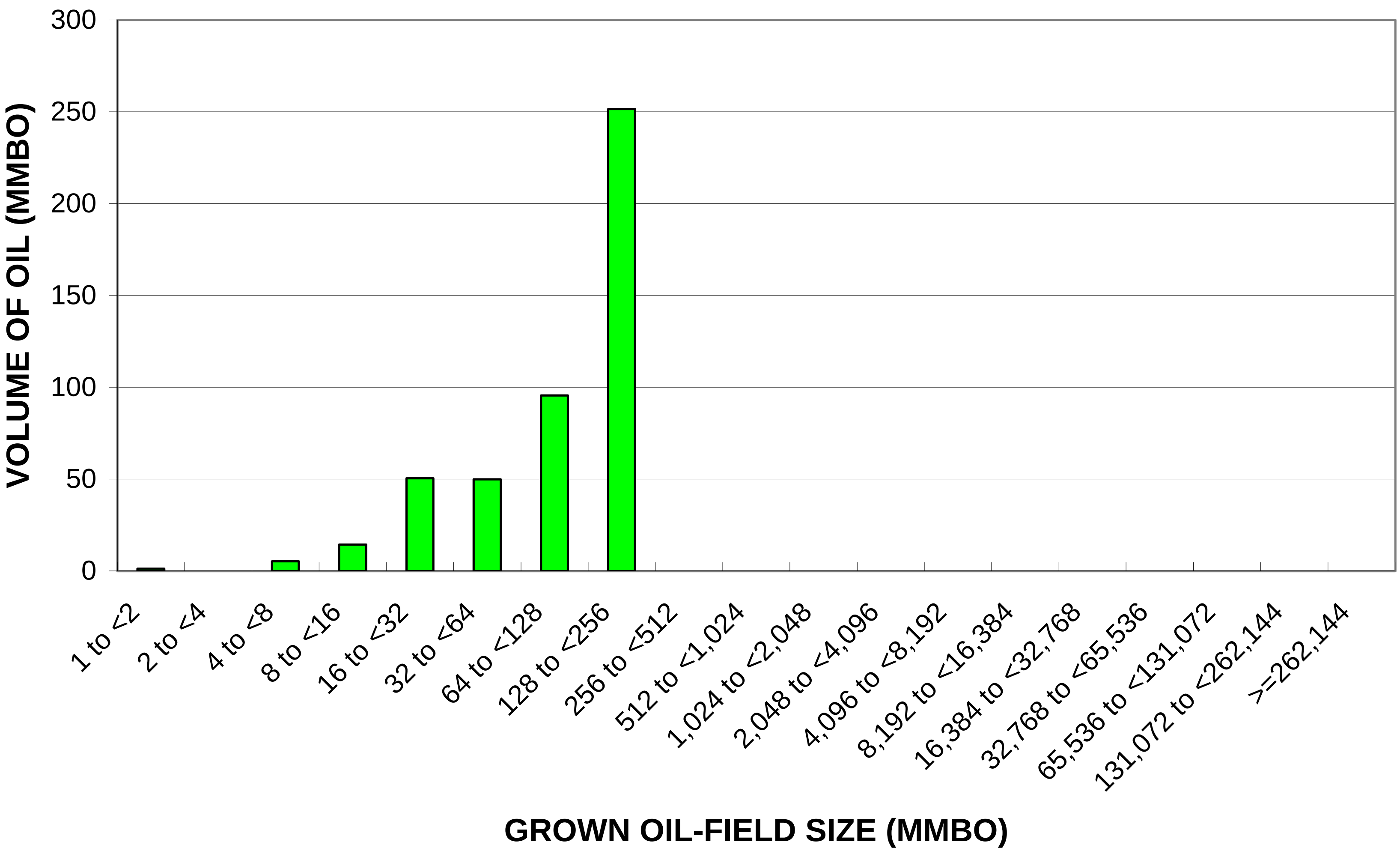


Tanezzuft-Sbaa Structural/Stratigraphic, Assessment Unit 20580301
GROWN OIL-FIELD SIZE (MMBO)
1,000
100
10
1
0
1
2
3
4
OIL-FIELD RANK BY SIZE
First half of fields discovered
Second half of fields discovered

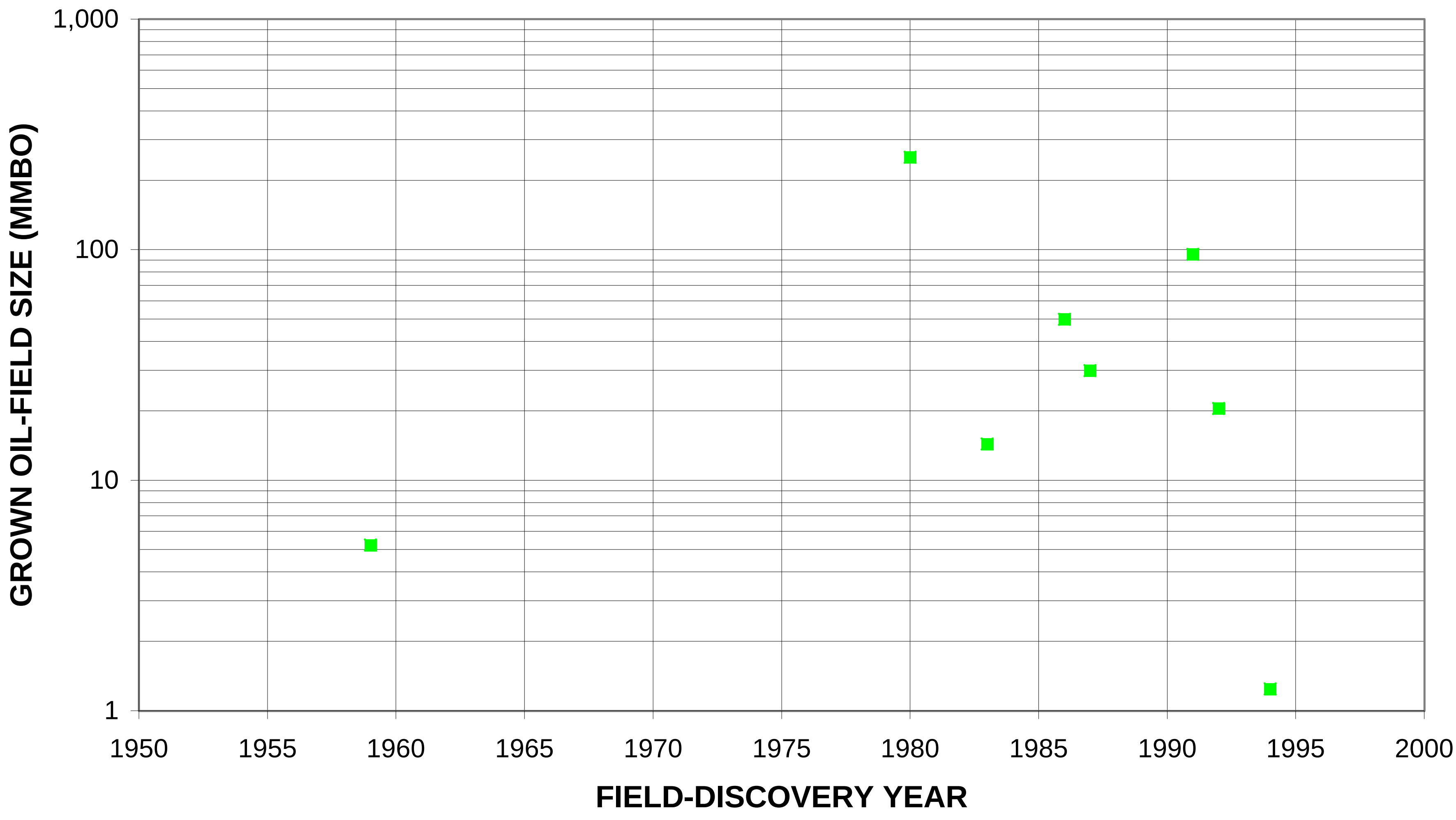
Tanezzuft-Sbaa Structural/Stratigraphic, Assessment Unit 20580301



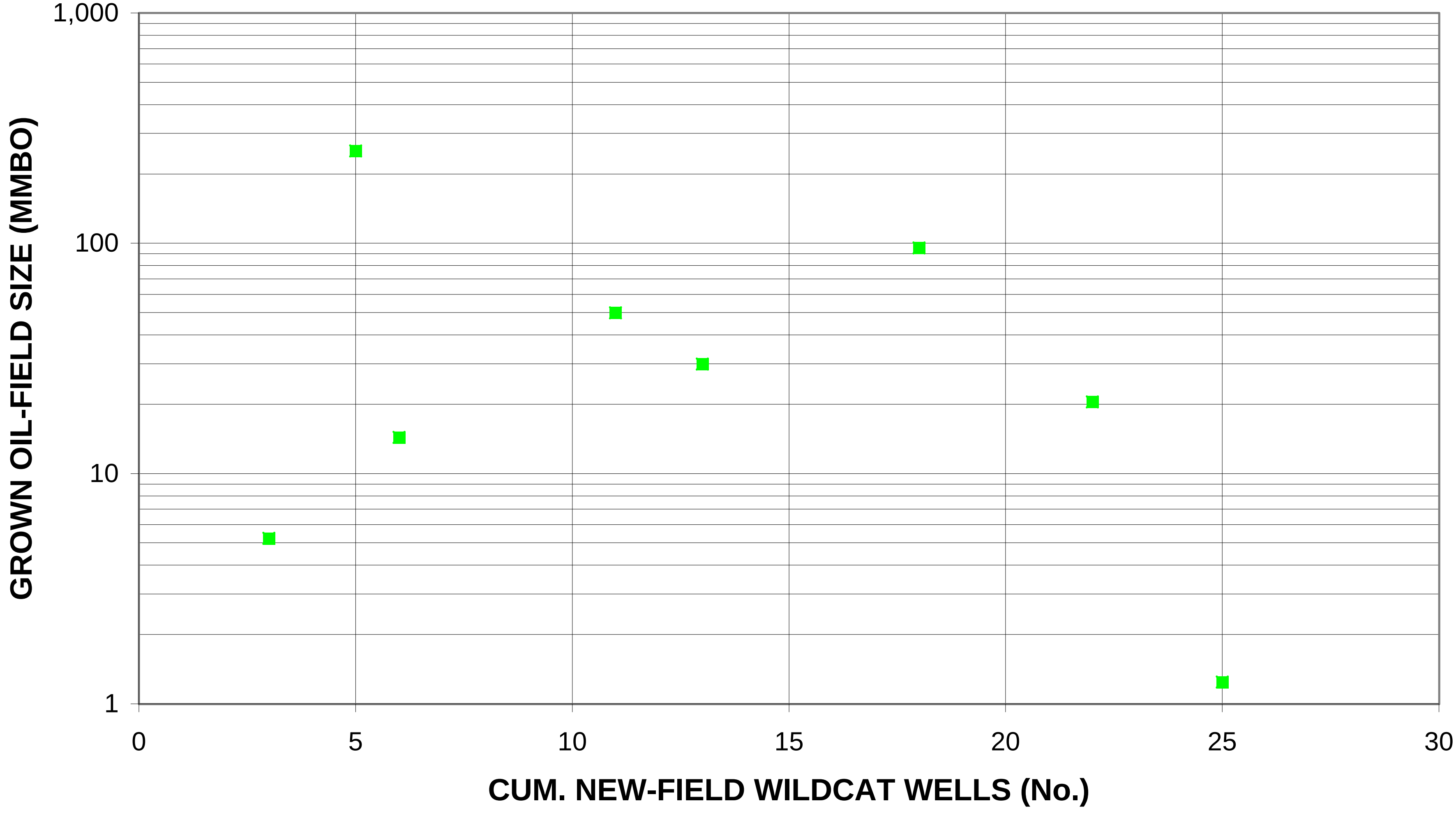
Tanezzuft-Sbaa Structural/Stratigraphic, Assessment Unit 20580301



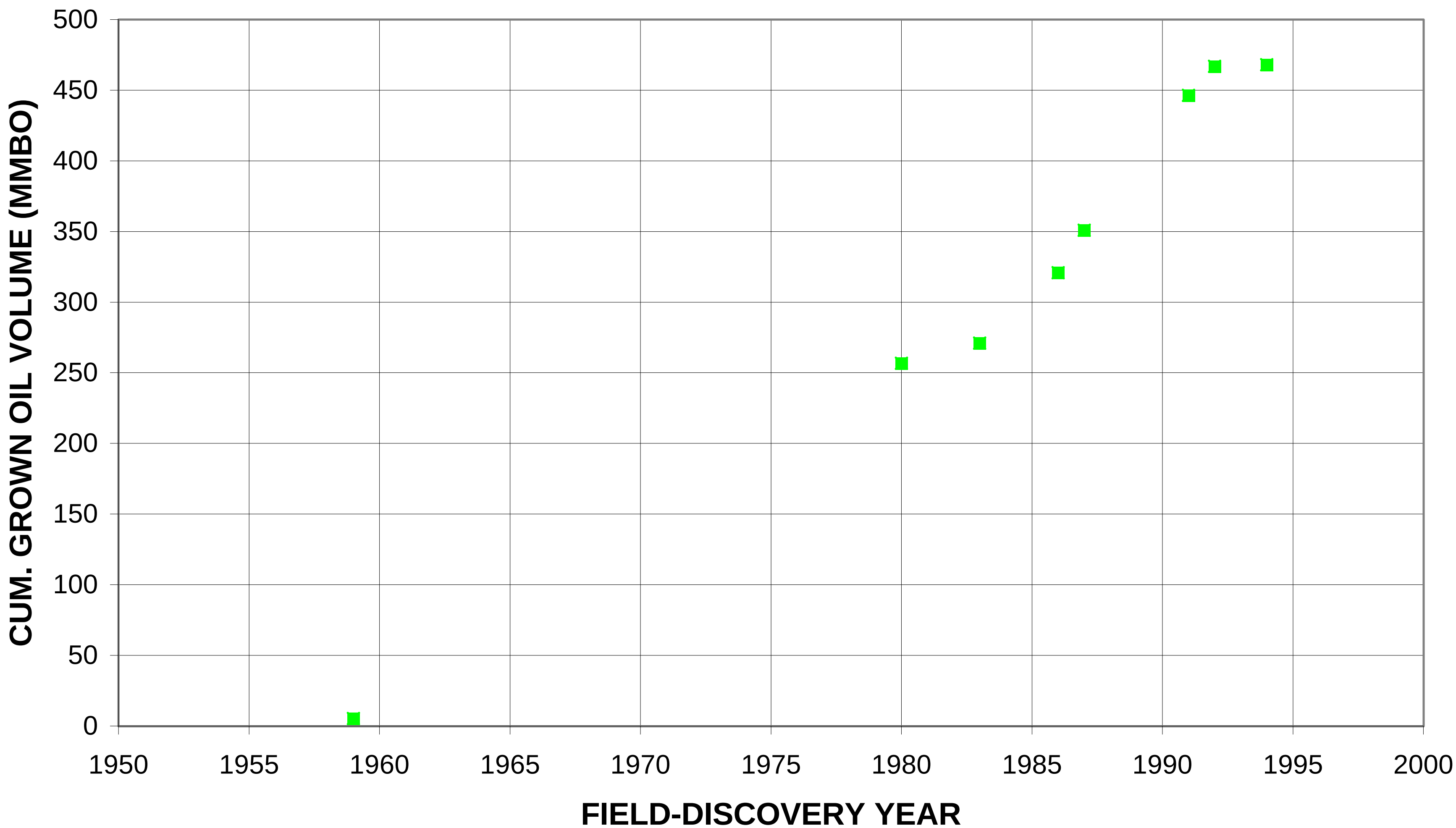
Tanezzuft-Sbaa Structural/Stratigraphic, Assessment Unit 20580301



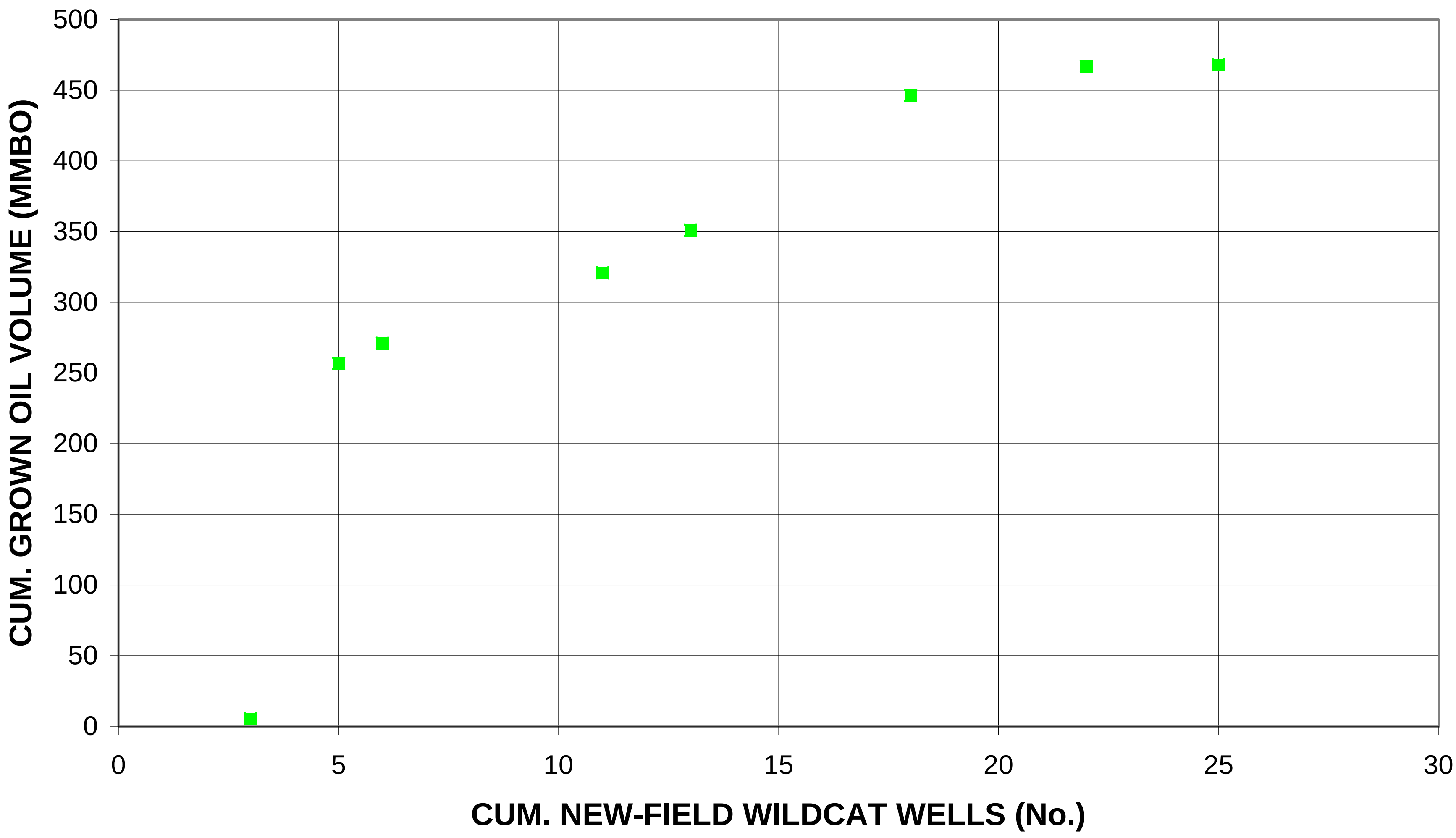
Tanezzuft-Sbaa Structural/Stratigraphic, Assessment Unit 20580301



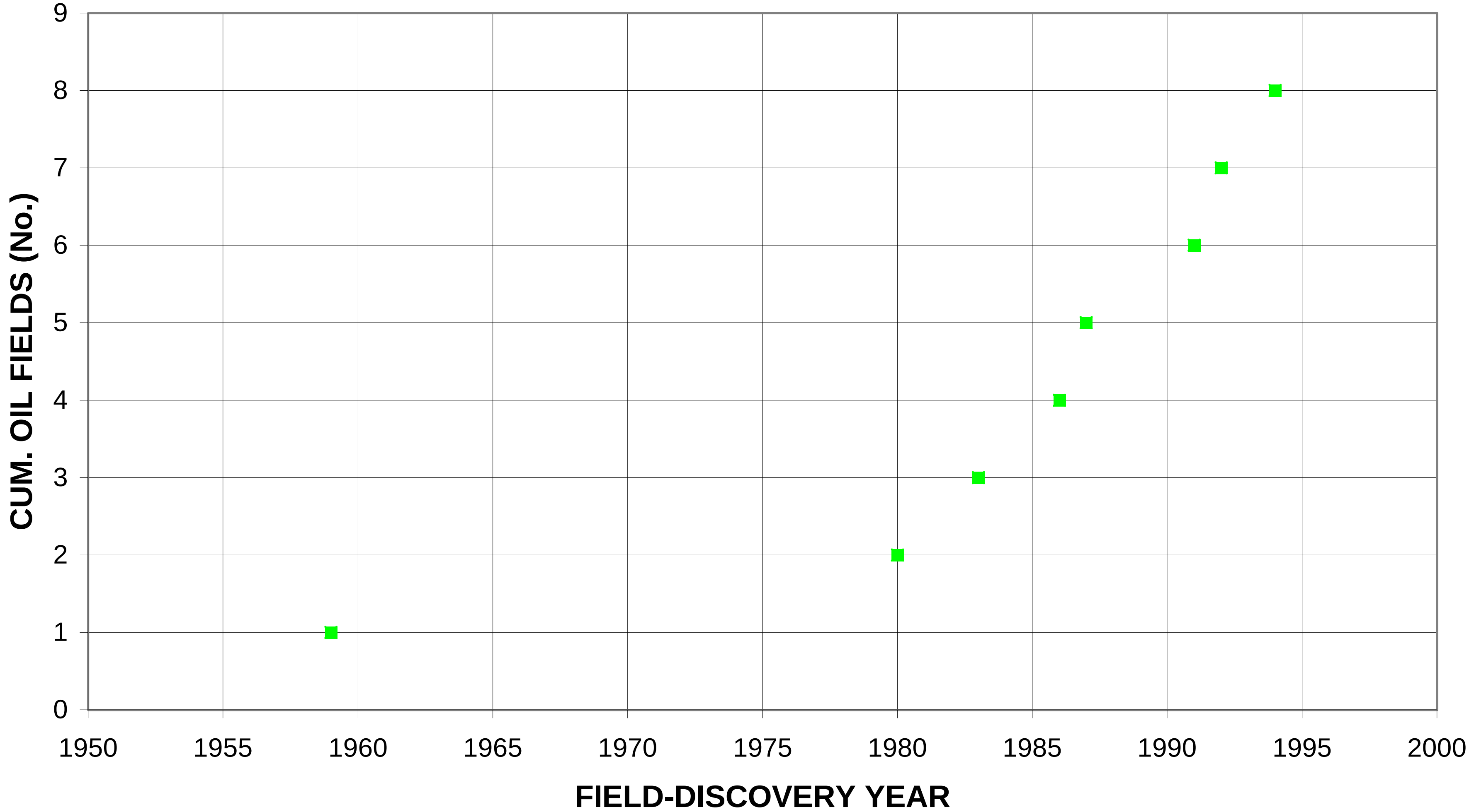
Tanezzuft-Sbaa Structural/Stratigraphic, Assessment Unit 20580301

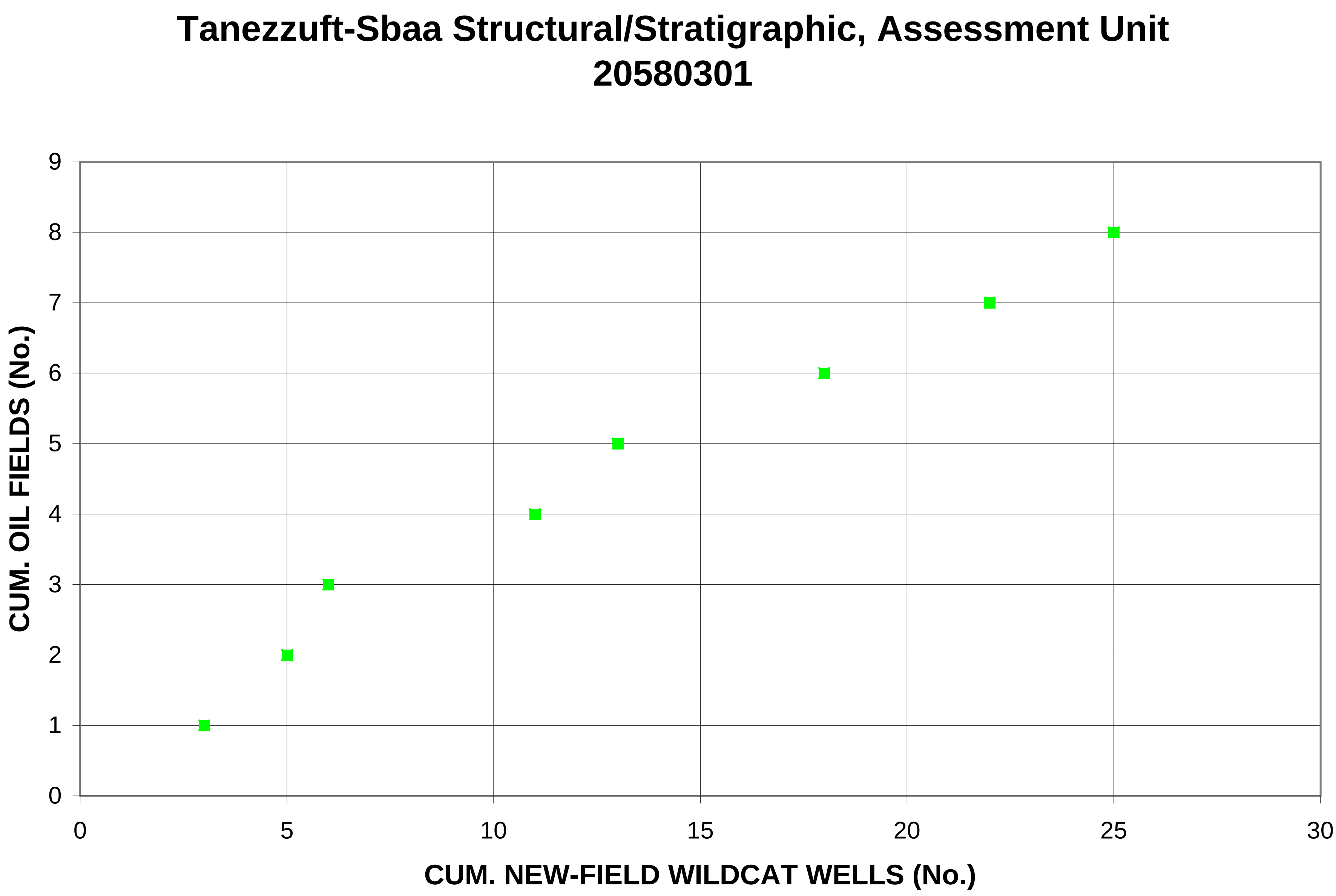


Tanezzuft-Sbaa Structural/Stratigraphic, Assessment Unit 20580301



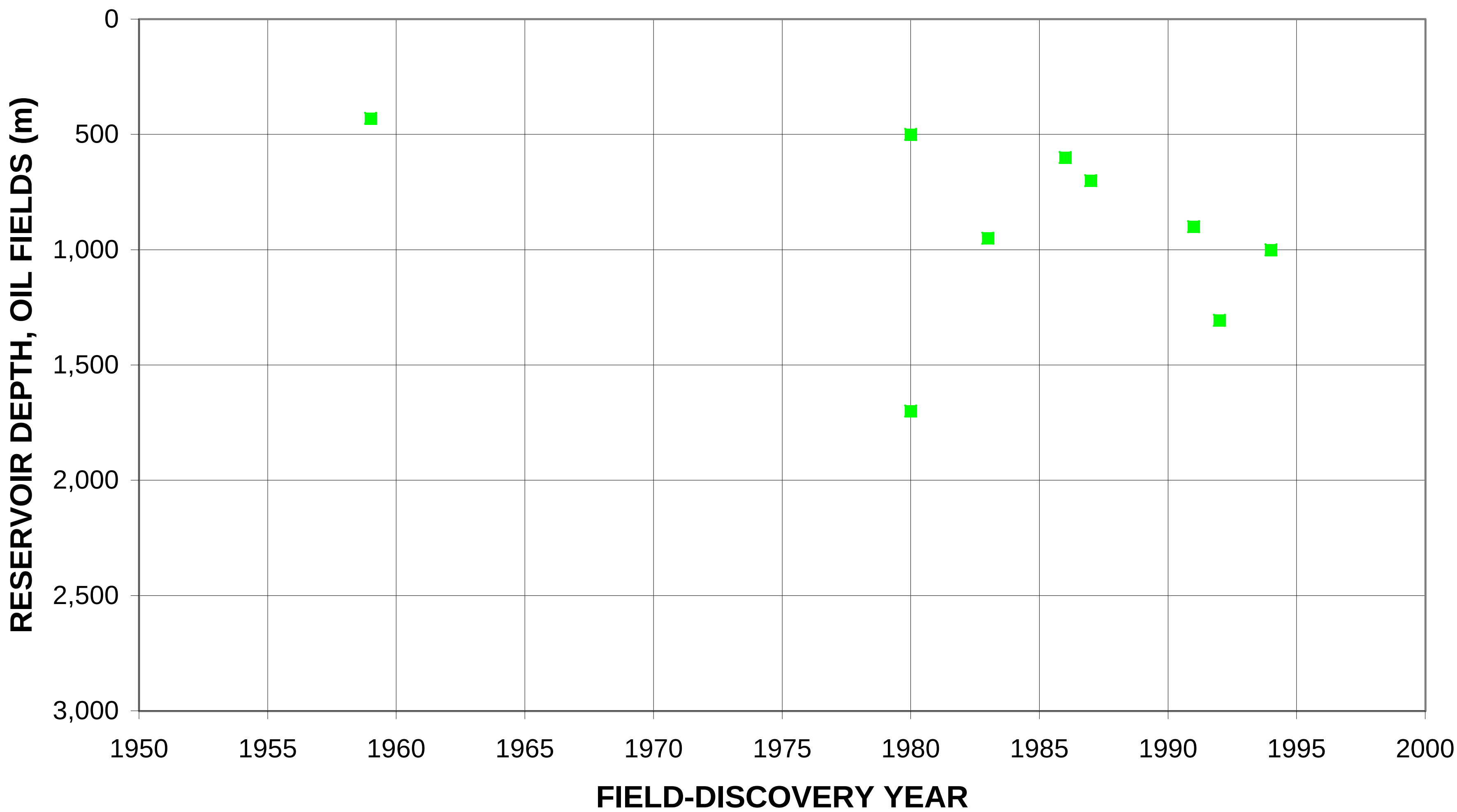
Tanezzuft-Sbaa Structural/Stratigraphic, Assessment Unit 20580301



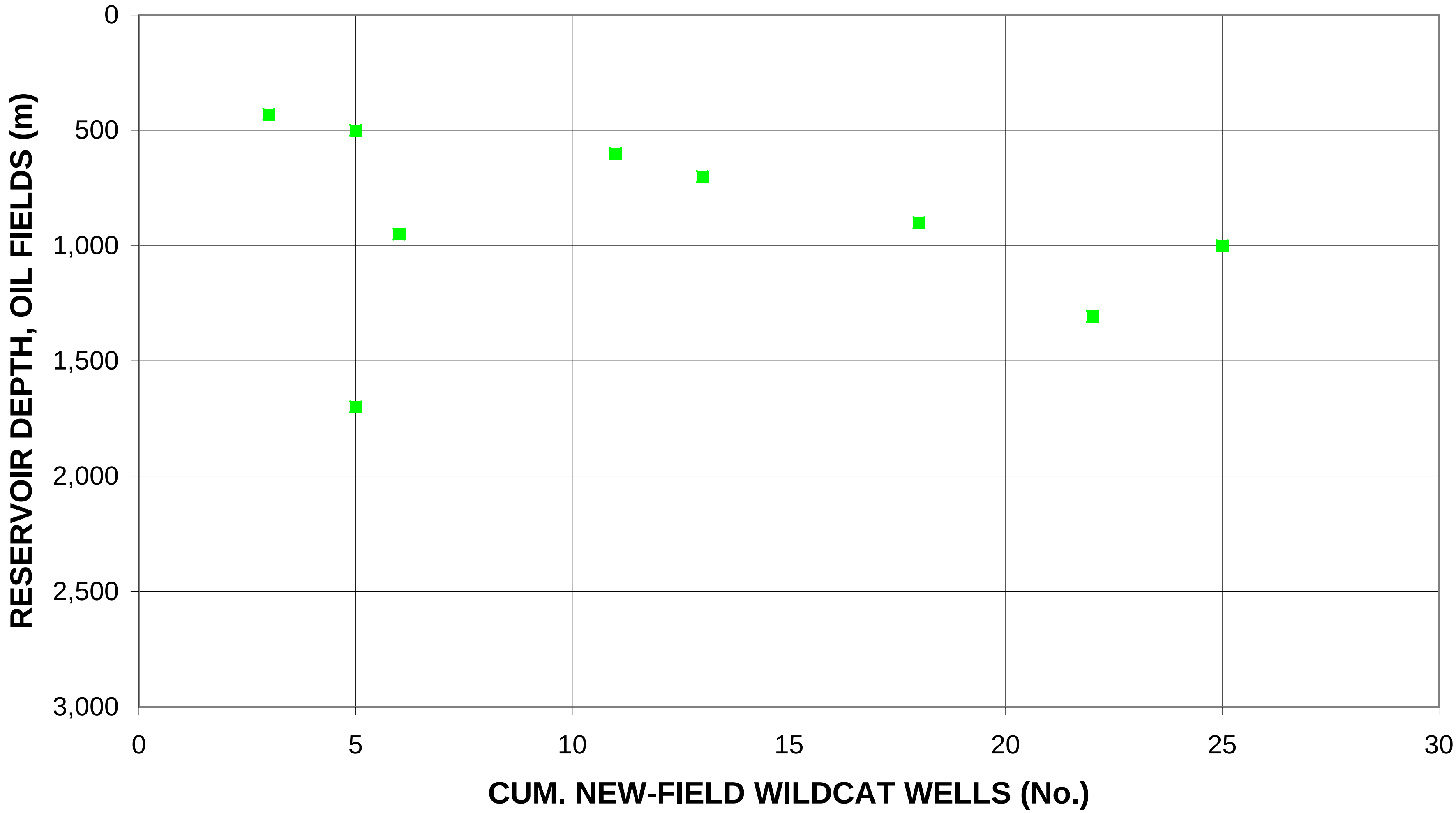


Tanezzuft-Sbaa Structural/Stratigraphic, Assessment Unit 20580301
CUM. OIL FIELDS (No.)
0
1
2
3
4
5
6
7
8
9
0
5
10
15
20
25
30
CUM. NEW-FIELD WILDCAT WELLS (No.)

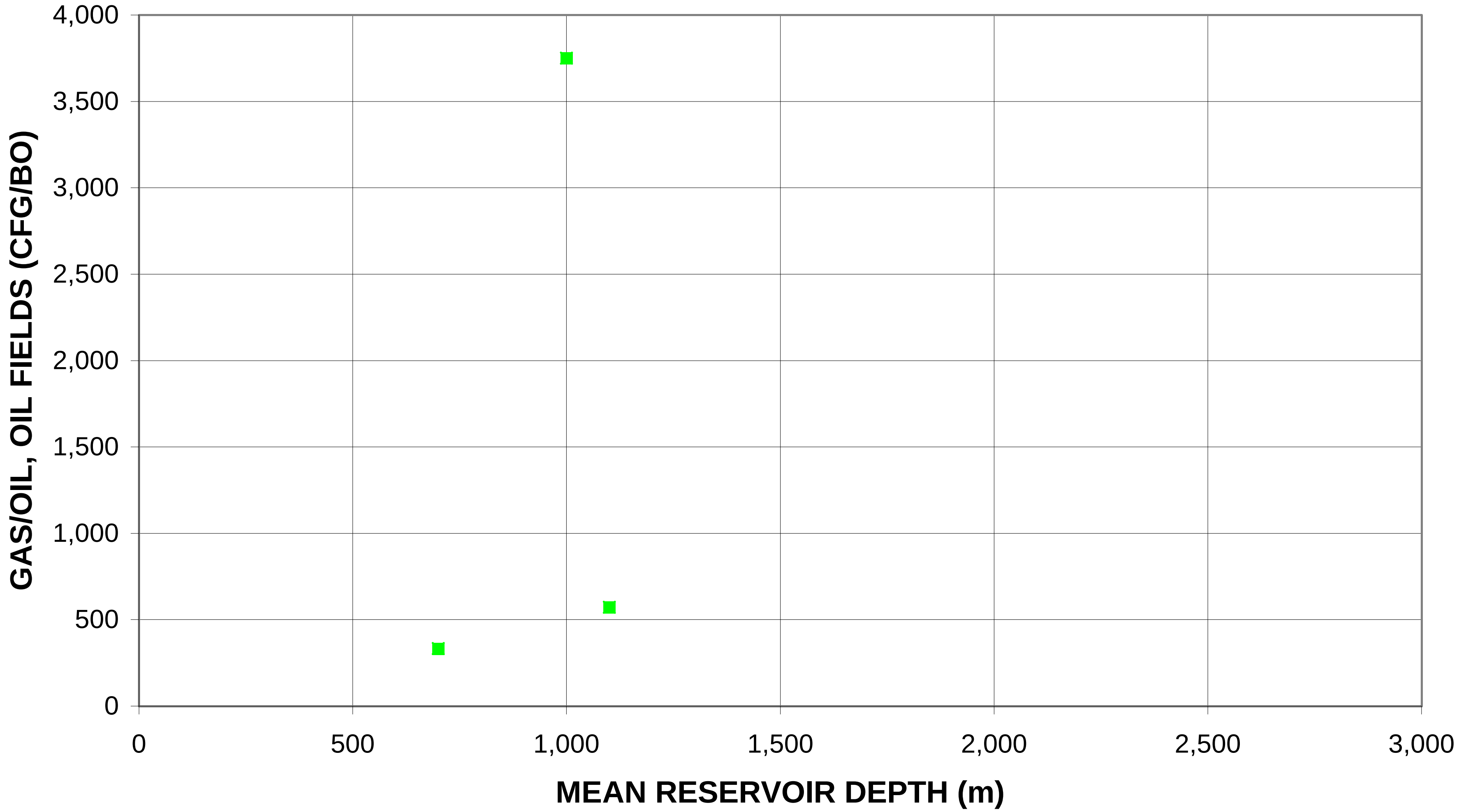
Tanezzuft-Sbaa Structural/Stratigraphic, Assessment Unit 20580301



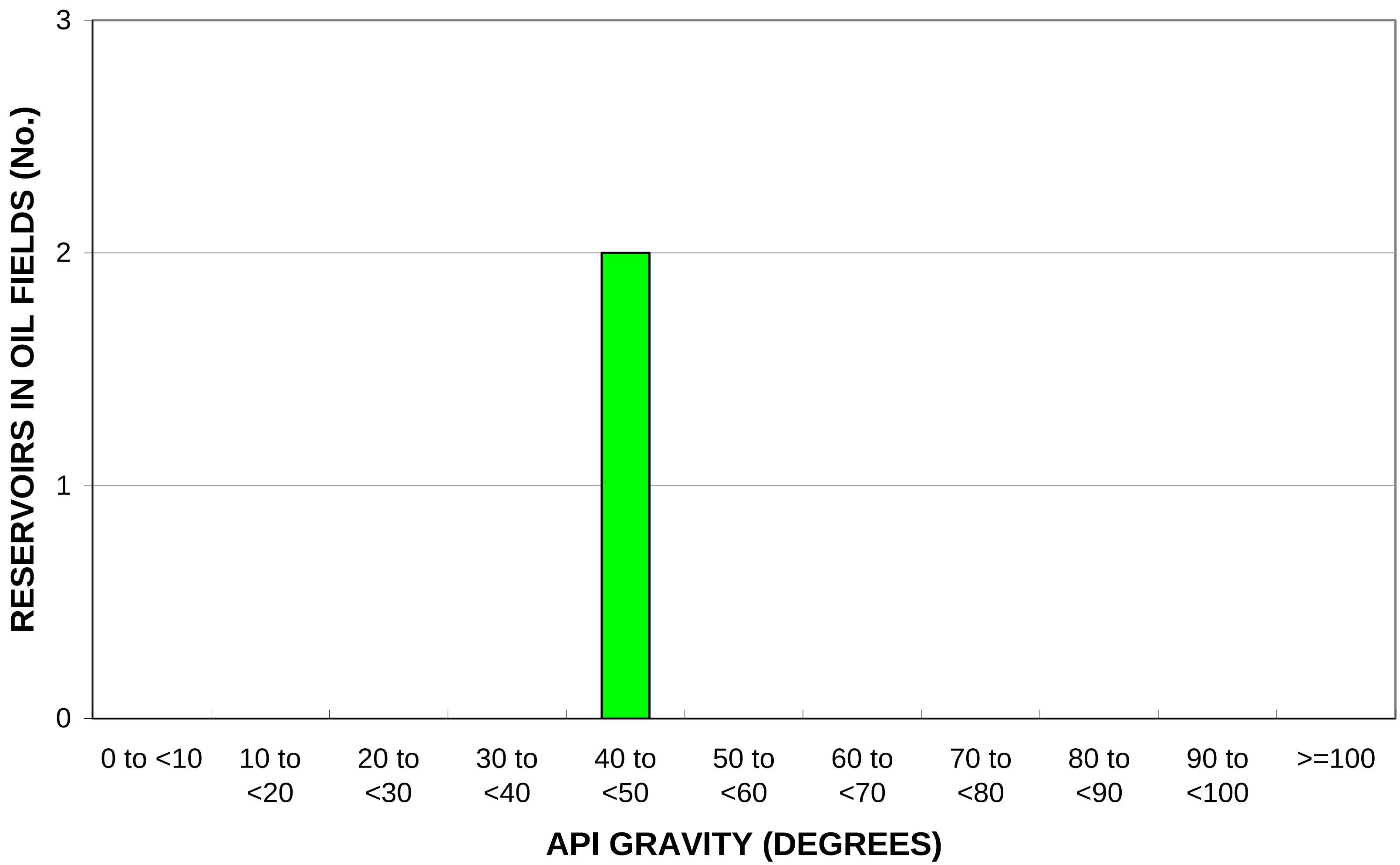
Tanezzuft-Sbaa Structural/Stratigraphic, Assessment Unit 20580301



Tanezzuft-Sbaa Structural/Stratigraphic, Assessment Unit 20580301



Tanezzuft-Sbaa Structural/Stratigraphic, Assessment Unit 20580301



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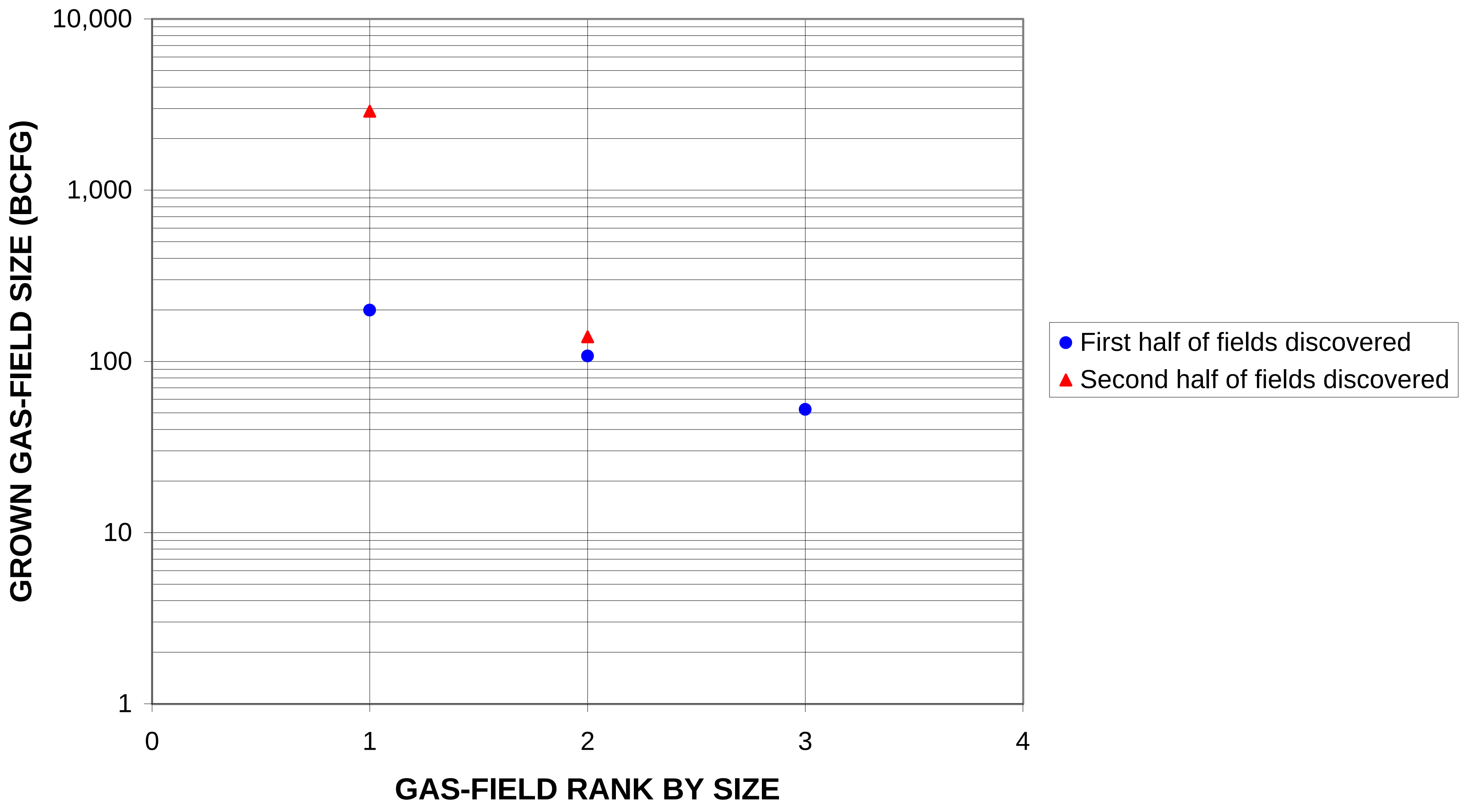

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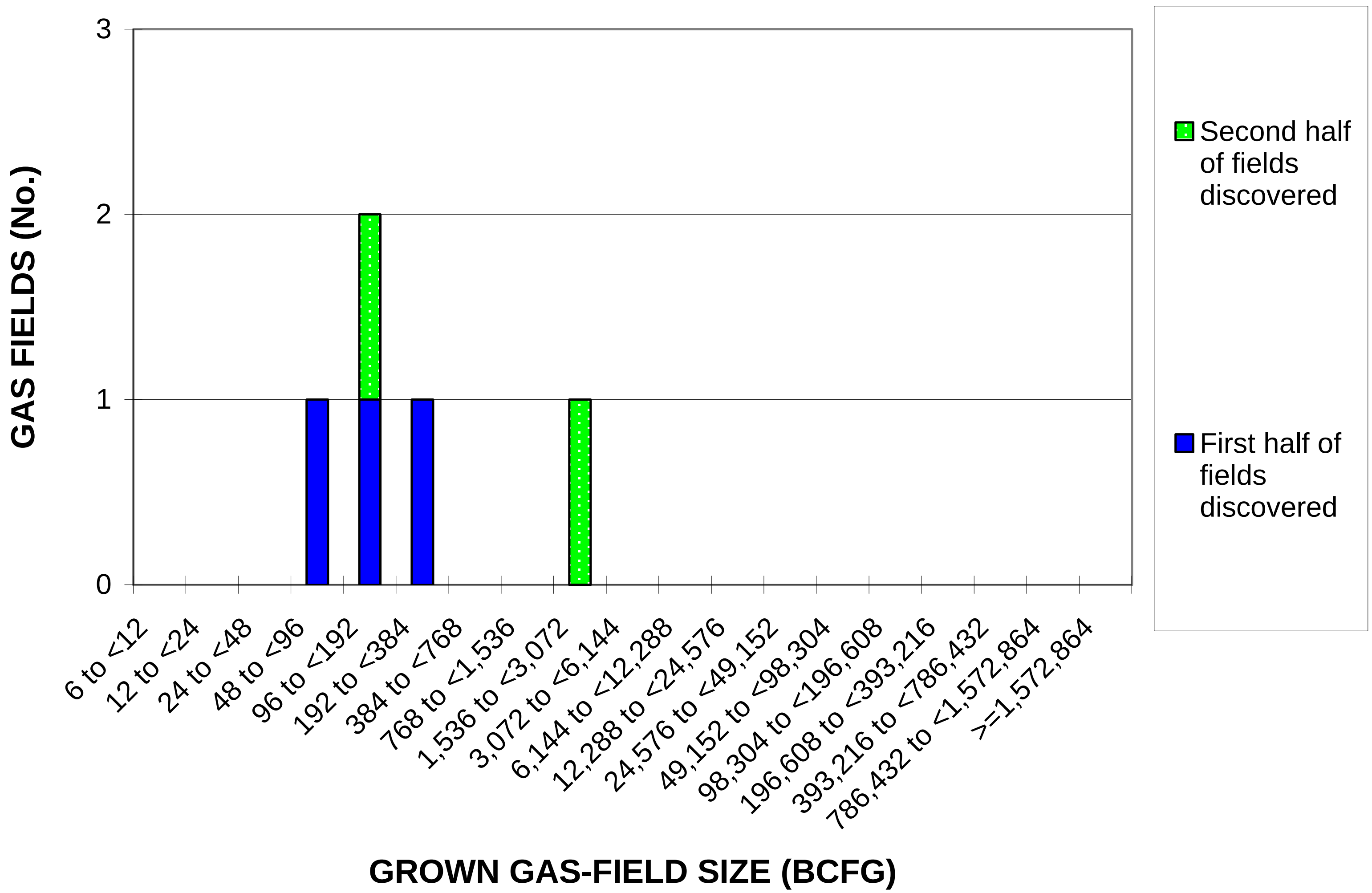

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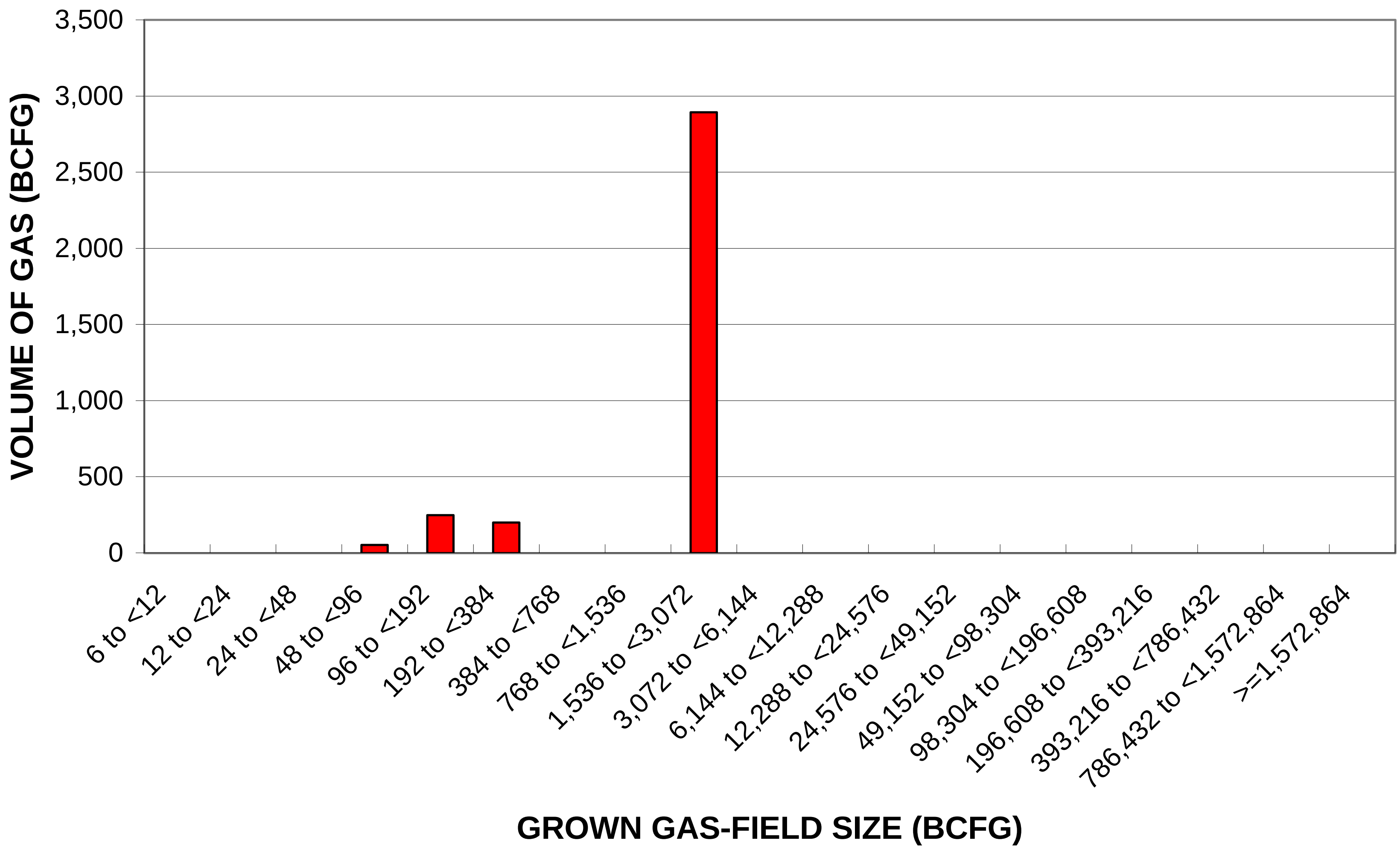

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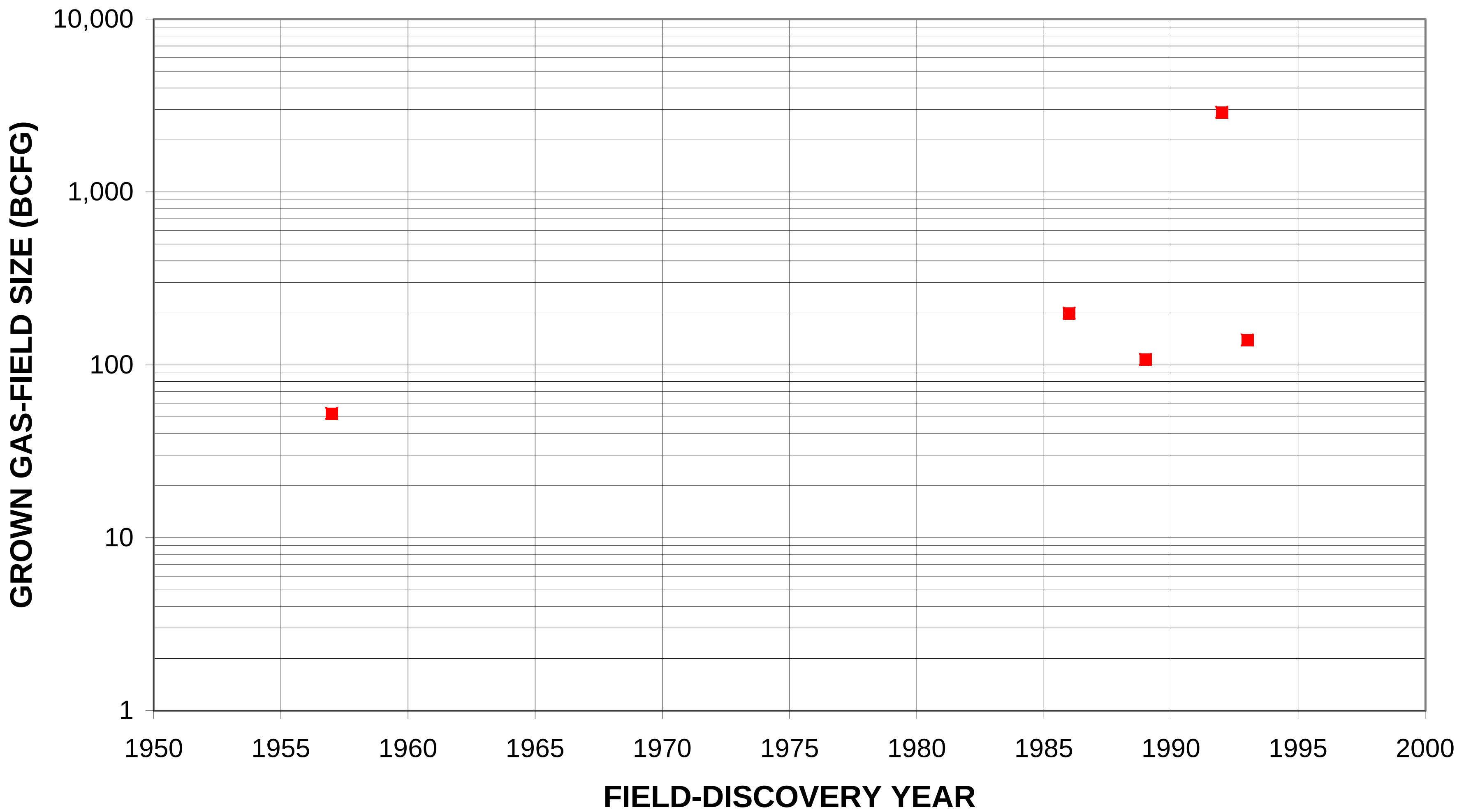

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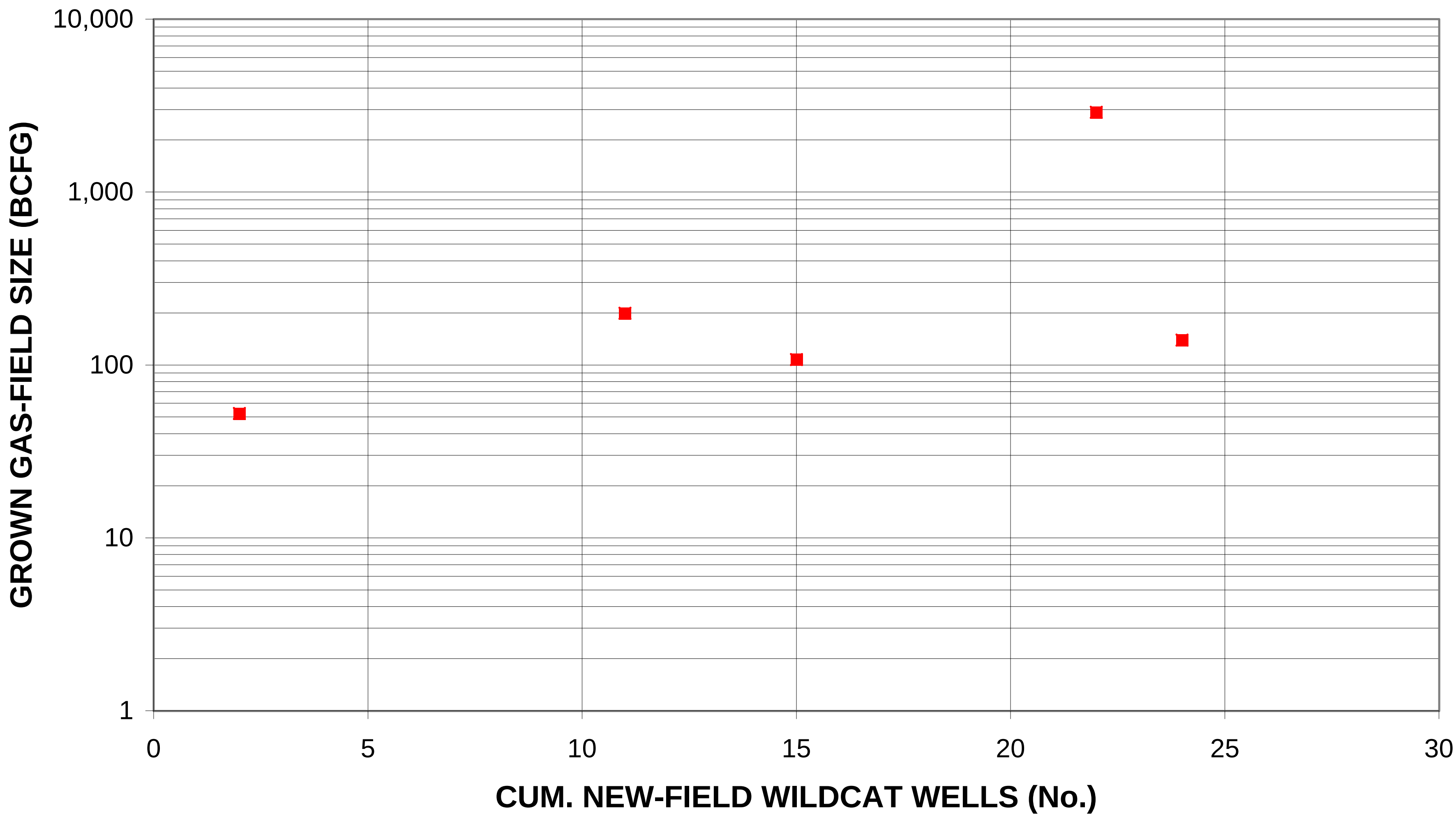

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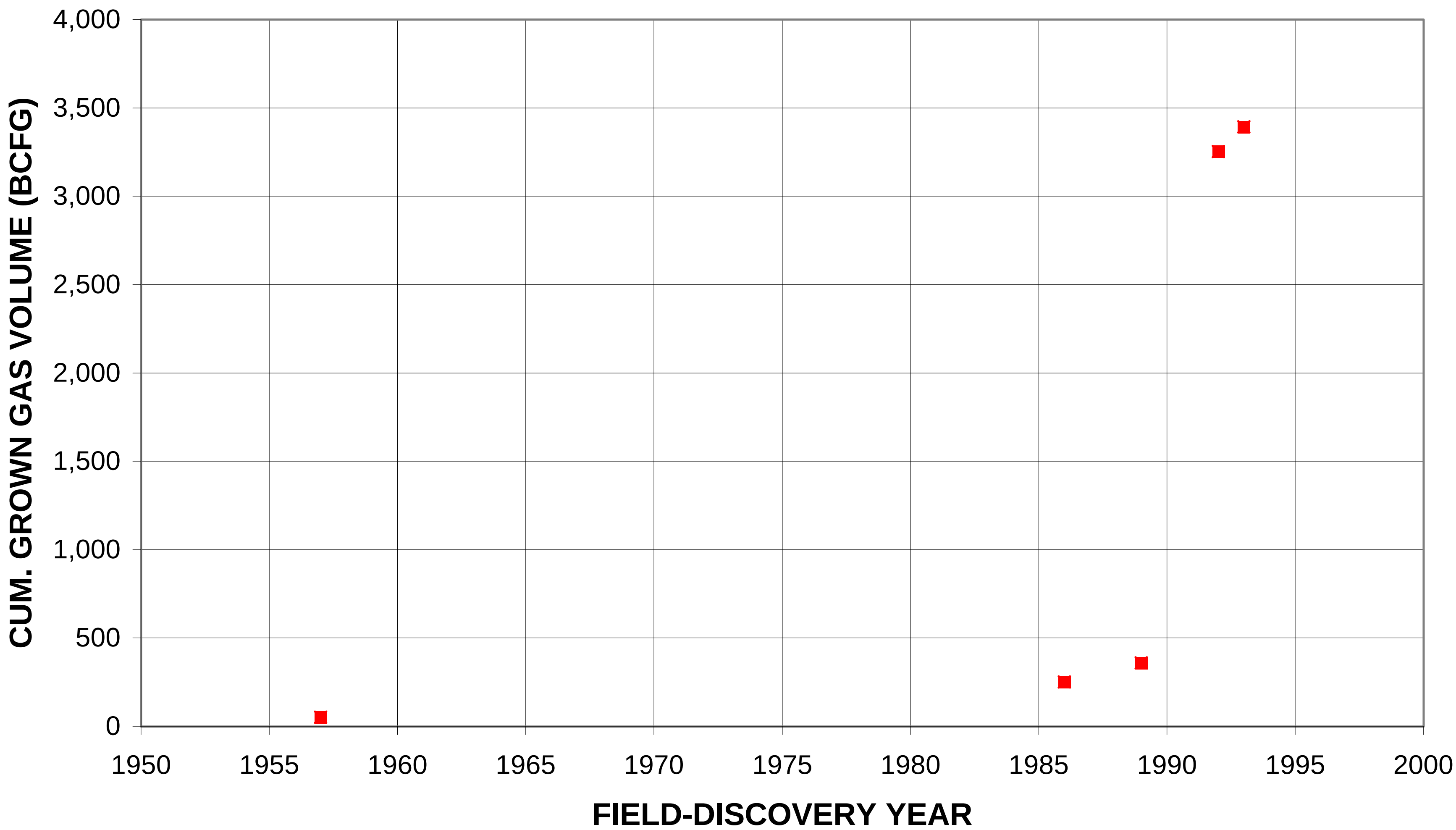

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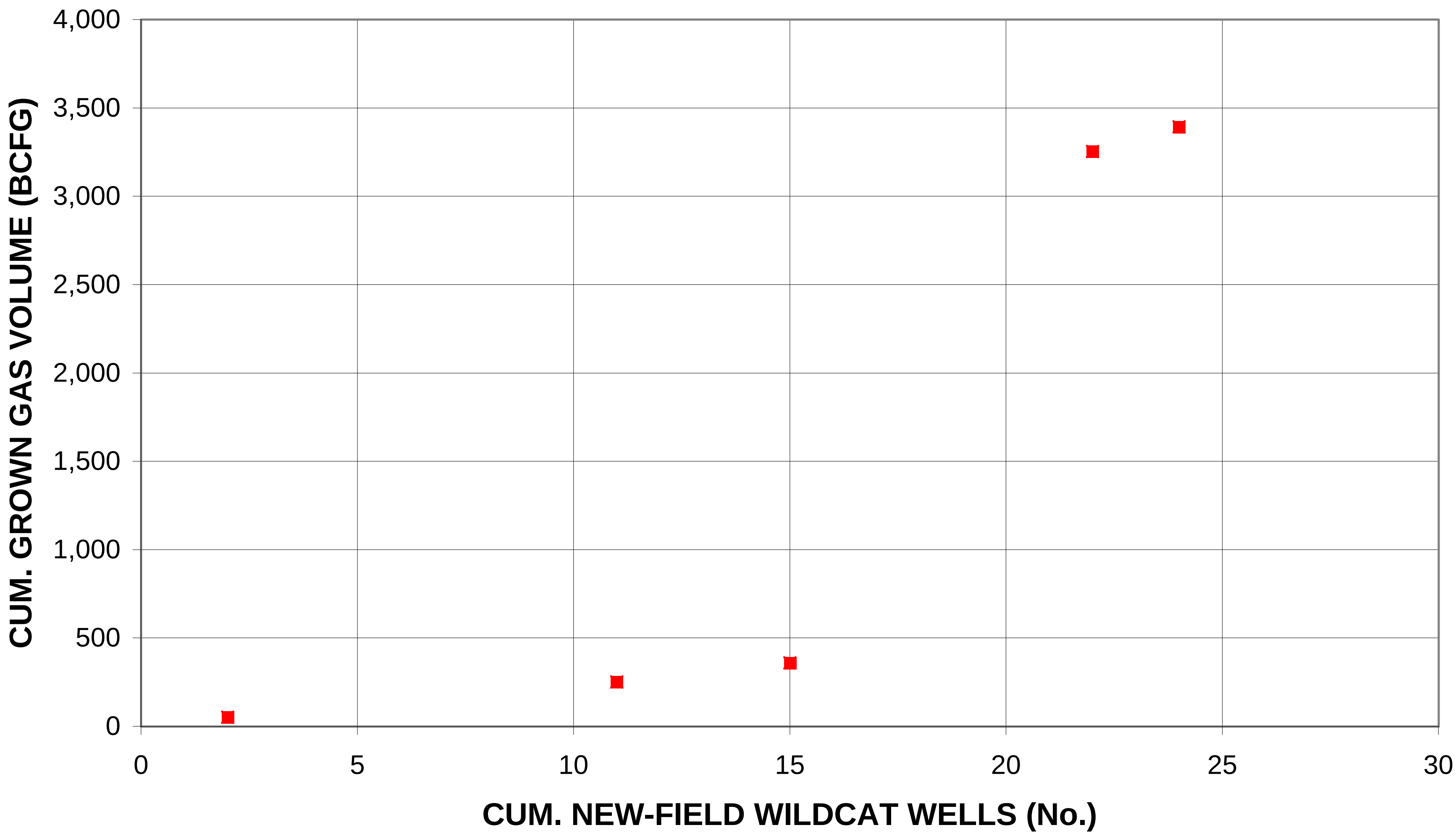

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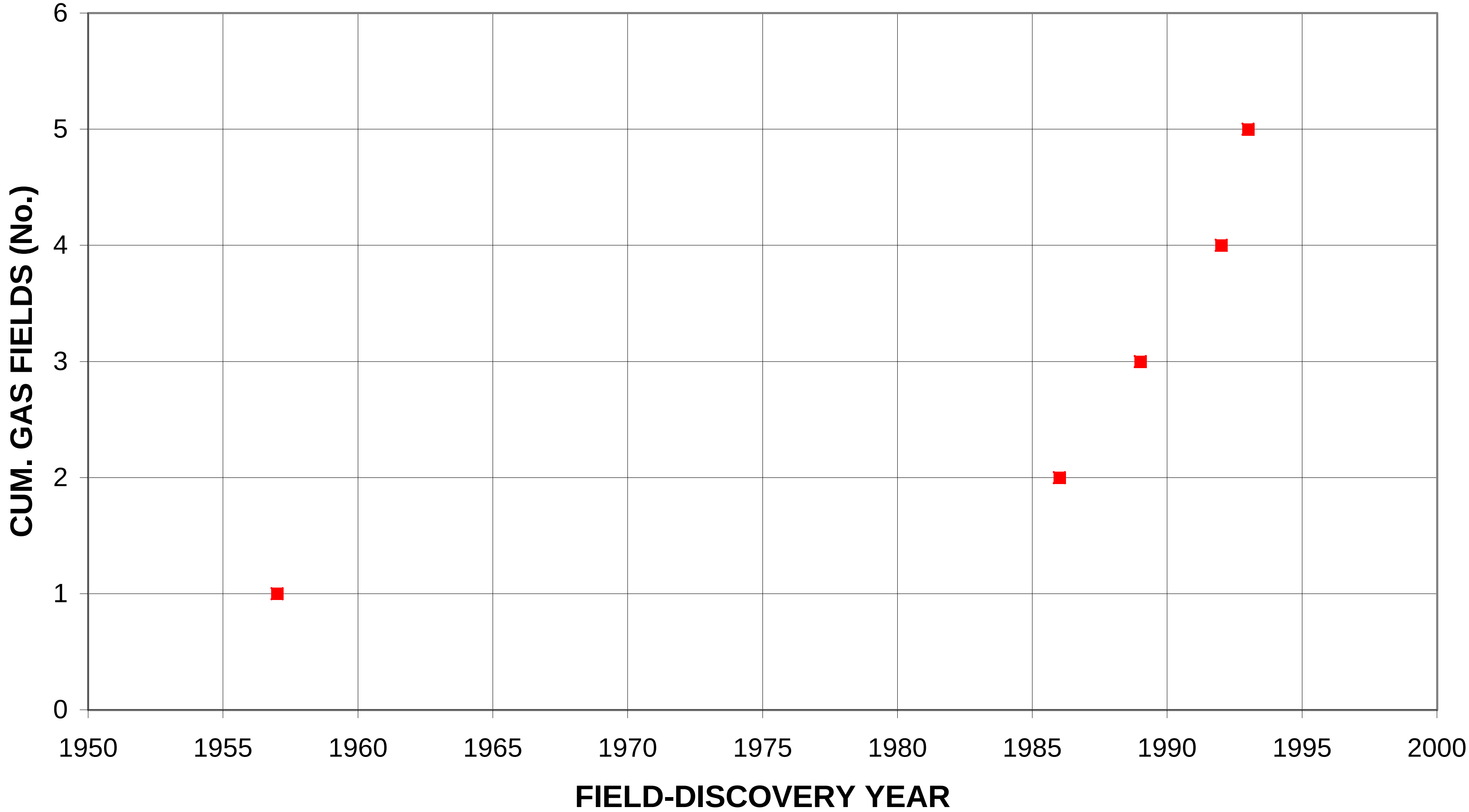

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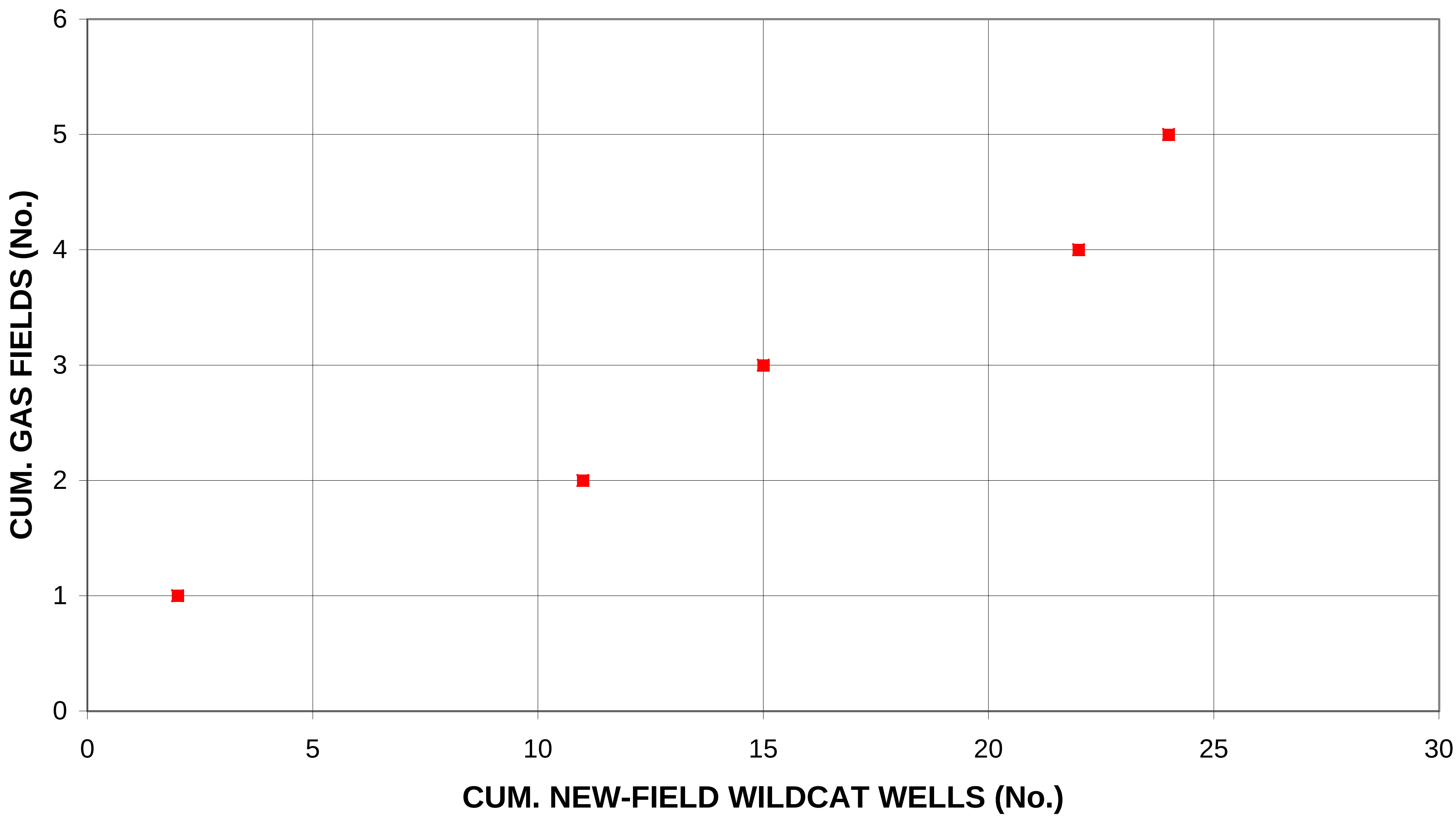

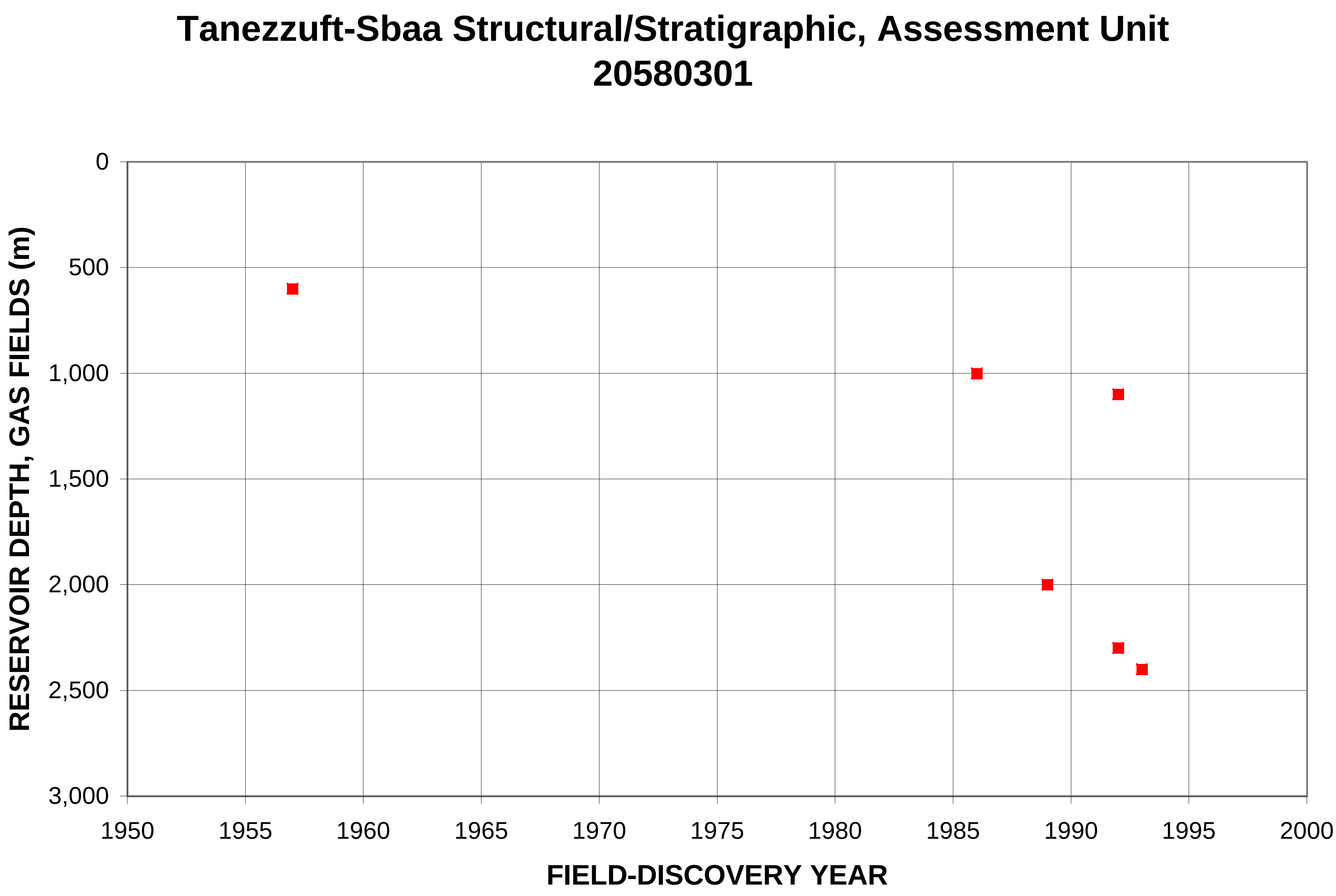

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RESERVOIR DEPTH, GAS FIELDS (m)
0
500
1,000
1,500
2,000
2,500
3,000
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
FIELD-DISCOVERY YEAR

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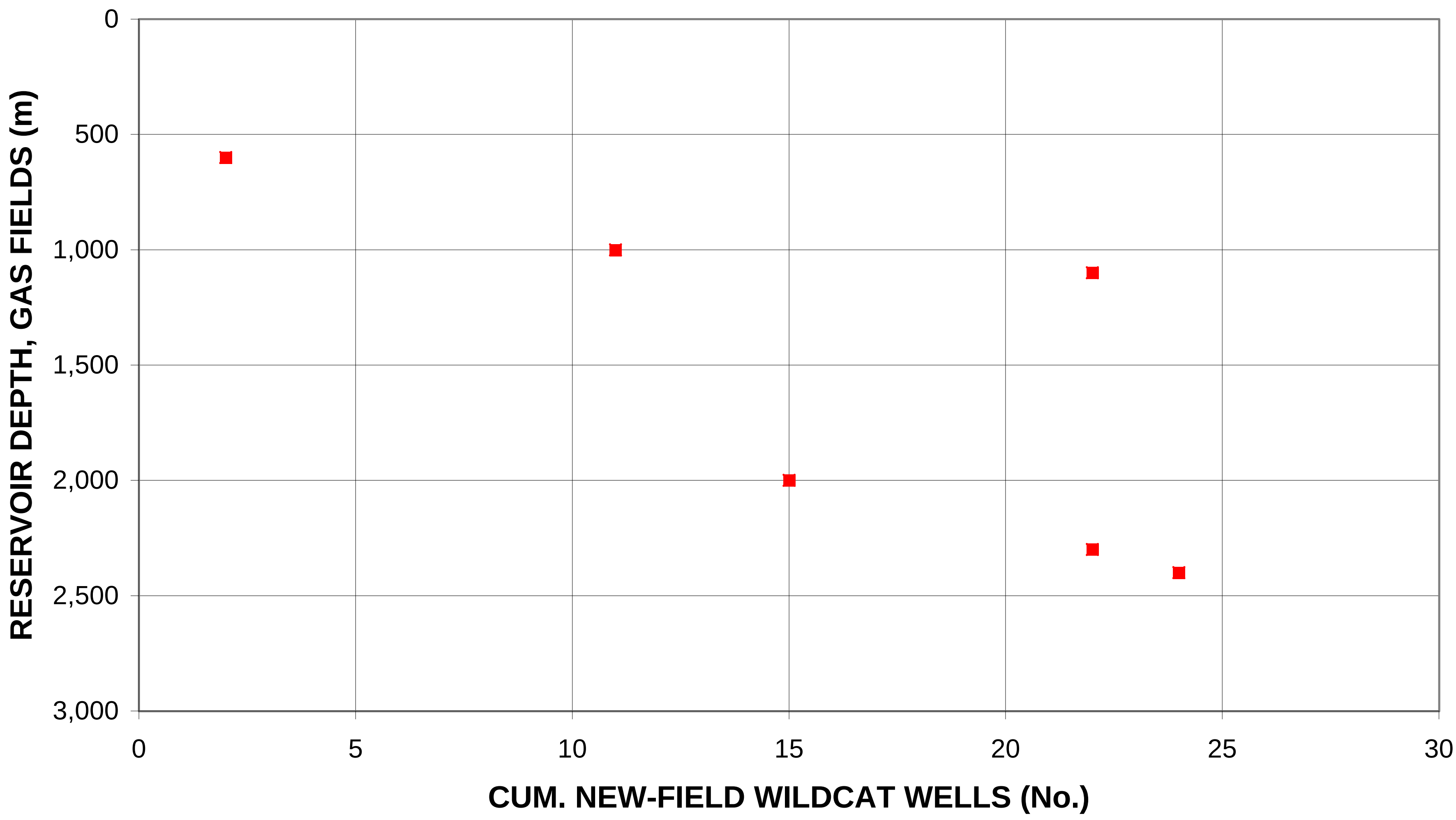

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