FINAL REPORT

Methodologies for Reservoir Characterizations Using Fluid Inclusion Gas Chemistry

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Prepared by:

Lorie M. Dilley, PhD, PE/CPG
Principal Geologist

HATTENBURG DILLEY & LINNELL
Engineering Consultants
3335 Arctic Boulevard, Suite 100
Anchorage, Alaska 99503

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EXECUTIVE SUMMARY

The project "Methodologies for Reservoir Characterization using Fluid Inclusion Gas Chemistry" has been completed. The project had the following goals:

1. Evaluate the relationship between the fluid inclusion gas signatures and rock types, vein mineralogy, geologic environment and temperature.
2. Evaluate FIS signatures based on processes affecting the fluids (boiling, mixing, condensation, and conductive cooling) and fluid/rock interactions.
3. Develop methodologies for interpretation of the fluid inclusion gas data in order to identify fluid types, regions of permeability, and geothermal processes.

The following has been accomplished:

1. Task 1 was completed with submission of the data to the National Geothermal Database in March, 2013.
2. Task 2 was accomplished in May, 2013 with additional sampling of three wells from the Puna geothermal field, Hawaii.
3. We have analyzed 66 wells from 12 different fields. More than 16,000 samples, representing more than 320,000 feet of drilling were analyzed. The relative concentrations of 180 mass spectra was determined on each sample.
4. The bulk fluid inclusion data was interpreted using standard geochemical relationships.
5. The data displayed systematic trends that reflect the effects of mixing, boiling, and condensation.
6. Although standard and replicate analysis indicate standard error of bulk analysis is greater than individual crystal analysis, the bulk data can be used due to the many orders of magnitude difference in the data for each chemical species.
7. Ratios of constituents proved most useful for interpretation of the qualitative bulk data.
8. Bulk fluid inclusion analysis can be utilized to determine fluid types (e.g. meteoric, magmatic, evolved waters).
9. Alkane/Alkene ratios can be used to qualitatively characterize the degree of oxidation of the fluid.
10. The bulk data can be used to evaluate relative temperatures.
11. In high temperature (>300 F) geothermal systems there does not appear to be correlation between rock type and fluid inclusion gas chemistry.
12. In low temperature (<300 F) geothermal systems there does appear to be some correlation between rock type and fluid inclusion gas chemistry.
13. Vein mineralogy has some correlation with fluid inclusion gas chemistry across all systems.
14. High temperature systems in granitic/continental settings have higher average values for several species and ratios than systems in basaltic geological settings.

15. There is a narrow range of concentrations of species in fluid inclusions from geothermal systems that reflect the unique geological environment of geothermal systems.
16. Minor overall correlation between select gas ratios and temperature occurs field wide but not with individual wells. Hotter wells tend to have a more robust fluid inclusion gas signature whereas lower temperature wells have an overall suppressed fluid inclusion gas signature.
17. Select ratios correspond to permeability in a well. The slope of CO_2/N_2 versus total gas indicates boiling occurring in open systems which occurs in fractures.
18. Statistically select species have a higher average concentration in fractures than in non-fractures.
19. Fluids (meteoric, condensate, and reservoir) can be interpreted from the abundance of select fluid inclusion gas species and ratios.
20. Margins and caps of a geothermal system can be interpreted from the N_2/Ar and 43/39 relative percentages and if these two ratios parallel each other in abundance.
21. Methodology for identifying fluid types is based on above average concentrations per field of select fluid inclusion gases.
22. Lower overall temperature systems (<300 F) do not sufficiently overprint the existing fluid inclusions in the rock package to record the geothermal system.
23. A refinement to the methodology is necessary to determine if boiling has occurred in the system prior to applying the rules for identifying fluid types.

1.0 INTRODUCTION

This report presents the results of the project: Methodologies for Reservoir Characterization using Fluid Inclusion Gas Chemistry. The purpose of this project was to: 1) evaluate the relationship between geothermal fluid processes and the compositions of the fluid inclusion gases trapped in the reservoir rocks; and 2) develop methodologies for interpreting fluid inclusion gas data in terms of the chemical, thermal and hydrological properties of geothermal reservoirs.

<u>The specific goals of the project are to:</u>

1. Gather existing well data into a data template and submit it to the National Geothermal Data System.
2. Evaluate existing well data and determine if additional sampling is needed. If so, obtain the additional samples.
3. Relate the bulk fluid inclusion gas signatures to processes occurring in the reservoir (e.g. boiling, mixing, condensation, and conductive cooling) and fluid/rock interactions.
4. Determine the differences in the fluid inclusion gas signatures of low- and high-temperature systems.
5. Evaluate the relationship between the fluid inclusion gas signatures and rock types, vein mineralogy, geologic environment and temperature.
6. Develop methodologies for interpretation of the fluid inclusion gas data in order to identify fluid types, regions of permeability, and geothermal processes.

Phase 1 of this project was designed to conduct the first three tasks. We had initially planned to: 1) model the effects of boiling, condensation, conductive cooling and mixing on selected gaseous species; using fluid compositions obtained from geothermal wells, 2) evaluate, using quantitative analyses provided by New Mexico Tech (NMT), how these processes are recorded by fluid inclusions trapped in individual crystals; and 3) determine if the results obtained on individual crystals can be applied to the bulk fluid inclusion analyses determined by Fluid Inclusion Technology (FIT). Our initial studies however, suggested that numerical modeling of the data would be premature. We observed that the gas compositions, determined on bulk and individual samples were not the same as those discharged by the geothermal wells. Gases discharged from geothermal wells are CO_2-rich and contain low concentrations of light gases (i.e. H_2, He, N, Ar, CH_4). In contrast many of our samples displayed enrichments in these light gases. Although previous studies demonstrated that light gases could be trapped in fluid inclusions during boiling and that this was likely to occur in high-temperature systems, similar results were observed in low temperature systems where there was no evidence of boiling. This result was not anticipated.

Efforts were initiated to evaluate the reasons for the observed gas distributions. As a first step, we examined the potential importance of different reservoir processes using a variety of commonly employed gas ratios (e.g. Giggenbach plots). It is important to recognize that many of these plots are based on the relative abundances of the minor gases because of their importance as tracers of fluid processes. Rigorous modeling of gas chemistries will ultimately be very useful however, such modeling first requires a basic understanding of changes occurring within the geothermal systems we have investigated. More work is still needed in this area before numerical models can be constructed. We therefore focused our efforts on understanding the distribution of gases in different geologic and geochemical environments.

The second technical target was the development of interpretational methodologies. We have develop methodologies for the interpretation of fluid inclusion gas data, based on the results of Phase 1, geologic interpretation of fluid inclusion data, and integration of the data. These methodologies can be used in conjunction with the relevant geological and hydrological information on the system to create fluid models for the system. The hope is that the methodologies developed will allow bulk fluid inclusion gas analysis to be a useful tool for estimating relative temperatures, identifying the sources and origins of the geothermal fluids, and developing conceptual models that can be used to help target areas of enhanced permeability.

2.0 GEOTHERMAL SYSTEMS

Figure 1 shows the general features of a high-temperature geothermal system. The model was originally developed for geothermal occurrences in the Taupo volcanic zone of New Zealand. However, it is equally applicable to the geothermal systems at Coso Hot Spring, CA and Roosevelt Hot Springs, UT, and many of the features shown in the figure can also be found in amagmatic systems associated with deep circulation of fluids along fault zones. The main features of the model are an upflow zone of NaCl waters, boiling within the upper several kilometers of the system and the formation of peripheral bicarbonate- and sulfate-rich waters, recharge by meteoric waters and mixing of the various fluid types.

There are several processes in addition to boiling, condensation and mixing that can influence the gas compositions of the geothermal fluids. Bacterial activity and organic decay can modify the compositions of shallow, low-temperature meteoric waters through the production of light hydrocarbons. At higher temperatures and greater depths within the reservoir, pyrolysis of organic material can produce a variety of heavy hydrocarbons. Magmatic vapors can contribute N_2, CO_2, He and H_2S gases. CO_2 and H_2S can subsequently be depleted by water-rock interactions that result in the formation of calcite and pyrite, respectively.

The effects of boiling, cooling and heating will also be reflected in the distribution of hydrothermal minerals. Boiling commonly results in the formation of adularia, bladed calcite and quartz. Heating results in the formation of anhydrite and calcite because of their retrograde solubility. Cooling will produce a broad range of silicate minerals. Steam-heated bicarbonate-rich waters will produce low-temperature clay minerals whereas acid-sulfate waters can produce distinctive advanced argillic alteration assemblages. Knowledge of the mineral distributions and their thermal stabilities will provide critical information on the processes and temperatures during fluid inclusion formation.

Geothermal systems occur over a relatively narrow band of temperatures (approximately 100 to 600 ^{0}F). The temperature definition is somewhat based on the system ability to produce electricity or not and if producing electricity either by binary plants or steam plants. The temperature ranges also affect the type and composition of the fluids observed.

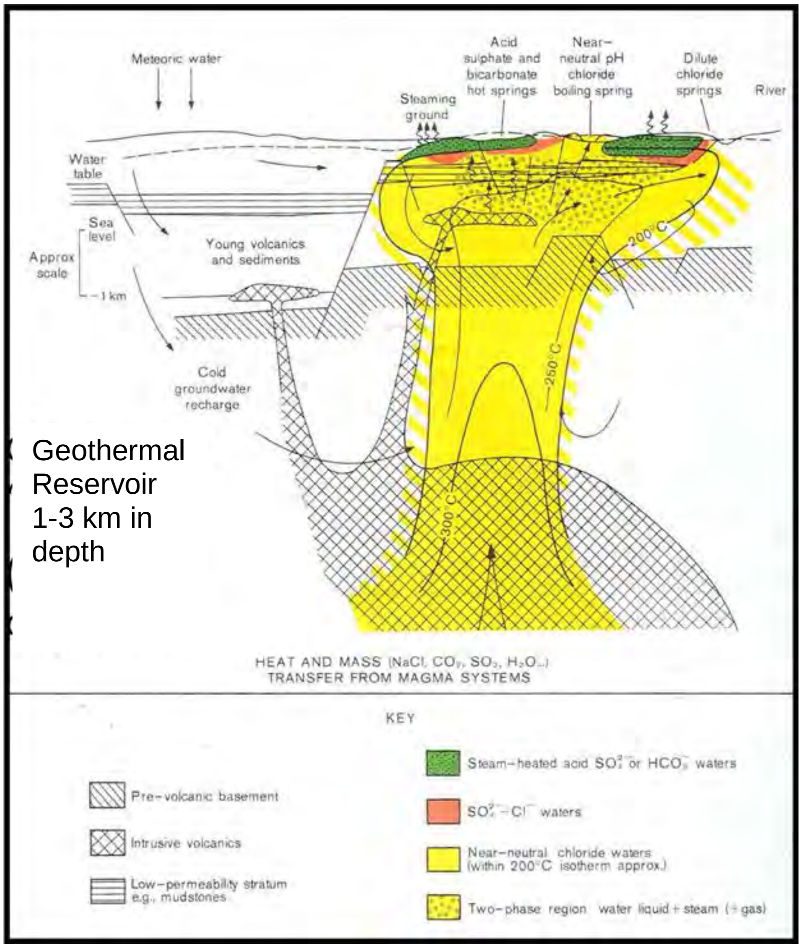


Figure 1. Simplified fluid flow model in a geothermal system. Modified from Henley 1985.

3.0 FLUID INCLUSIONS ANALYSES

Major gaseous species that occur in geothermal fluids include carbon dioxide (CO_2), hydrogen sulfide (H_2S), hydrogen (H_2), nitrogen (N_2), ammonia (NH_3), methane (CH_4), argon (Ar), inert gases and light gaseous hydrocarbons including ethane (C_2H_6), propane (C_3H_8), and butane(C_4H_{10}) (Ellis & Mahon 1977; Henley et al. 1984, Giggenbach 1986; Taran & Giggenbach, 2003). Carbon dioxide typically occurs in the highest concentration in well discharges. In 1986, Giggenbach presented the basic geothermal equilibrium gas chemistry and calculated how boiling might affect CO_2-CH_4-H_2 ratios in geothermal fluids (Giggenbach 1986). Norman and Sawkins (1987) extended the interpretations being developed for well discharges to gas analyses of fluid inclusions. The gases were extracted from individual crystals by thermal decrepitation or crushing and analyzed for H_2O, CO_2, CH_4, H_2S, N_2, H_2, Ar, and C_{2-7} organic species using a quadrupole mass spectrometer. Norman and Sawkins, 1987 and Norman et al, 1996, describe the details of the analytical techniques. In the late 1980's, Amoco scientists developed a technique for the rapid analysis of fluid inclusions in bulk samples. As with the methods developed by Norman and Sawkins (1987), the samples were crushed and analyzed by quadrupole mass spectrometry. This technique was patented by Fluid Inclusion Technology (FIT). Analyses of individual crystals used in this study were conducted by Norman at New Mexico Tech (NMT) and are referred to as NMT analyses.

Fluid Inclusion Technology conducted the bulk fluid inclusion analyses and these are referred to as FIT analyses.

Release of the gases by crushing involves opening the inclusions in a vacuum chamber attached to high vacuum pumps. This method avoids any potential thermal decomposition of the inclusion gases and is the preferred analytical methods. FIT analyzes the gases from a single crush. NMT will crush the sample repeatedly until the gas yield is too small to measure. In this way multiple generations, as indicated by differences in the gas compositions, can be analyzed (Moore et al, 2001).

Fluid inclusion gas analyses conducted at NMT are conducted on individual crystals selected by researchers and typically, homogenization temperatures and salinities are available from the same mineral assemblage or crystal. Because the samples are collected from cores or cuttings and therefore the rock type and vein paragenesis can be determined. Calcite, quartz, pyrite and anhydrite are the most commonly analyzed minerals. Only 10 to 15 gaseous species are analyzed and the analysis is quantifiable. Concentrations are typically provided in mol % or parts per million (ppm).

The samples for FIT analyses are collected from a 10-20 gram bulk well chip sample. There is no attempt to collect individual minerals. The wall rock as well as any veins are included in the analysis. In our studies, core samples of veins and wall rock from the same depths were analyzed for comparison. The fluid inclusion gas chemistry is delivered by FIT in an Excel spreadsheet with relative concentrations for 180 mass spectrometer peaks. Many of the masses (generally above mass 92) are fragments of heavier organic compounds and therefore are not necessary for our interpretations. The analysis is qualitative and concentrations are provided as counts. There is no a direct correlation between the FIT and NMT data. FIT does not calibrate their system with known gas ratios and fluid inclusion standards. Calibrating the analytical system would allow for making quantitative analyses; however, this would involve elaborate data reduction programs to deconvolute the mass spectra.

Geothermal fluid inclusion mass spectra generally show major peaks at masses 2 (H_2), 18 (H_2O), 28 (N_2) and 44 (CO_2)(Figure 2). Mass peaks at mass 5 through mass 11, mass 19 and 20, and masses 158, 170 and 172 typically have a value of zero. Many of the masses display several orders of magnitude between the minimum value and the maximum value.

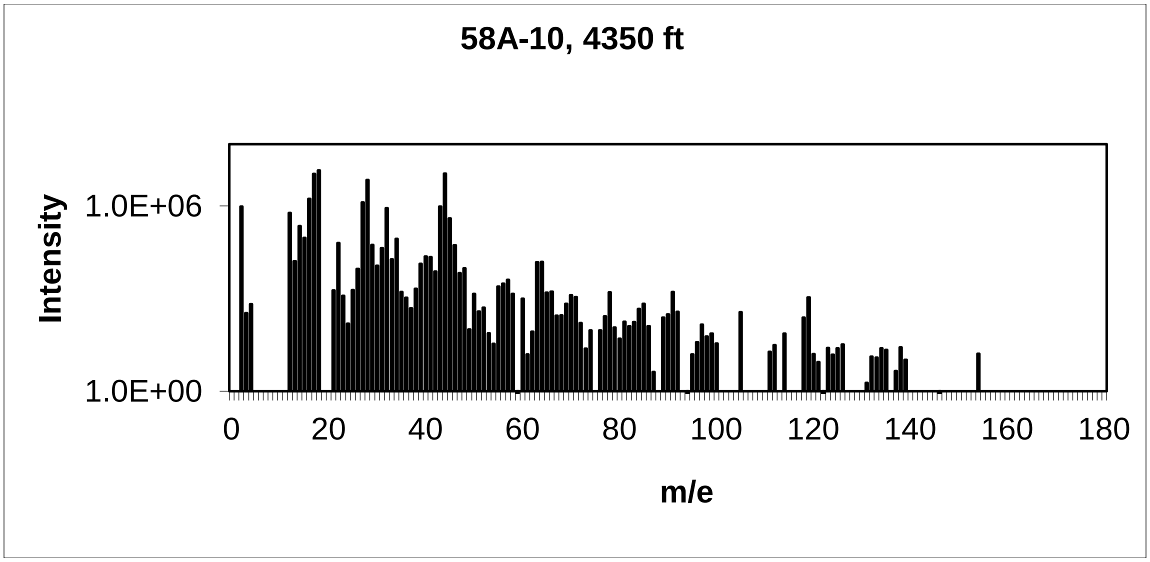


Figure 2. FIT mass spectra of fluid inclusions from 4350 ft in Coso 58A-10.

4.0 TASK 1: DATA SUBMISSION

Fluid inclusion gas data has been collected from liquid dominated Basin and Range geothermal systems hosted in granite (Steamboat Springs, Nevada; Coso, California), basalts (Puna, Hawaii; Iceland) volcanic rocks (Beowawe, Nevada; Fallon, Nevada; Glass Mountain, California; Hawthorne, Nevada; Karaha-Telaga Bodas, Indonesia), and sedimentary rocks (Beowawe, Nevada; Salton Sea, California; El Centro, California). The original SOPO did include studies of carbonate and metamorphic reservoirs. During the course of our investigation, samples from three wells from the Puna geothermal system hosted in basalt became available. Because of the limited funding available for analyses, DOE approved substituting the Puna study for investigations of carbonate-and metamorphic-hosted reservoirs.

In total, data was collected from 66 wells from 12 different geothermal fields. Data for each well was submitted to the National Geothermal Data Repository (GDR) in March, 2013 as required by the DOE. Table 1 presents the fields, wells and geological information on the wells we have studied. Typically the wells were sampled at 20 foot intervals.

4.1 Geological Settings

The following paragraphs present short descriptions of each geothermal system studied. A summary of each well is presented on Table 1.

4.1.1 Beowawe Geothermal System

The Beowawe geothermal system is located in northern Nevada within the Basin and Range geologic province. Here, Miocene volcanic rocks overlie older chert, shale and quartzite of the Valmy Formation (Garside et al. 2002). The reservoir is developed in highly fractured rocks of the Valmy Formation . The field produces 17.7 MWe.

Figure 3 is a well location map and cross section of the field showing the original two Chevron wells, drilled in 1985, and their relationship to the Malpais fault, which serves as a major conduit for the upwelling geothermal fluids. A third production well, 77-13, was placed on line in 1991. Well 77-13 is the principal producer at Beowawe. It encountered temperatures up to 420°F and penetrated a fault at approximately 5500 ft beneath the Malpais fault. A fourth well 57-13 was drilled in to intersect the fault in a different part of the field. The well was drilled to 10,600 ft, but TerraGen, the operator was unable to determine with certainty if the fault was intersected. FIT analyses of the well cuttings was used to address this question.

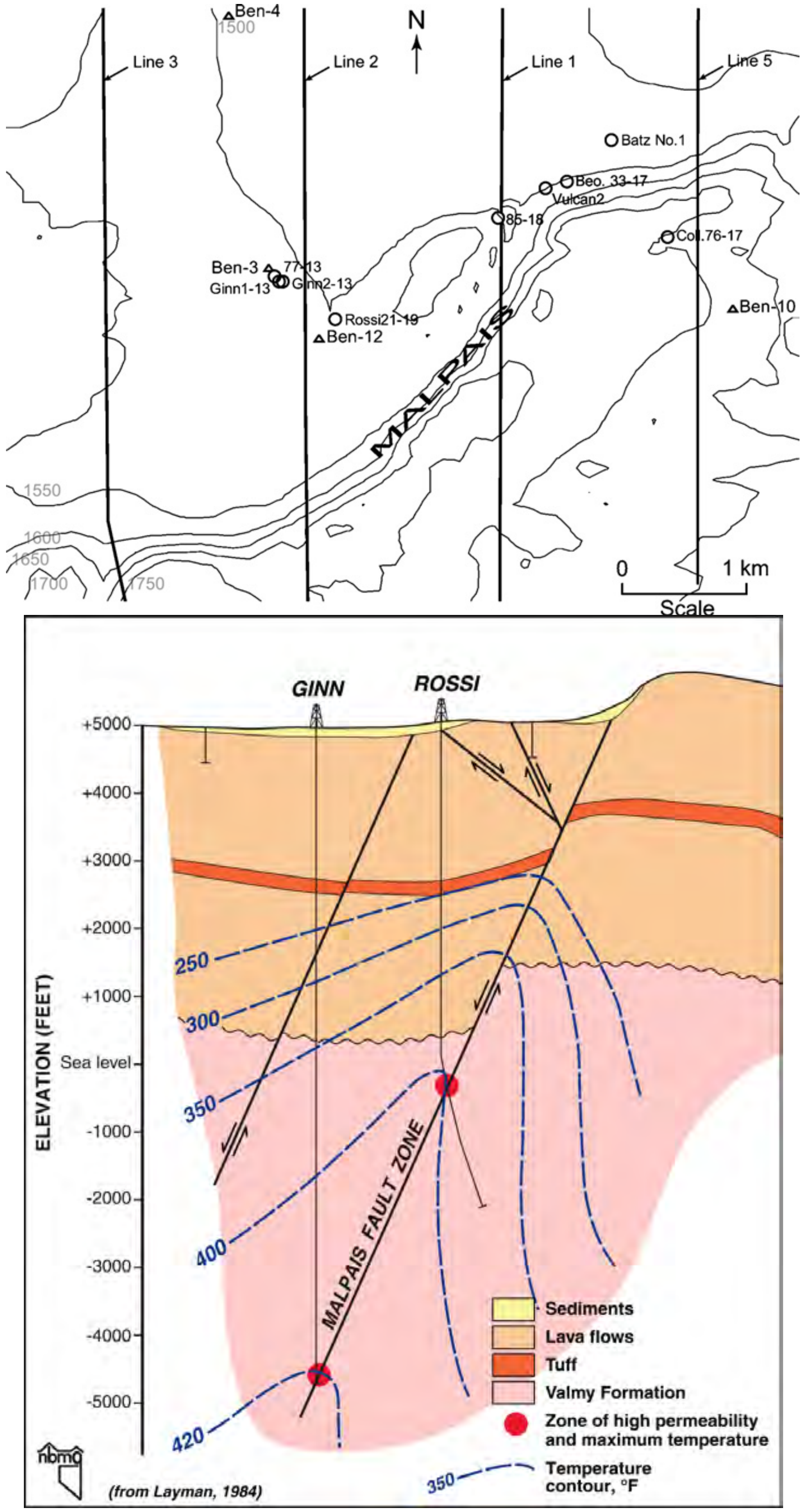


Figure 3. Map showing wellhead locations (circles) and dipole–dipole resistivity lines, and MT stations (triangles). Elevations in masl; contour interval: 50 m (from Garg et al., 2007). Cross-sectional model of the Beowawe geothermal system. Note the Rossi well cuts the Malpais fault at about 5500 feet and the zone of high permeability lies within the Valmy Formation (from: Layman, 1984).

4.1.2 **Coso Geothermal System**

Coso, the largest geothermal system in the Basin and Range Province is developed entirely in intrusive rocks of the Sierra Nevada Batholith. The modern geothermal reservoir is characterized by temperatures up to 650 ^{0}F and fluid salinities of ~10,000 ppm TDS. Variations in fluid salinities and temperatures indicate the presence of at least three upflow zones located in the southwest and eastern parts of the field. Temperature and compositional data show that the fluids from the southwest upflow zone migrated laterally upward to the north, along the western side of the field.

The rocks have been affected by multiple episodes of hydrothermal alteration. Paragentic and fluid inclusion investigations indicate that the youngest event is related to recent geothermal activity. Hydrothermal assemblages in the caprock of the modern system consist of carbonates, quartz, smectite, mixed-layer clays, chlorite, illite and zeolites. Epidote, wairakite, magnetite, and pyrite are present but uncommon, within the modern geothermal reservoir rocks. These alteration assemblages overprint rocks altered to the greenshist facies of regional metamorphism. The present geothermal system may have been initiated in the recent past. ^{14}C dating of pollen trapped in travertine and sinter deposits have yielded ages of approximately 11,000 to 9,000 y BP (J. Moore, personal comm.).

Figure 4 presents a map of the Coso field showing the wells that were studied. Subsurface temperatures along the western side of the system based on the fluid inclusion measurements are shown in Figure 5 (Adams et al.,2000). These temperatures are similar to the current measured conditions. The homogenization temperatures range from 69°F to 622°F and the salinities from 0 to 3.4 weight percent NaCl equivalent. The highest temperatures are found near the southern end of the field, where they define a shallow up-flow zone in an area that contains no surface manifestations. The variations in temperatures and salinities suggest that the high-temperature fluids were diluted by a low-temperature, low-salinity meteoric water that is no longer present.

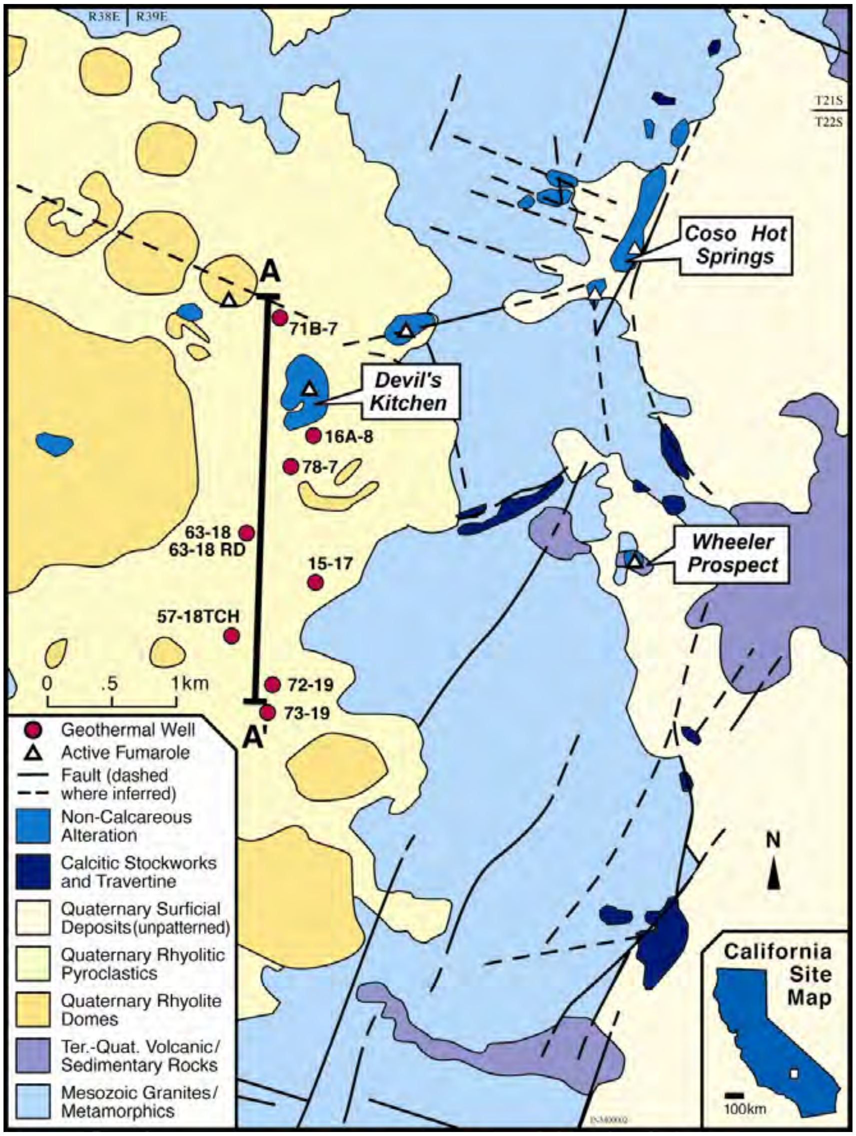
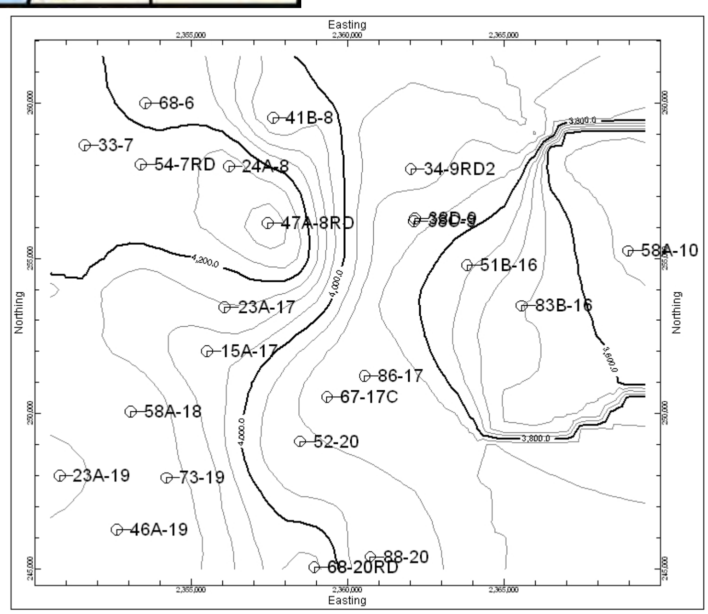


Figure 4: Simplified geological map and wellhead location map of the Coso field with wells studied identified. Contour intervals are 50 feet. (McCulloch, personal communication).



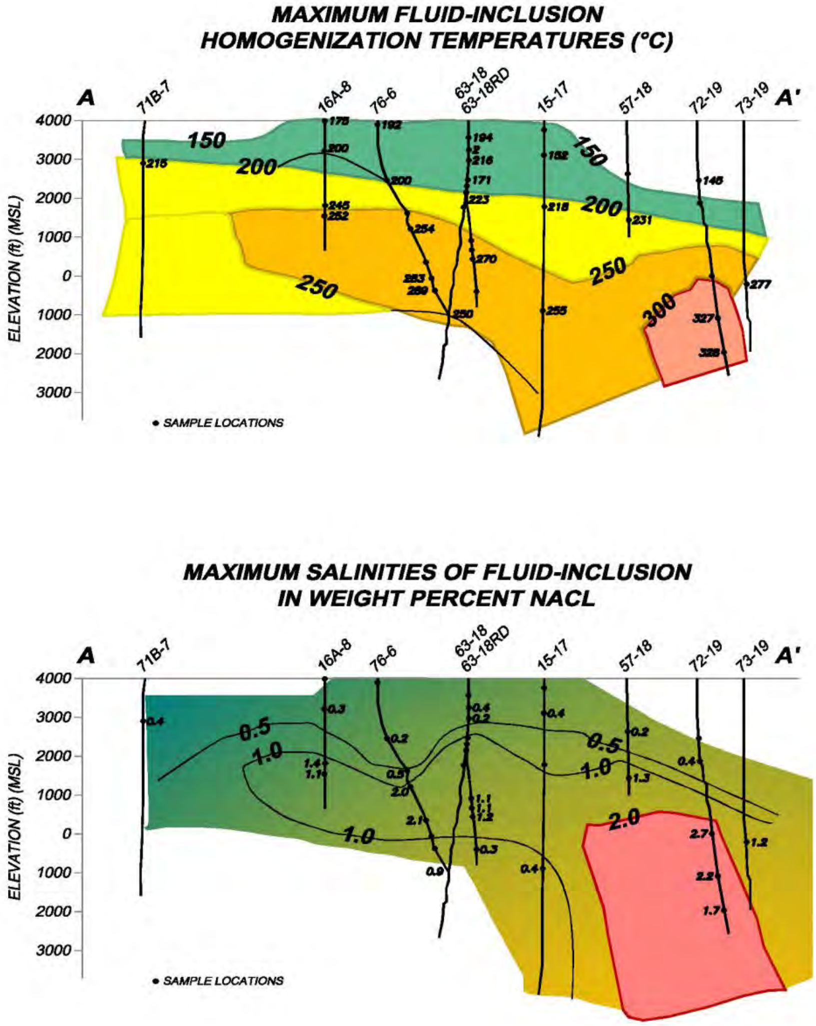


Figure 5. North-south cross-sections of the reservoir based on fluid inclusion data (from Adams et al.,2000). A) Maximum fluid-inclusion homogenization temperatures and B) maximum salinities of inclusion in weight percent NaCl equivalent. A on the cross-section is to the north and A' is to the south.

4.1.3 El Centro, California

The Superstition Mountain geothermal project is located in the West Mesa area of the Imperial Valley, south of the Salton Sea (Figure 6). The site is located west of the Salton trough, which represents the northern extension of the rift valley forming the Gulf of California. West Mesa has been thought to be dominated by a left-stepping transpressional (Bjornstad et al, 2006). The geology of the project area is dominated by Superstition Mountain, a granitic knob, and Pliocene to recent marine/lacustrine deposits, and Superstition Hill faults (Tiedeman & Bjornstad, 2011).

The U.S. Navy Geothermal Program Office (GPO) drilled three, deep, temperature gradient holes between 2008 and2010 (NAFEC-1, -2, -3). Figure 6 presents the location of the wells with respect to Superstition Mountain. The Navy released the lithology and temperature data for these wells.

Comparison of the temperature profiles for the NAFEC wells clearly indicates that NAFEC-3, located closest to the range front fault zone on the northeast flank of Superstition Mountain, is the hottest of the three wells, reaching a temperature of 250^{0}F at a depth of approximately 2,000 ft. The temperature remains nearly constant to the total depth of the well at 3,500 ft.

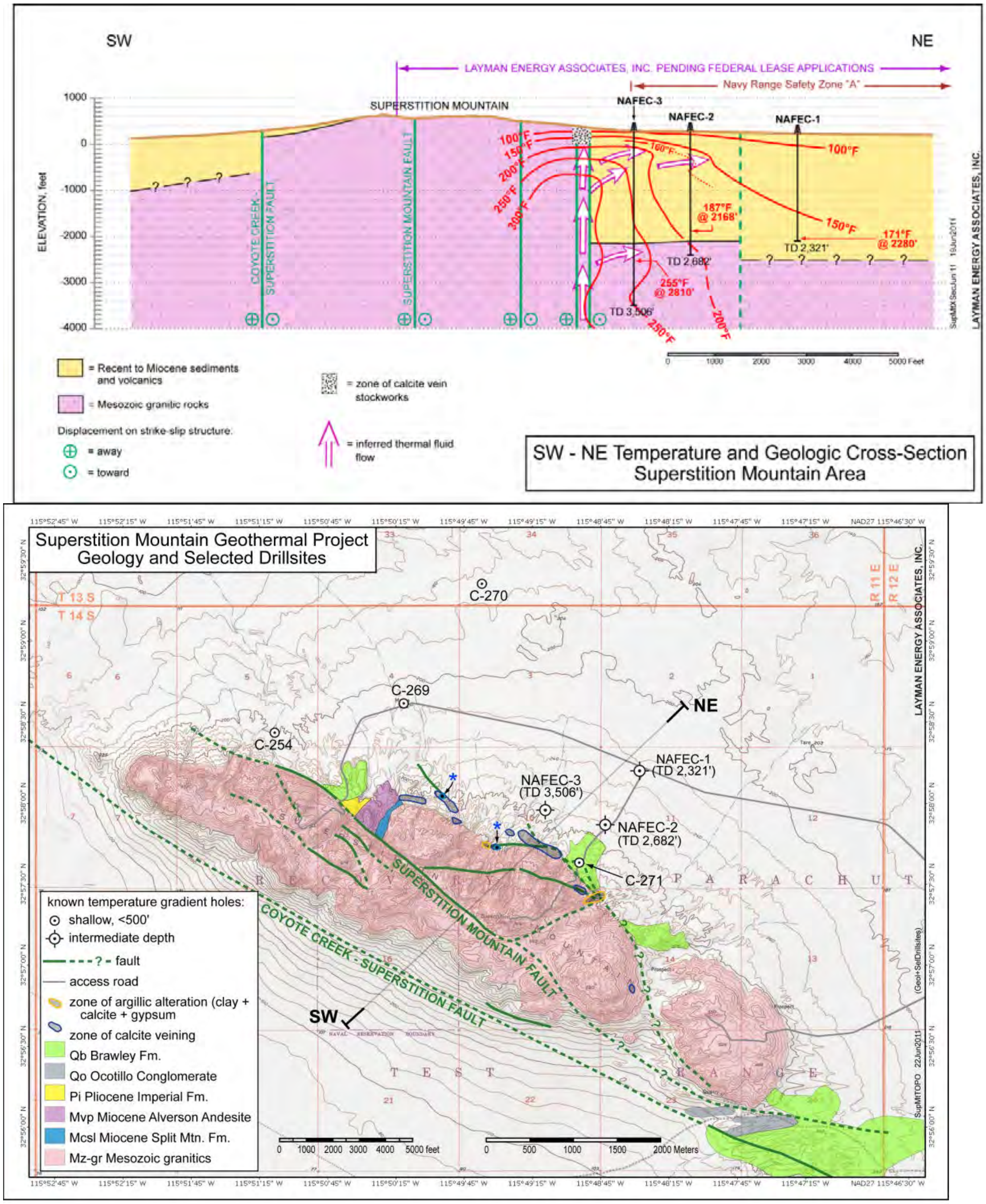


Figure 6: Cross-section of Superstition Mountain Area and well location map. (from US Navy GPO, 2011).

4.1.4 Fallon Geothermal System

The Carson Lake thermal area is located on the southeastern edge of the Carson Sink in northwestern Nevada. Geothermal reservoirs in the area have been found at Soda Lake, Stillwater, Desert Peak, Brady's and Dixie Valley. The regional geology is typical of other portions of the Basin and Range. At Fallon, Quaternary alluvium overlies Tertiary tuffs, basalts and siliceous volcanics and Tertiary to Mesozoic granitic rocks (Desormier 1997). The dominant structures are generally north-south to northeast-southwest trending normal faults.

Well logs for 2011 wells (CL84-31, FOH3, CL82-36) were supplied by the US Navy GPO. Figure 7 presents a well location map for Fallon. Well FOH3 had two well logs available: one above 6,900 feet and one from 6,959 feet to 8,959 feet. Additional information about the overall subsurface geology was provided by Desormier 1997 paper on the geothermal project at Carson Lake, Nevada. Additional analysis was conducted by Energy & Geoscience Institute (EGI) and they arrived at different conclusions than the well logs. The basalts in the three wells were classified as andesites and volcanic sediments by EGI. We will use EGI classifications here.

Well 84-31 is comprised of a series of volcanic sediments interbedded with thick layers of andesite lava flows. Rhyolite occurs from about 1,400 feet to 2,200 ft. It is underlain by andesite to a depth of 3,000 ft. Between 3,000 and 3,500 ft the well encountered sediments underlain by another sequence of andesite lava flows. Argillic alteration occurs to a depth of approximately 4,500 feet followed by phyllic alteration. No propylitic alteration occurs in the well. Smectite and illite occur throughout the well but not continuously. Epidote does not occur at all.

Well FOH3 is comprised of a thick sequence of Quaternary alluvium underlain by Tertiary andesite lava flow. The alluvium/andesite contact occurs at a depth of 2,256 ft. A 150 foot thick unit of Triassic phyllite occurs between the andesite lava flows and the Mesozoic basement granitic rocks. At approximately 5,900 quartzite and schist were encountered. At approximately 7,100 ft, the well penetrated interbedded lithic tuffs and andesite lava. Epidote first appears. occurs starting at about 6,000 feet to the end of the well.

The lithologies encountered in Well CL82-36 are similar to those in FOH3. Sediments occur to a depth of about 2,400 ft, followed by interlayered sediments and andesite lava flows and occasional tuffs to a depth of 5,700 feet. Quartz diorite, quartz monzonite, and marble occur to approximately 7,100 ft. These intrusive and metamorphic rocks overlie a series of tuffs interlayered with andesitic flows. Argillic alteration extends to a depth of 4,900 ft and is found in the sediments and upper andesitic flows. At greater depth, phyllic to propylitic alteration assemblages are found well. Smectite occurs to a depth of about 4,500 feet. Illite strongly occurs and epidote occurs from about 5,700 feet to the depth of the well at 9,450 feet.

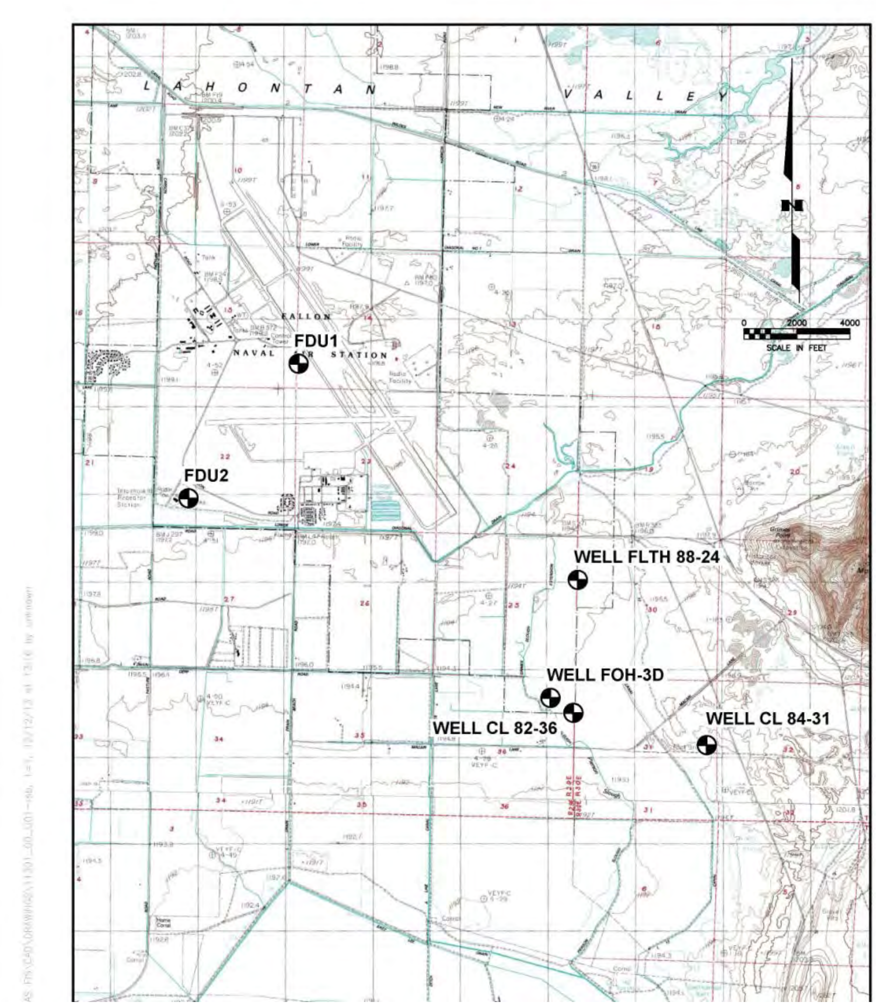


Figure 7: Well location map for Fallon Field. Well locations provided by the US Navy GPO.

4.1.5 Hawthorne Geothermal System

Hawthorne lies within the Walker Lane Fault Zone (WLFZ), which stretches from Las Vegas, NV to Honey Creek CA and ranges from 60 miles to 180 miles in width. The Walker Lane accommodates transtensional stress created by extensional movement within the Great Basin and by dextral shear motion associated with the San Andreas system. The area has undergone near continuous volcanism since the Oligocene. Ash flow tuffs are distributed on top of eroded Mesozoic basement rocks and mainly consist of Triassic metavolcanics of the Excelsior Formation (Ferguson and Muller, 1949). Deposits of rhyodacite and siliceous ash-flow tuffs overlie the Excelsior Formation. Alluvium and conglomerates overlie the tuffs.

The wells lie near the east and west edges of a graben between the Wassuk Range to the west and the Garfield Hills to the east (Figure 8) . Wells HAD #2 and #3 were drilled in a zone of complex normal faulting. Well logs for all three wells were supplied by the US Navy GPO. Mineralogic analyses were conducted by the Energy & Geoscience Institute (EGI). According to EGI the three wells encountered a series of metavolcanics and tuffs overlain by sandstones and sands. Intrusive rocks were also encountered in HAD#1 and HAD#2.

HAD#1, located closest to the Wassuk Range penetrated sediments and sedimentary rocks to approximately 530 ft. Interbedded metavolcanics and metasediments occur to a depth of 1,020 ft. EGI identified these rocks as acid-leached diorites, granites, granodiorites, and quartz diorite. There were no lost circulation zones or major fractures noted on the log. However, petrographic evidence from EGI suggests a fault zone and open fractures at approximately 525 ft. The depth is associated with a temperature spike and loss of circulation. HAD#2 encountered sands to a depth of 850 ft. The basement intrusive complex consisting of amphibolite, metadiorite, and granites was encountered from this depth to TD at 4,700 ft was. The rocks included. A number of lost circulation zones occurred in this well between 1,129 and 3,224 feet. HAD#3 encountered sand to about 1,750 ft underlain by a sandstone to approximately 3,500 feet. One possible fracture from about 2,986 to 2,989 ft was noted on the log. A fault zone was noted by EGI at 3,700 ft.

Argillic alteration assemblages were noted in all of the wells. This assemblage contains low-temperature smectite and interlayered clays. The assemblage is characteristic of temperatures less than 430 ^{0}F. Higher temperature alteration assemblages were noted but were considered to represent older events. Epidote and actinolite (which is indicative of temperatures >550 ^{o}F) are present but are interpreted to be relict phases that were overprinted by lower temperature minerals.

Figure 8: Well location map of the Hawthorne geothermal field. Well locations provided by the US Navy GPO .

4.1.6 Glass Mountain Geothermal System

The Glass Mountain geothermal system is located on Medicine Lake Volcano in the Cascade Range of Northern California (Figure 9). Medicine Lake Volcano (MLV) is a shield volcano just east of the main arc of the Cascades in a Basin and Range-style extensional environment. Regional north-south trending normal faults project under the volcano from the north and the south. The northwestern extension of the Walker Lane fault system also coincides with MLV (Donnelly-Nolan 2002). Volcanic activity at MLV seems to be strongly episodic, with the most recent episode ending about 900 years ago with the eruption of dacite and rhyolite at Glass Mountain and other east rim vents (Donnelly-Nolan 1990). MLV is the largest volcano by volume in the Cascades. Vent and fault alignments on MLV are generally north-south and rarely trend outside of 30 degrees of north. Exceptions to this include the southwest flank where vents trending 55 degrees east of north and the vents near the caldera, which tend to be tangential to the rim. Ground cracks are evident on the upper northwest flank and lower north, east and south flanks, oriented typically NNW to NNE but with east-west openings, consistent with the regional tectonic regime (Donnelly-Nolan 1990).

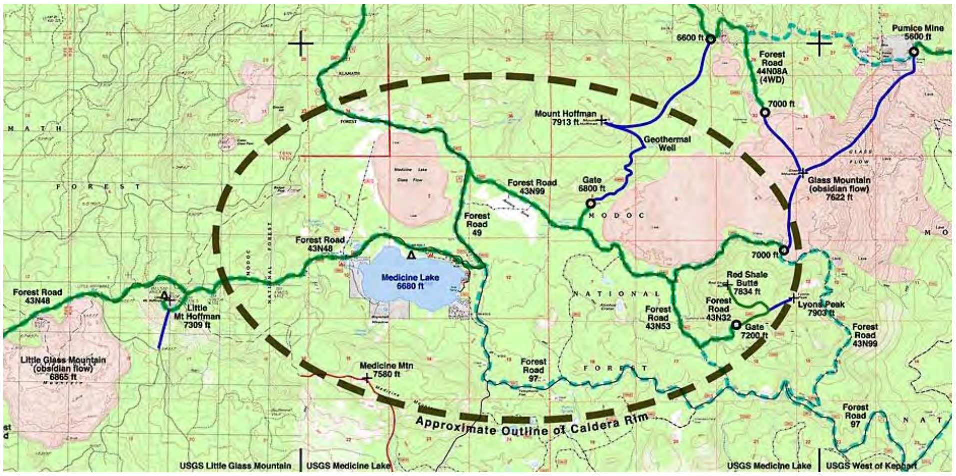


Figure 9: Glass Mountain and Caldera area of Medicine Lake Volcano.

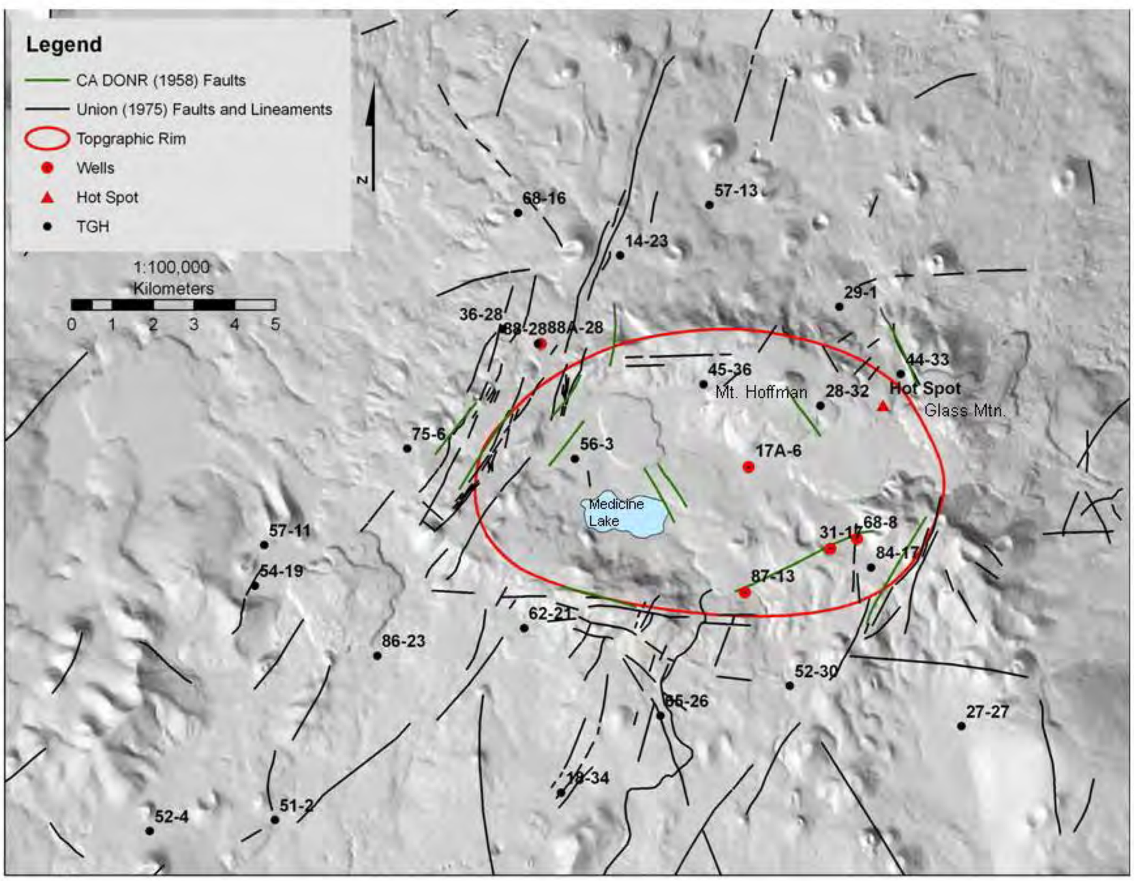


Figure 10: Map showing dominant structures and well locations at Medicine Lake Volcano. Well 88-28 is located near the topographic rim to the north of Medicine Lake. Compiled by M.Gwynn (unpublished report, 2010)

Lavas range in composition from basalt through rhyolite. Glass Mountain on the upper east flank of MLV is a rhyolite dome complex with rhyolite and dacite obsidian flows. It is believed that MLV formed from many small differentiated magma bodies and a complex of mafic dike. MLV is located within the rain shadow of the Cascades and springs of any temperature are rare. Despite the high temperatures encountered in the deepest wells, the surface manifestations of the system are limited to one weak fumerole near Glass Mountain (Donnelly-Nolan 1990).

Two wells, 88-28 and 17A-6, were included in our study. Well 88-28 encountered felsic volcanics overlying mafic lavas. The well was advanced to a total depth of 8,000 ft. however core was available for only the top 3,600 ft. At approximately 1,200 ft., the lithology changes from mixed volcanics (altered basalts) to felsic volcanics. The estimated static temperature increases rapidly from 350°F at 1500 ft. to 400°F at 2800 ft. Well 17A-6 was advanced to 9,610 feet.

4.1.7 Karaha-Telaga Bodas, Indonesia

Karaha-Telaga Bodas is a vapor-dominated geothermal system in west-central Java, Indonesia (Figure 11) (Nemcock et al., 2004; Moore et al., 2008). The tectonics of this area is dominated by the subduction of the Australia Plate beneath the Eurasia Plate at the convergent margin of the Sunda arc (Lee and Lawver 1995). Volcanoes of the arc include Kawah Galunggung, an active vent which is geologically similar to Mt. St. Helens. (Figure 11).

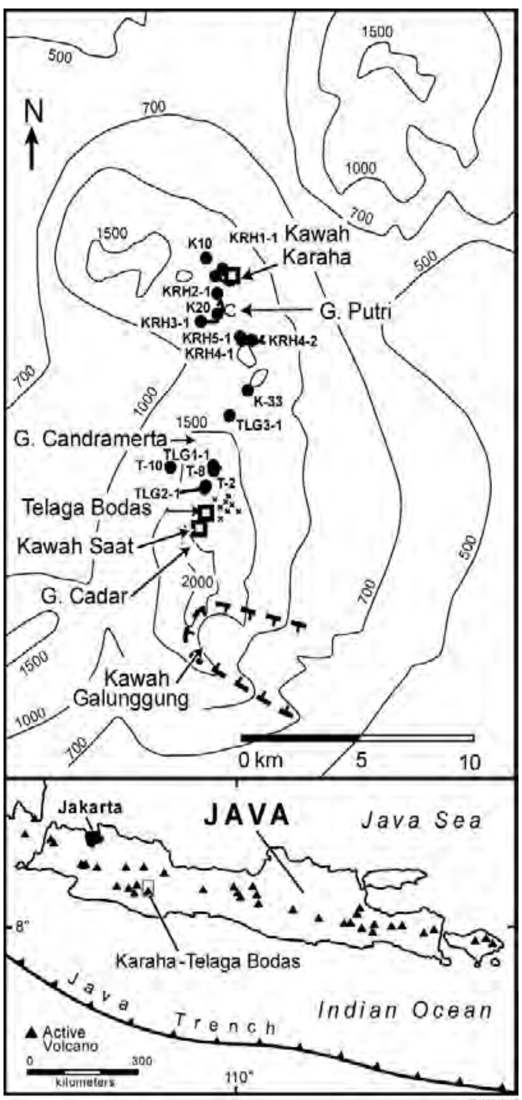


Figure 12 shows the geometry of the present-day system. More than two dozen wells have been drilled with some reaching depths near 10,000 ft and temperatures as high as 660°F. Moore et al. (2008) recognized four distinct hydrothermal mineral assemblages document the evolution of the geothermal system and the transition from liquid- to vapor-dominated conditions. The earliest assemblage represents the initial liquid dominated system generated during emplacement of the granodiorite between 5910 $\pm$ 76 and 4200 $\pm$ 150 y BP. Gravity temperature and mineralogic data suggest the granodiorite underlies the thermal area between Telaga Bodas and Kawh Kararah and provides the heat driving the system (Tripp et al., 2002; Moore et al., 2008). The intrusion is shallowest beneath the southern end of the field where an acid lake overlies a nearly vertical low resistivity structure (<10 ohm-m) defined by magnetotelluric measurements. This structure is interpreted to represent a vapor-dominated chimney that provides a pathway to the surface for magmatic gases. Tourmaline, biotite, actinolite, epidote and clay minerals were deposited contemporaneously at progressively greater distances from the intrusive contact (assemblage 1). At 4200 $\pm$ 150 y BP, flank collapse and the formation of the volcano's crater, Kawah Galunggung (Katili and

Sudradjat 1984), resulted in catastrophic decompression and boiling of the hydrothermal fluids. This event initiated development of the modern vapor-dominated regime. Chalcedony and then quartz were deposited as the early low salinity liquids boiled (assemblage 2). Both vapor- and liquid-rich fluid inclusions were trapped in the quartz crystals. As pressures declined, CO_2-and SO_4-rich steam-heated water drained downward, depositing anhydrite and calcite (assemblage 3) in the fractures, limiting further recharge.

Two wells were studied in this investigation. Well T2 was drilled to a depth of 4,400 ft on the northern side of Telaga Bodas (Figure 12) in 1997. The well did not penetrate the magmatic vapor chimney but did encounter a vapor-dominated conditions below 3000 ft. The well encountered a series of lithic tuffs and andesitic tuffs. Temperatures dramatically increased at approximately 2,200 ft. from below 200°F to slightly above 500°F. Well K-33 is located in the central part of the field where the steam zone is thin.

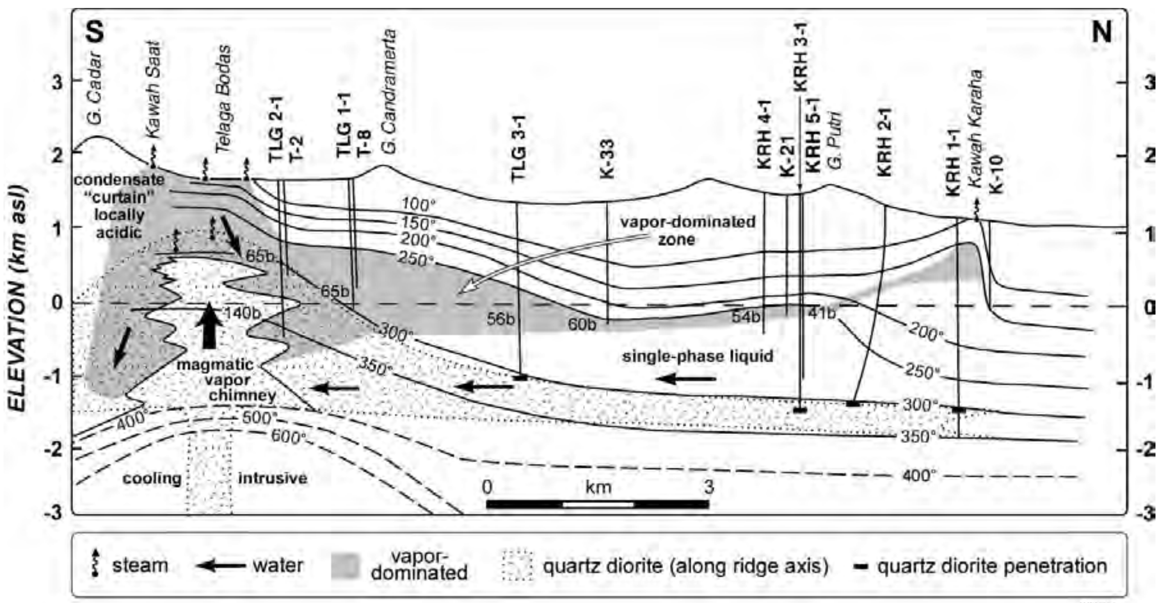


Figure 12: North-south cross section through the geothermal system. ; From Moore et al. 2008)

4.1.8 Puna Geothermal System

The Puna geothermal system is located on the east rift zone of Kilauea Volcano on the island of Hawaii. The rift zone is comprised of dikes and fractures extending more than 60 miles from the summit caldera to the ocean floor. Substantial volumes of magma have been intruded into this complex. Several deep wells have confirmed the presence of high temperatures (700 ^{0}F) and an active hydrothermal system (Thomas, 1987). There is a sharp decline in temperatures at the southern boundary of the rift. The locations of the three wells studied, SOH-1, SOH-2, SOH-4 are shown on Figure 13. Recharge to the system is from four different sources: 1) cold meteoric fluids (rainfall), 2) cold sea water, 3) hydrothermally altered meteoric fluids, and 4) hydrothermally altered saline water (Kinslow et al, 2012).

Figure 13: Well location map of the Puna geothermal field. Different recharge waters are shown on the map (from Kinslow et al., 2012).

4.1.9 **Salton Sea Geothermal System**

The Salton Sea geothermal field lies within the Salton Trough of Southern California, an actively growing rift valley representing the northern extension of the Gulf of California. The trough is filled with deltaic, alluvial, and lacustrine deposits, including evaporates (Figure 14) (Hulen et al., 2003). Stratabound sulfides suggest periods of brackish water conditions and evaporates, bedded anhydrite, and mudcracks record subaerial exposure and a sabkha-like environment (Lippman et al, 1999). Within the geothermal field, the lithologies change rapidly, both vertically and horizontally. Rhyolites occur at depth below the clastic sediments suggesting an older than 10 ka age for Obsidian Dome and other surface rhyolites (Hulen and Pulka, 2001).

Figure 15 shows the temperatures at a depth of 4,9000 ft. (1,500 m)(feet) (Hulen et al., 2003). The wells that were studied were are marked on the map by two letter abbreviations. CalEnergy provided the samples but no downhole temperatures. Estimates of the well temperatures are based on their mapped locations shown in Figure 15. The hottest part of the field was encountered by Well Elmore 16. Although temperatures are above boiling there is no petrological evidence of boiling. The salinity of the fluids are to high for boiling to occur (personal communication Joe Moore, 2015).

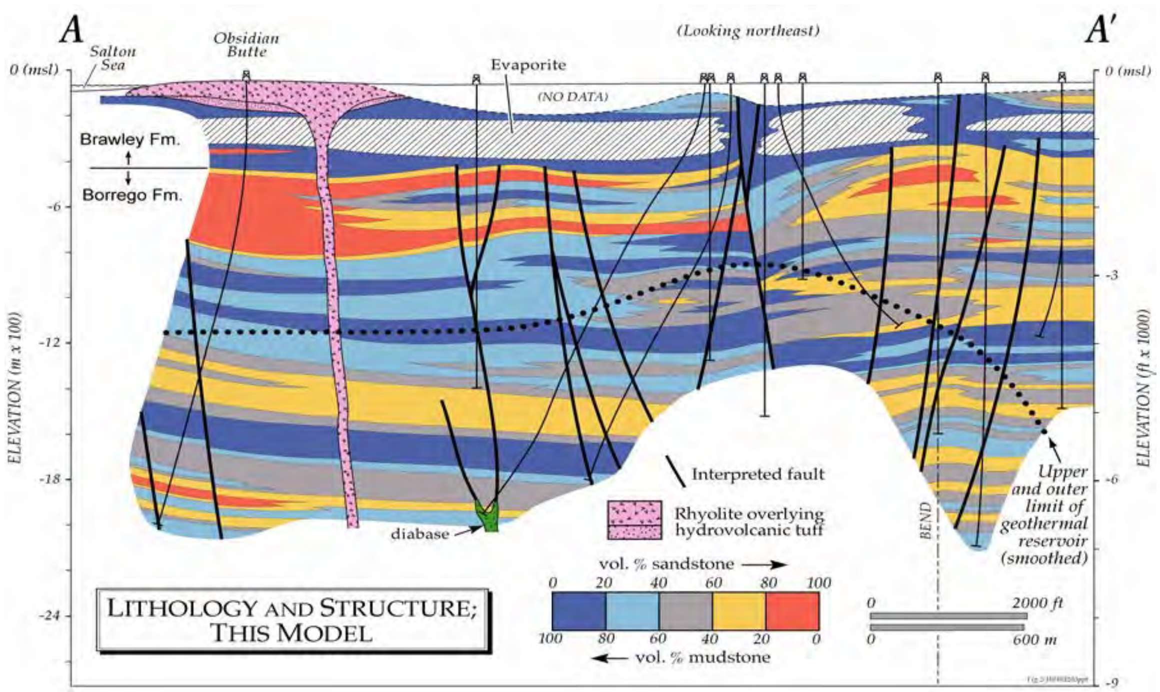


Figure 14: Cross-section of Salton Sea field (From Hulen et al., 2003).

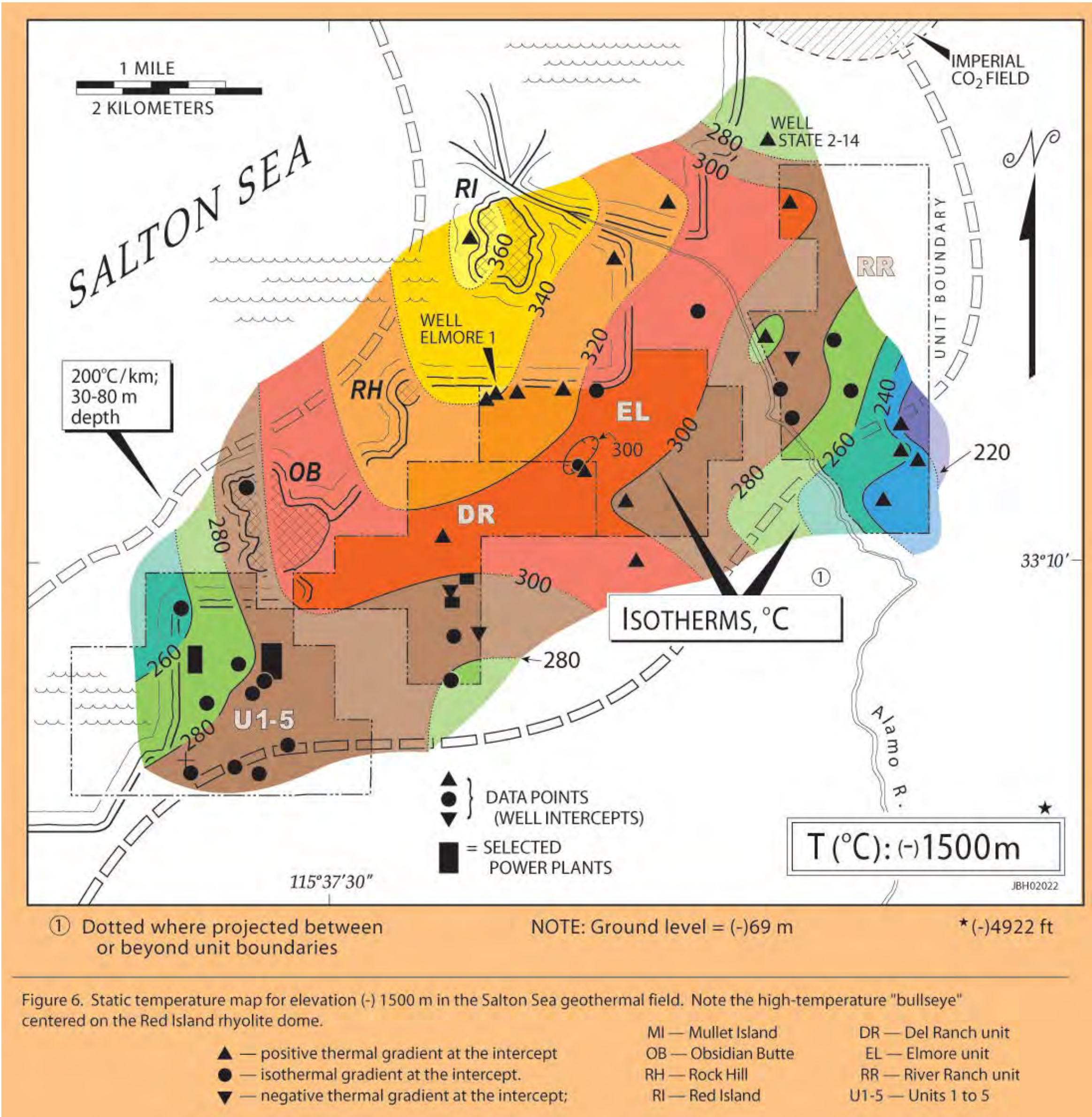


Figure 6. Static temperature map for elevation (-) 1500 m in the Salton Sea geothermal field. Note the high-temperature "bullseye" centered on the Red Island rhyolite dome.

Figure 15: Static temperatures for at an elevation of (-) 4900 ft (1500 m. From Hulen et al. 2003).

4.1.10 Steamboat Springs Geothermal System

The Steamboat Springs geothermal system is located in the Humboldt zone of the Basin and Range in northern Nevada. The Humboldt zone is a northeast-trending structural zone containing northeast-striking left-lateral and normal faults and northeast-trending folds. Several major geothermal fields lie in this zone (Faulds et al., 2002). North and northeast striking faults in the Steamboat area likely provide conduits for fluid flow (Figure 16).

Steamboat Springs has been used and developed for purposes ranging from recreation to power since about 1860. The field is characterized by a large sinter terrace and areas of intense acid alteration. The reservoir fluids, which reach a temperature of 458°F are hosted in hydrothermally altered Cretaceous granodiorite and metamorphic. Fluids encountered beneath the sinter terrace have a temperature of 325°F (at about 1312 ft. depth). It is believed that these fluids represent cooled outflow from higher temperature portions of the field (Garside et al., 2002).

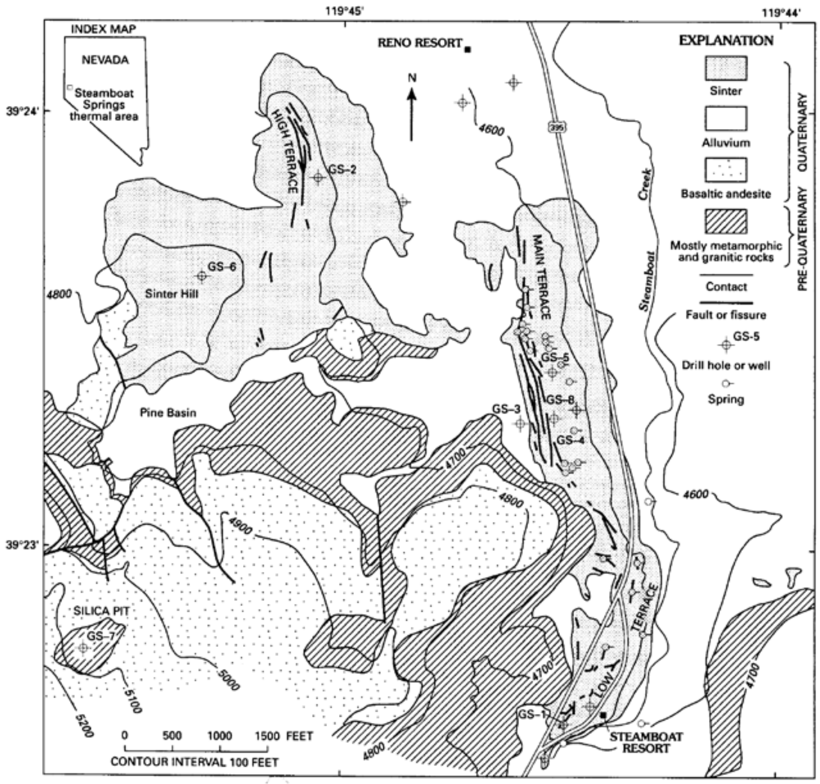


Figure 16: Location and geology of the Steamboat Springs geothermal system, Nevada (from White et al., 1992).

Several 1.1 million year-old rhyolite domes occur in the area and a rhyolite intrusion may lie under the thermal area (White et al., 1964). The area has been hydrothermally active, at least intermittently, for over 2.5 million years (Silberman et al., 1979). There is debate about whether the hydrothermal system is due to deep circulation of fluids in an extensional environment or due to heat from a magmatic intrusion at depth. Both types of hydrothermal systems are present in the Basin and Range. Support for an origin related to deep circulation comes from the system's close proximity to an active range front fault. The known rhyolite domes are too old to have provided this heat source, but younger intrusions may be buried .

Well 87-29 was drilled to a depth of 3990 ft on the sinter terrace. The well encountered lahars and the underlying granodiorite. Primary production is from 500 to 1200 ft. with temperatures above 300°F.

4.2 Data Quality

Data from FIT and quantitative analyses conducted at New Mexico Tech (NMT) were compared to evaluate the quality of the FIT data. NMT measures selected mass peaks to maximize precision and calibrates the system with known gas ratios and natural fluid inclusion standards. These calibrations allow NMT to provide quantitative analyses. NMT analyses are presented in mol % or parts per million (ppm) of various species. NMT used two mass spectrometers and measured 12 species at a time.

FIT runs internal standards to control analytical drift but does not analyze standard gases and fluid inclusion standards to quantify the analyses. Consequently, we conducted replicate analyses to help assess the quality of the data. Replicate analyses measure homogeneity of sample material, homogeneity of sample shape and of fracturing, impact repeatability, and machine measurement factors, in addition to analytical precision. One hundred and twenty-four replicate analyses were made over a time period of 3 years.

Gas ratios were calculated from the analyses of standards by FIT and NMT and are compared (Table 2). NMT measures duplicate N_2/Ar of air in artificial inclusions with a standard error (precision) of about 1 percent. However, natural standards all show heterogeneity that in part masks the analytical precision. Because some of the standards yield results that are very repeatable, they are useful in monitoring long term machine stability. Standards HF1, SCLQ, and BHQ-1 have gas ratios that are repeatable to 20 percent or better; standard SCLQ N_2/Ar is repeatable to 3 percent. Table 2 shows that FIT analyses have lower precision than NMT analyses. Analyses of over 100 sample replicates suggest the precision for major species is better than 50 percent and ratios of major gaseous species is better than 30 percent.

Table 2. Comparison of standard errors (%) of analyses performed by NMT and FIT. The standard error is the precision in measuring the standard's gas ratios.

Standard Type		N_2/Ar	CO_2/H_2O	CO_2/N_2	H_2S/N_2
HQ-1	FIT	69	131	59	103
	NMT	54	33	49	94
SCLQ	FIT	56	39	20	102
	NMT	3	36	16	52
HF-1	FIT	24	181	50	73
	NMT	20	15	17	67
BHQ-1	FIT	40	96	66	49
	NMT	13	26	18	38

There has been an on-going data analysis program on fluid inclusion gas data provided by FIT as part of the US Navy GPO program. We have calculated precision for duplicate pairs for 22 of the more common mass spectra used then we averaged the calculations for each pair. In general the major species have a precision of less than 35 percent except for H_2O which has an average precision ranging from 50 to 80 percent. Water is typically under measured in the FIT system due to it sorbing onto the vacuum system. The other major species CH_4 (m15 or m16), N_2 (m28), and CO_2 (m44) have average precisions of less than 30 percent. Standards are also submitted with each batch of wells analyzed. These are natural standards and therefore still show heterogeneity that in part masks the analytical precision. Appendix A contains the analyses for the data quality program that was employed. Despite the high standard error for some species, the data can be interpreted due to the several orders of magnitude difference between samples. Ratios are also useful because they limit the impact of the high standard error.

4.3 Mass Spectra Fragmentation

Of principal concern with the FIT analyses was the overlap of mass peaks. Most of the gaseous species present in fluid inclusions exhibit more than one peak when ionized in a mass spectrometer. Carbon dioxide, for example, commonly yields fragments of C^+ (m/e =12), O^+ (m/e = 16), CO_2^{++} (m/e = 22), CO^+ (m/e = 28) and CO_2^+ (m/e = 44) where m is the mass of the fragment and e is the charge. Organic species fragment by splitting C-C bonds and loss of H atoms, which results in complex mass spectrums.

Measurement of nitrogen potentially is problematic because of overlap of the N_2 m/e =28 peak with organic molecule fragments and CO^+ from the fragmentation of CO_2. Carbon dioxide is commonly the principal gaseous species in fluid inclusions, hence its fragment could mask N_2 which is generally one or two orders of magnitude lower in concentration. To determine if mass 28 represents nitrogen or carbon dioxide, the values for mass 28 are plotted against mass 14 (N^+, N_2^{2+}) and against mass 44 (CO_2) (Figure 17a: Coso wells, Figure 17b: Fallon Wells, and Appendix B: other wells). If m/e=28 represents mostly N_2 it should strongly correlate with m/e=14. A linear trend for mass 14 against mass 28, and lack of correlation of mass 28 with 44, indicates that the mass 28 represents nitrogen and not carbon dioxide (Figure 17).

Occasionally, the mass 14 does not correlate with mass 28, (Hawaiian and Salton Sea wells shown in Appendix B). When this occurs, the ratio N_2/Ar is plotted using both mass 14 and mass 28 to determine if there is a large difference in the ratios Typically one of the masses will yield higher counts or higher concentrations than the other and this is the mass that is used when there is fragmentation.

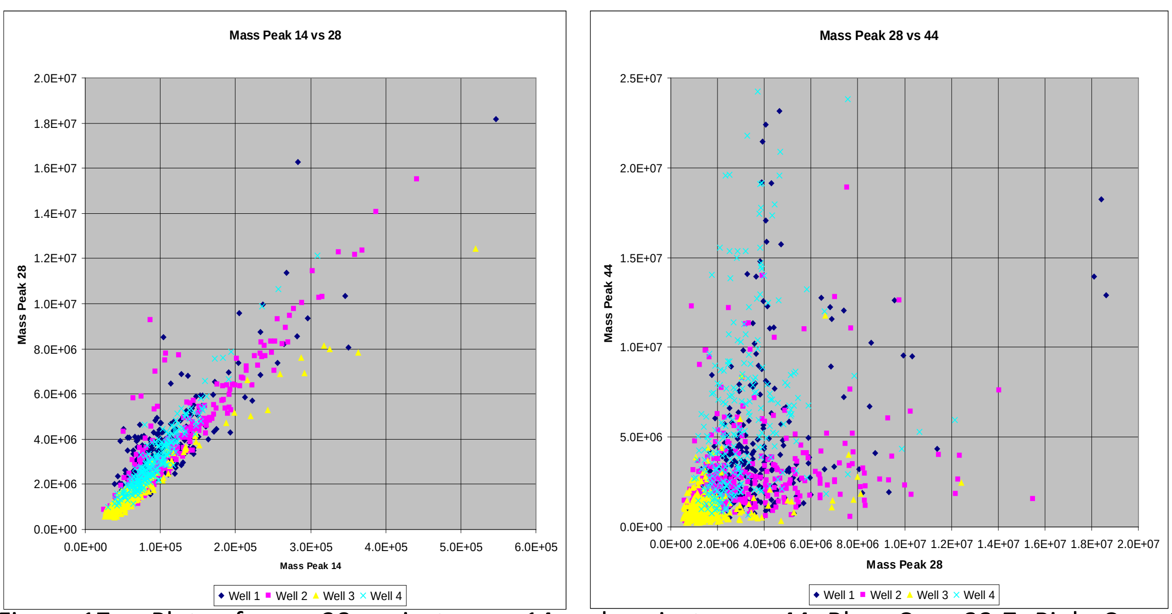
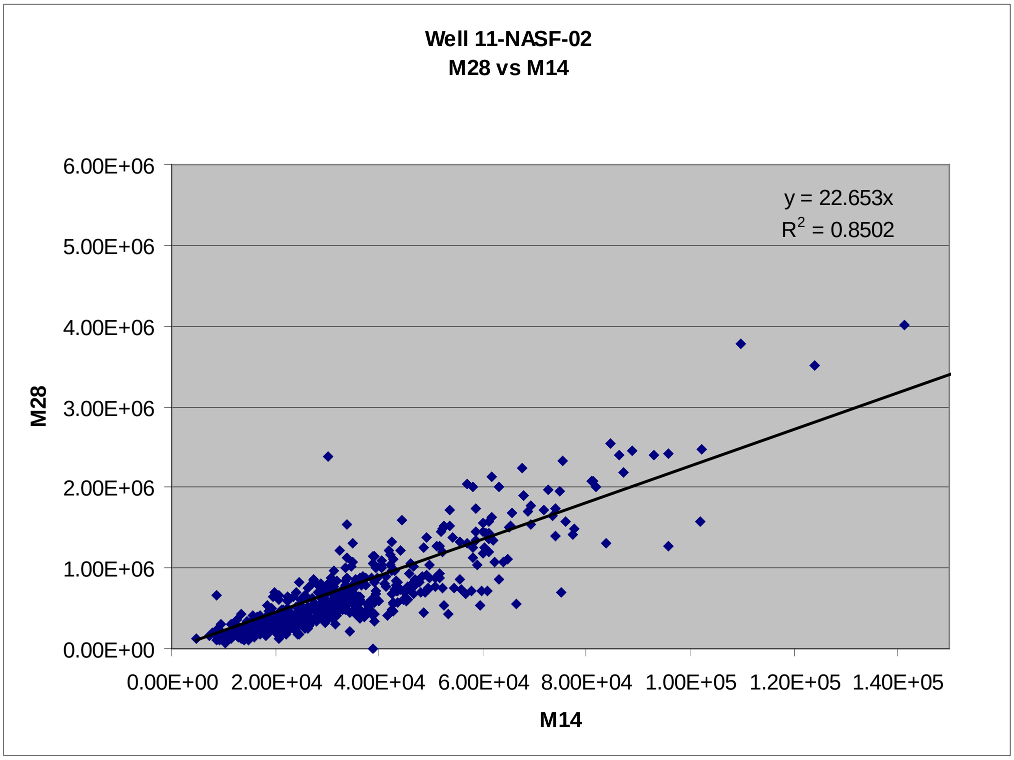


Figure 17a: Plots of mass 28 against mass 14 and against mass 44. Blue: Coso 33-7; Pink: Coso 38C-9; Yellow: Coso 84-30; Light Blue: Coso 58A-18.



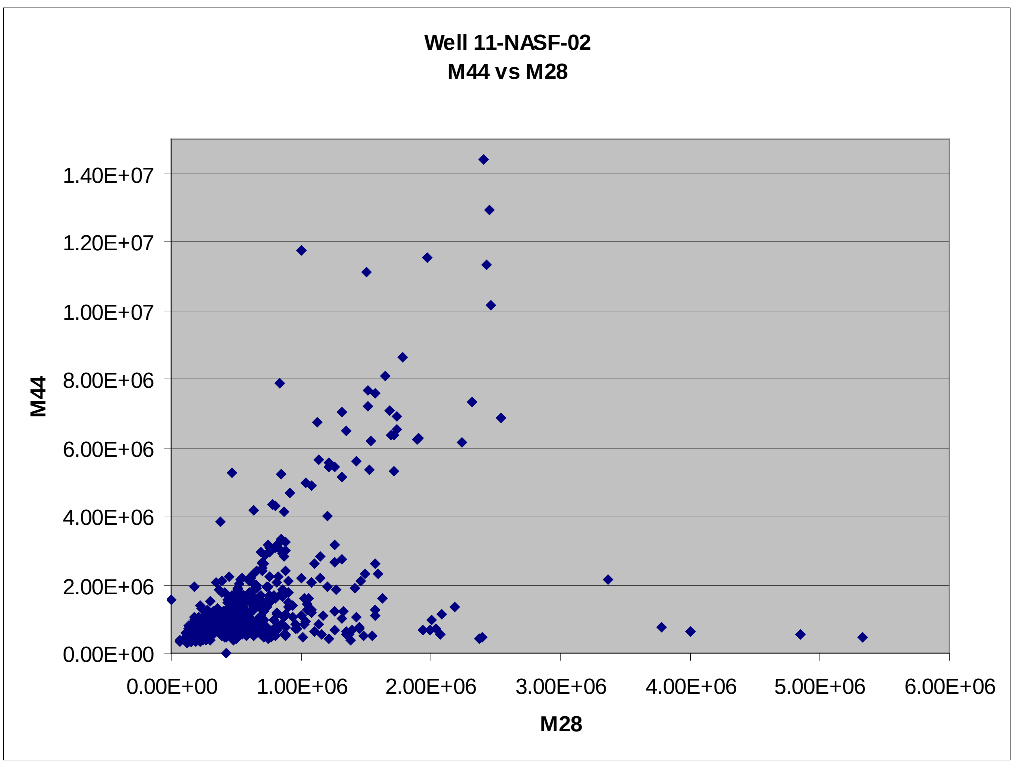


Figure 17b: Plots of mass 14 vs. mass 28 and mass 44 versus mass 28 for Fallon wells.

5.0 TASK 2: ADDITIONAL DATA COLLECTION

Task 2 was to collect additional data if needed. During the course of our investigation, samples from three wells from the Puna geothermal system hosted in basalt became available. At the time, only sparse samples were available from Iceland geothermal systems. Because of the limited funding available for analyses, DOE approved substituting the Puna study for investigations of carbonate-and metamorphic-hosted reservoirs. Core sampling followed protocols established in prior fluid inclusion gas analysis projects (Norman et al., 2005; Dilley, 2009). Samples were collected from three wells, typically at 20 ft. intervals. A total of 9,670 feet was sampled. Samples were submitted to Fluid Inclusion Technologies, Inc (FIT) located in Tulsa Oklahoma and the results returned to us for interpretation. The samples were analyzed as described above. Table 3 presents a sample of this data.

Table 3: A small sample of the FIT data for Hawaii Well SOH1. Note the relative concentrations are not presented in mol% or ppm but in counts. There are 180 mass species for each depth sampled. This table presents 5 of the species including hydrogen (mass 2), helium (mass 4), fragment of methane (mass 15), methane (mass 16) and water (mass 18).

SOH1 HDL SAMPLE	DEPTH	AMU002	AMU004	AMU015	AMU016	AMU018
			He		**CH4**	**H20**
Hawaii#1-001	2000	1.89E+05	7.50E-13	4.59E+04	2.04E+05	1.31E+05
Hawaii#1-002	2020	2.27E+05	1.17E+01	1.03E+05	3.48E+05	1.03E+05
Hawaii#1-003	2040	1.94E+05	3.01E+00	7.74E+04	2.09E+05	8.89E+04
Hawaii#1-004	2060	2.45E+05	5.73E+00	1.12E+05	2.30E+05	8.61E+04
Hawaii#1-005	2080	1.15E+05	5.41E+00	1.06E+05	2.28E+05	0.00E+00
Hawaii#1-006	2100	2.09E+05	0.00E+00	1.26E+05	2.80E+05	7.39E+04
Hawaii#1-007	2120	1.48E+05	0.00E+00	6.71E+04	1.70E+05	4.72E+04
Hawaii#1-008	2140	1.92E+05	9.13E+00	3.72E+04	1.49E+05	6.72E+04
Hawaii#1-009	2160	2.53E+05	1.96E+01	1.14E+05	7.11E+05	1.69E+05

6.0 TASK 3: GEOCHEMICAL INTERPRETATION

The purpose of Task 3 was to evaluate the nature of the fluid-inclusion gas signatures produced as a result of processes occurring within the geothermal systems, including boiling, condensation, cooling and mixing. We were originally going to model the effects of these processes using fluid compositions obtained from geothermal wells. Our initial studies however, suggested that numerical modeling of the data would be premature. We observed that the gas compositions, determined on bulk and individual samples were not the same as those discharged by the geothermal wells. As a first step, we examined the potential importance of different reservoir processes using a variety of standard gas ratios (e.g. Giggenbach ternary plots). It is important to recognize that many of these plots are based on the relative abundances of the minor gases because of their importance as tracers of fluid processes.

The results of this "back to basics approach" showed that gas compositions, particularly in low-temperature regimes, could be strongly influenced by near surface processes, rock type, and the degree of alteration. Furthermore, we recognized that fluid inclusions trapped in crystals from veins reflected a fluid-dominated environment whereas those from the bulk wall rock (FIT analyses) were more likely to reflect a rock-dominated environment. As the study progressed, it become increasingly apparent that more effort is required to understand the distribution of gases in different geologic and geochemical environments.

6.1 GAS FROM WELLS

Chemical analyses of gases discharged from 40 Coso wells were supplied by TerraGen for comparison with the fluid inclusion data. A summary of that data as well as additional data from Karaha-Telaga Bodas, Reykjanes, and the Salton Sea are presented in Table 4. The data indicate CO_2 is the dominant gas species and its abundance is generally one to two orders of magnitude greater than any of the other gases measured (Figure 18).

Table 4: Summary of gas data (ppm/v) from fluid samples from Coso, Karaha-Telaga Bodas (K-33, T-2), Reykjanes (Iceland), and the Salton Sea geothermal fields.

Species	Coso High	Coso Low	Coso Average	K-33a Mole %	K-33b Mole %	T2 Mole %	Iceland Mm/mol	Salton Sea Mm/mol
CO_2	52900	640	11,900	95.8	96.1	97	962	957
H_2S	1,110	2.43	183	2.64	3.11	1.87	29	43.9
NH_3	8.14	0	1.18	0.190	0.051	0.161		
Ar	1.71	0.05	0.46	0.0075	0.0020	0.0022		
N_2	1,030	3.03	58.6	0.481	0.183	0.247	6	
CH_4	11.0	0	1.56	0.556	0.355	0.321	1	`
H_2	14.6	0.008	1.10	0.326	0.173	0.403	2	

In contrast to the gases discharged by the wells, analyses of fluid inclusions are commonly enriched in CH_4, N_2, H_2S, and other species that occur only in trace amounts in the initial gas concentrations from the wells. The data from Dixie Valley by McLin (2012) provides a good illustration of the differences between discharged and fluid inclusion gases. McLin's analyses were conducted on scale samples that formed on tubing hung in the well. Thus they were formed from the same fluids that were analyzed at the well head. McLin (2012) concluded these differences could result from separation and trapping of the light gases during boiling. As discussed below, other processes such as fluid mixing, boiling, fluid-rock interactions and the decomposition of organic matter can also affect the composition of the trapped fluids.

6.2 GECHEMICAL ANALYSES OF INDIVIDUAL CRYSTALS

Fluid inclusion gas analyses of the type performed at NMT on individual crystals have the advantage over FIT analyses of providing quantitative analyses on a relatively small number of inclusions. Norman and others have shown that these data can be interpreted using techniques originally developed for gas discharges (Giggenbach 1986; Norman and Sawkins 1987; Graney and Kesler, 1995; Giggenbach, 1997; Moore, 1998; Norman and Musgrave, 1995; Norman et al., 1997; Norman et al, 2002). In this section we review the interpretational techniques that have been developed to evaluate these fluid inclusion analyses.

6.2.1 FLUID INCLUSION GASES AS TRACERS OF FLUID SOURCES

Giggenbach (1986) demonstrated that the compositions of the minor gases could be used to trace their origins. Norman and Musgrave (1995) extended this analysis to fluid inclusion gas compositions. Figure 19 shows the compositional fields for the major fluid types. Meteoric fluids have N_2/Ar ratios between 38 (air saturated water), and 84 (air). Deeply circulating meteoric and crustal waters are enriched in He. Crustal fluids have low argon values. Magmatic fluids have high N_2/Ar ratios well above 84. Mixed fluids would plot between the various fields.

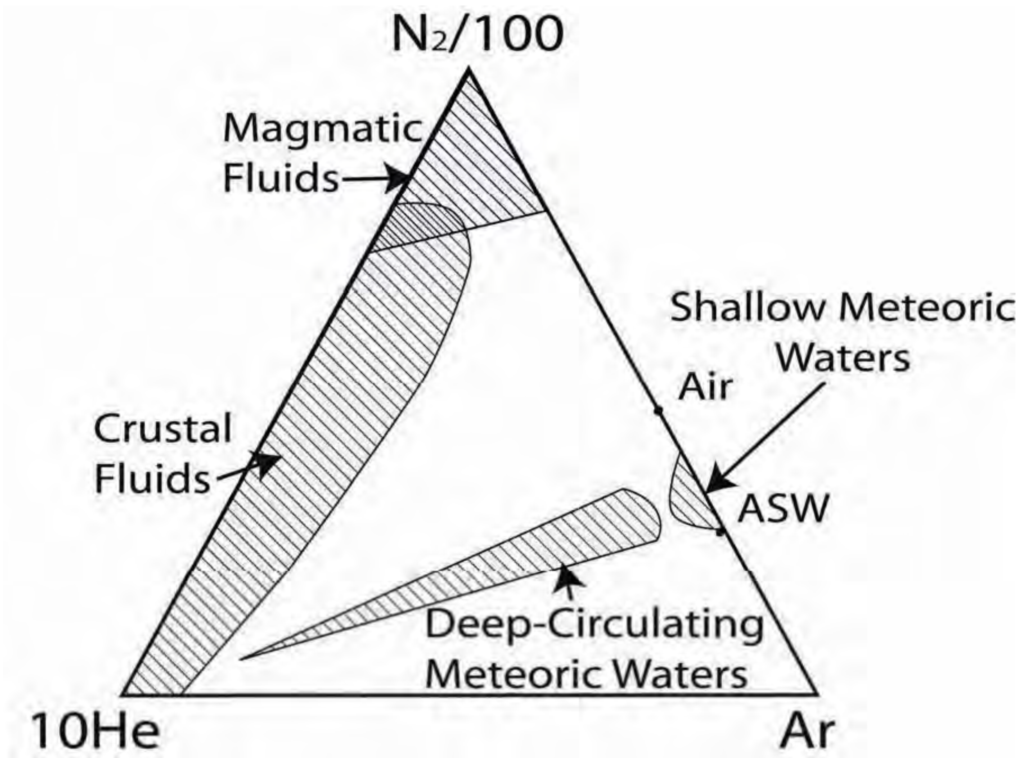


Figure 19: N_2-Ar-He compositional fields for magmatic, crustal, deeply circulated meteoric, and shallow meteoric fluid sources (modified from Norman and Musgrave 1995).

6.2.2 BOILING AND CONDENSATION

Boiling and condensation are important processes that occur in geothermal systems. Petrographic evidence for boiling includes hydrothermal breccias, veins containing adularia or bladed calcite and quartz, vapor-rich fluid inclusions and inclusions with variable liquid/vapor ratios and anomalously high salinities. Several of the wells in the study display petrographic evidence of boiling including Karaha Telaga Bodas wells T2 and K33.

Fluid inclusions that trap steam and gas will commonly have relatively high gas/water ratios. Calculations using Henry's Law coefficients predict gas contents of not more than about 2 mole percent in a the liquid phase at geothermal temperatures and pressures. Thus, fluid inclusions that contain significantly more than several mole percent gas must have trapped steam and gas. As the fluids boil, the composition of the evolved gases will change in a predictable fashion. Fluid inclusion analyses have shown, as predicted, early stages of boiling will result in the trapping of light gases (e.g., CH_4, ethylene, H_2, He, N, Ar,) (Norman et al., 2002). During the later stages of boiling, the more soluble gases (CO_2 and H_2S) will become increasingly abundant in the inclusions. Condensation, in contrast, will concentrate the more soluble species including aromatic organic species, H_2S, and CO_2. Boiling and condensation will display opposite trends when gas ratios (e.g. CO_2/N_2) are plotted against the total gas content. Because the early formed gas will be enriched in N_2 relative to CO_2, this ratio will increase as the total gas decreases during boiling. Fluid inclusions from Geysers indicated extremely low H_2O and high CO_2, CH_4, H_2, and N_2 contents. High gas contents indicate inclusions must have trapped early-formed steam and that compositions changes induced by boiling triggered mineral deposition.

Moore et al. (2002) described the effects of open and closed system boiling on the compositions of CO_2, CH_4 and H_2. These effects are illustrated in Figure 21 for starting compositions of $0.12CH_4$, $0.48CO_2$ and $0.40H_2$ for the closed system and $0.50CH_4$, $0.40CO_2$ and $0.10H_2$ for the open system .

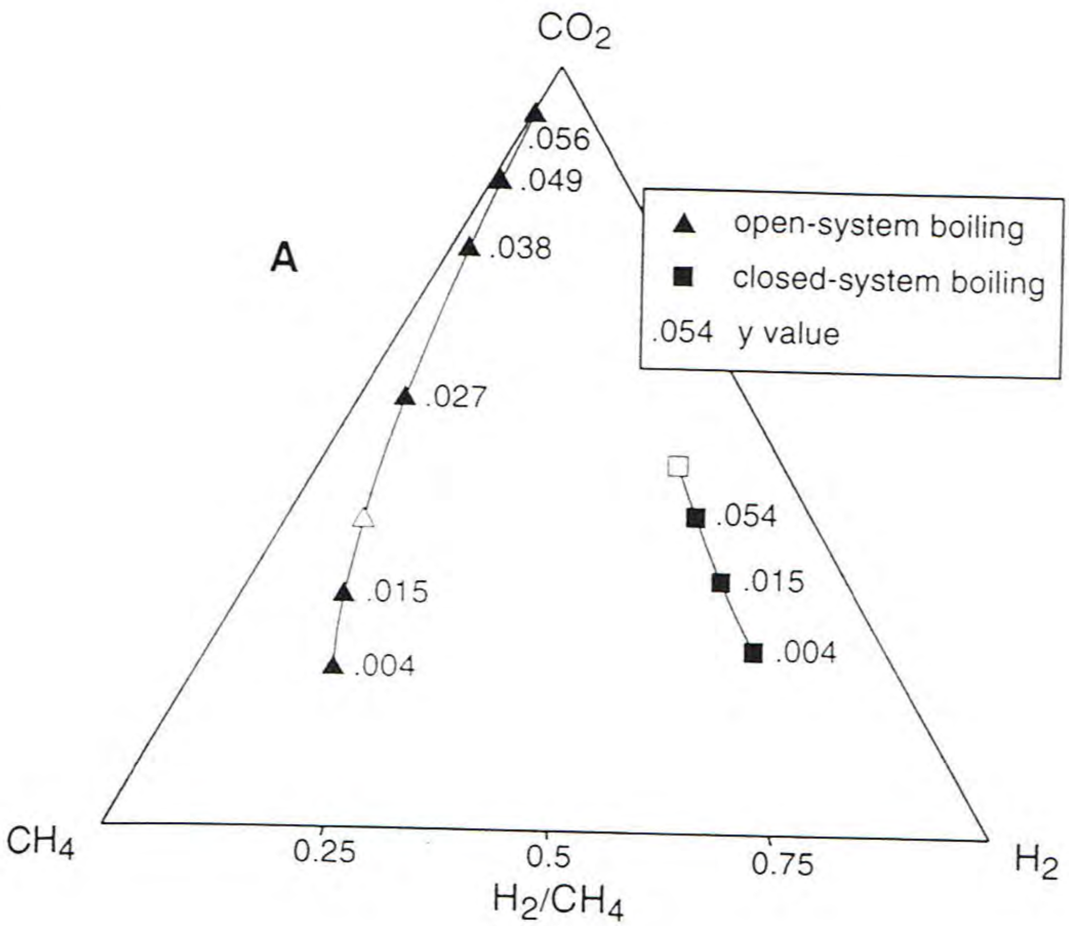


Figure 21: Distribution of CH_4, CO_2 and H_2 in a vapor phase during open and close system boiling (after Moore et al., 2002).

Analyses of fluid inclusions from volcanic- (Karaha-Telega Bodas) and granitic-hosted (Coso) geothermal systems also contain organic compounds at concentrations ranging from about 1 ppm/v to almost 900 ppm/v (Norman et al., 2002). The concentrations and type of organic species measured indicate inorganic processes as the source. Biogeneic processes typically occur at less than 200°F and produce mostly methane. Inorganic sources include pyrolysis of organic material, which produce alkanes and heavier hydrocarbon species, and Fischer-Tropsch reactions, which produce lighter hydrocarbon species and alkenes (Norman et al, 2002). Wall rock reactions with alkanes can produce alkenes. Norman et al. (2002) conclude that the ratio of alkanes/alkenes (C_{n+1} / C_n) can be used to indicate the source of hydrocarbon gaseous species.

In summary, previous work on interpreting fluid sources and processes from geothermal gas chemistry based on fluid inclusions from individual crystals has shown the following (Table 5): (1) meteoric-air saturated water (shallow groundwater) has low concentrations of gaseous species and N_2/Ar ratios of between 38 to 84; (2) the deep circulating alkaline chloride waters typically have N_2/Ar ratios indicating a meteoric source, CO_2/CH_4 ratios greater than 4 (if the reservoir rocks have low organic contents), and H_2S concentrations controlled by equilibrium with pyrite and magnetite; (3) steam-heated waters have high concentrations of the more soluble gaseous species such as H_2S, CO_2, and benzene; steam caps have inclusions rich in gaseous species and much less water than assemblages of aqueous inclusions (Moore et al., 2001); (4) boiling creates inclusions with gas contents greater than several mole percent and high gas/water ratios. Condensation results in increasing CO_2/N_2 ratios with increasing gas contents.

Table 5. Summary of Fluid Inclusion Gas Chemistry and Fluid Types.

Fluid Types	N_2 / Ar	CO_2 / CH_4	H_2S	Other
1) Meteoric-Air Saturated Waters	38 -84	Low <4	Low	Low total gas Alkanes/alkenes high
2) Reservoir fluids	Varies	>4	Present maybe high	High CO_2, Total gas >0.1
3) Steam-heated waters/steam caps		Typically >4	High >0.01 mol%	Soluble gases, H_2S/N_2>0.1
4) Boiling Condensation	>110	>4	Present Condensation high	Gas/Water high, CO_2/N_2 increases with total gas

6.2.3 FIT Calibration

FIT analyses were compared to NMT analyses to determine if a correction factor was needed due to FIT analyses are counts and not actual concentrations, like NMT analyses FIT mass spectra shows sample to sample and well to well variations that can be interpreted in the relative proportions of the gaseous species similar to NMT data. FIT analyses show common low and high N_2/Ar ratios. We interpret the low ratios that are about 100 as the meteoric and the higher ratios as magmatic. It was decided to use FIT analysis as is and use empirical relationships between gas ratios and abundances to interpret the spectra. Gas ratios are calculated from the raw data and show sample to sample variations.

Figure 22 presents an example of comparison between FIT and NMT analyses for samples from Coso Well 83-16, (Norman et al. 2004) Although there are differences in the values, the overall patterns appear similar. For N_2/Ar ratios (the first graph in each group) the majority of the peaks occur below 6000 ft. The propane/propene ratio graphs (second graph in each group) display peaks above 6500 ft. The graphs are also similar for the CO_2/CH_4 ratios, with peaks occurring in the upper portion of both graphs. Comparisons of FIT data from other fields showed that the overall trends for the gases of interest were similar but that the magnitude of the differences varied from well to well and field to field. Based on these observations, we decided not to correct the values but use the raw FIT data instead.

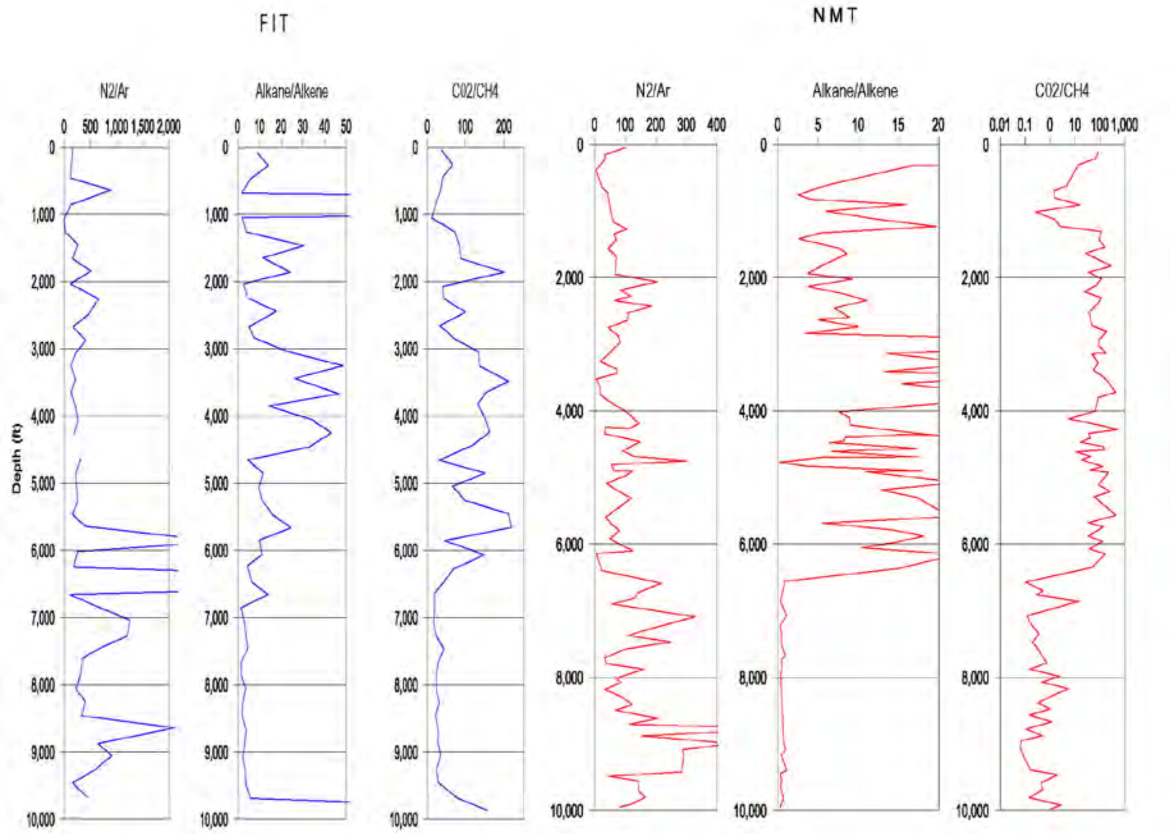


Figure 22. FIT and NMT data for several ratios for samples from Coso 83-16 (Norman et al, 2004). Although the absolute abundances differ, the patterns of high and low concentrations are similar.

6.3 BULK ANALYSIS

Bulk analyses of fluid inclusions combines veins and the surrounding wall rock. The underlying assumption is that the bulk analyses can be interpreted in the same way as analyses from individual crystals. The unique approach that was developed was to assess the gases in terms of their sources (e.g. meteoric, crustal, and magmatic) and then consider the modifying effects of boiling, mixing, and condensation. Five assumptions are made: 1) the gas chemistry of geothermal reservoir fluids is different than the gas chemistry of non-thermal waters; 2) reservoir fluids may have additions of magmatic volatiles or deep crustal fluids; 3) the interpretations not be reflective of the total fluid compositions; 4) boiling, condensation, and fluid mixing processes result in systematic changes in gas chemistry; and 5) the bulk analyses can be interpreted using standard geochemical models.

We focused on wells from Coso because we had the most analyses from this field. As can be seen in Table 1, many of the Coso wells were producers, however there are several injection wells and one well, 84-30, is located south of the field margin. In addition, two wells from Karaha-Telaga Bodas, T-2 and K-33, were used to compare NMT and FIT data. Both Coso and Karaha Telaga Bodas are high-temperature geothermal systems. We have included analyses from Fallon, El Centro, and Hawthorne, which are low-temperature Basin and Range geothermal systems. Salton Sea wells were used for analyzing organic compounds in geothermal systems. Plots for the other fields are presented in the appropriate appendices.

6.3.1 N_2-Ar-He relationships

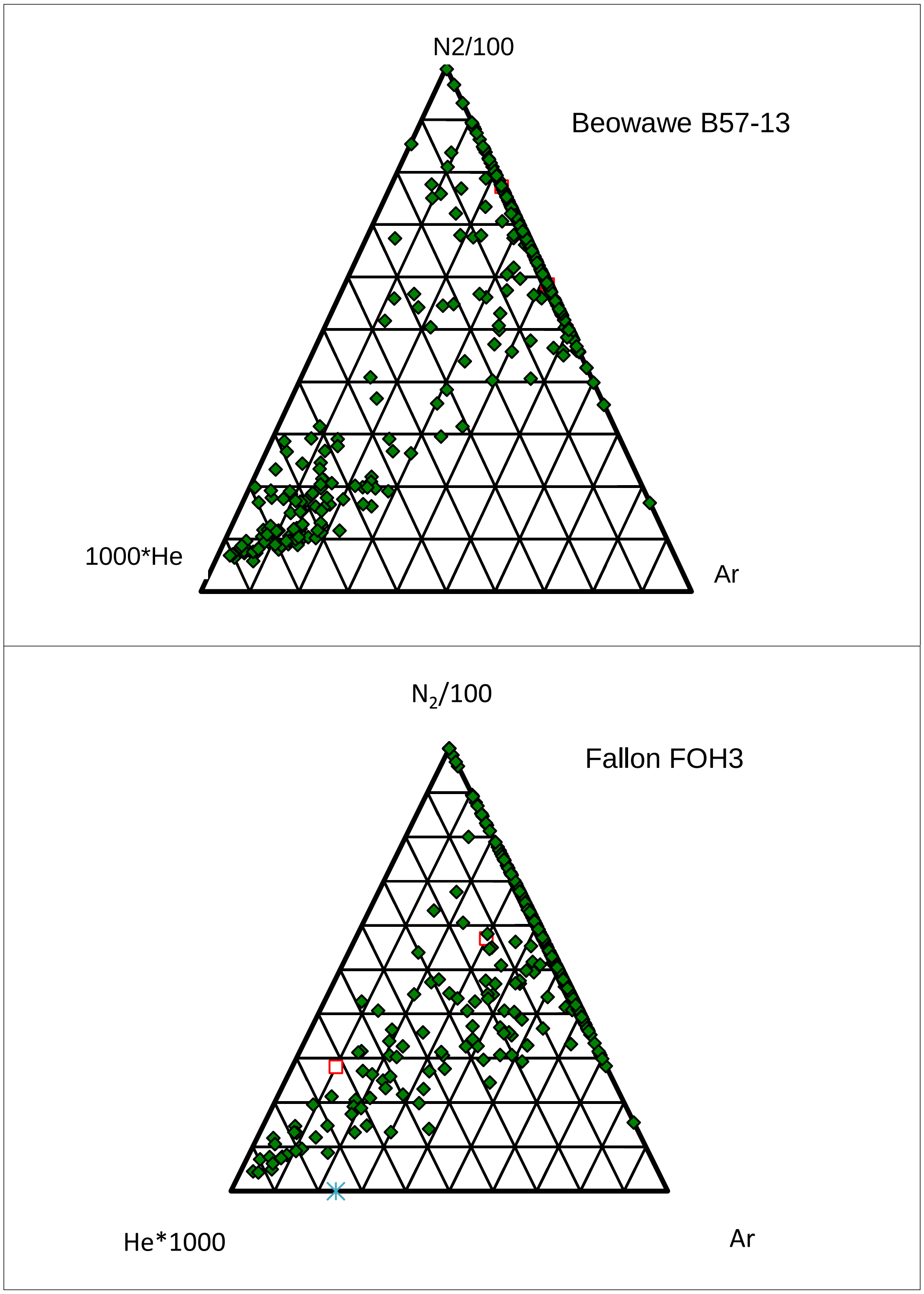
The N_2-Ar-He diagram compares the relative gas contents derived from magmatic, crustal, and meteoric sources. Appendix C presents diagrams for the wells studied. The derivation of this diagram is discussed in Section 6.2. Many of the geothermal systems studied have inclusions that plot as meteoric and crustal fluids. With a bulk analysis, the value of the N_2/Ar ratios of air and air saturated water are unknown, however analyses plotted with higher values of argon are assumed to have meteoric fluids, those plotted with high nitrogen, more magmatic in nature.

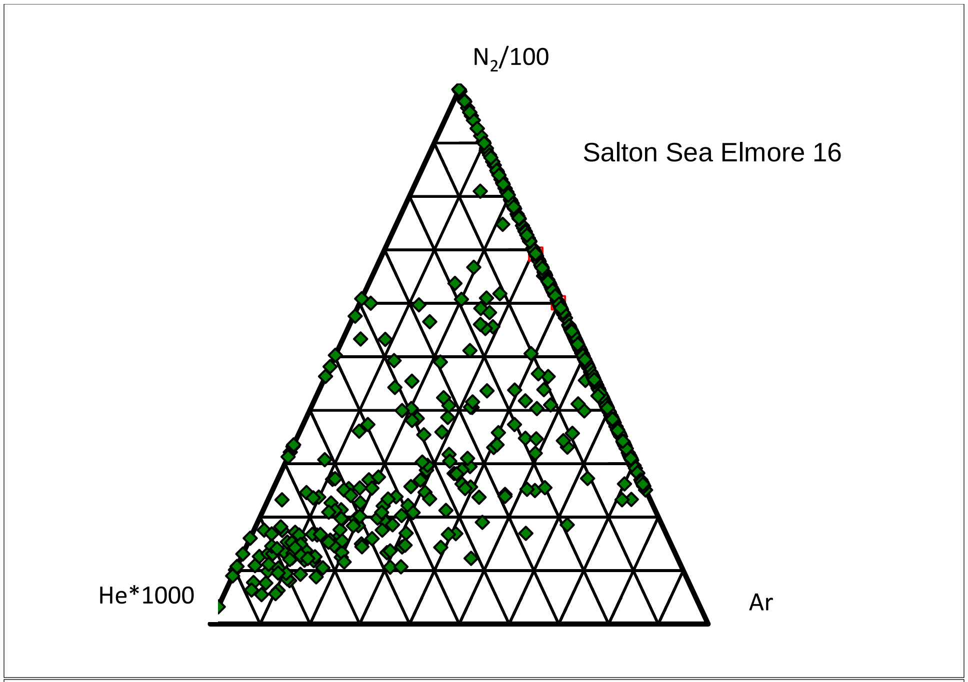
The lower temperature systems such as Fallon, El Centro, and Hawthorne have multiple inclusions that plot in the meteoric field and indicate mixing of meteoric and crustal fluids. Several of the plots indicate inclusions with high He (Figure 23). Fallon Well FOH3 encountered Mesozoic granitic rocks that contained inclusions with high He. These systems have temperatures below 350^{o}F. Beowawe wells display similar relationships, except there are more samples that plot in the magmatic region. Beowawe is a moderate temperature, Basin and Range system. Salton Sea wells trapped meteoric fluids, with the exception of Sinclair 24 and Elmore 16, whose gas analyses indicate a crustal origin.

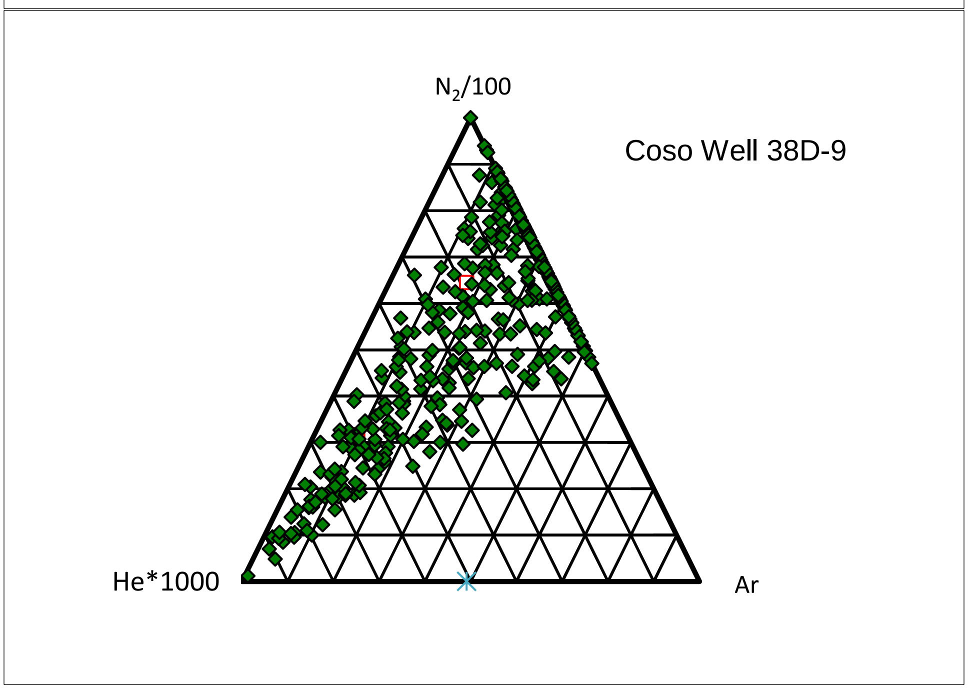
There is a difference between the low-and high-temperature wells at Coso. Two main fluid types occur in the low temperature wells: meteoric and crustal fluids. The crustal fluids contain high He concentrations and low N_2 in these wells. The higher temperature wells have inclusions that indicate mixing of crustal and meteoric fluids and have numerous inclusions that plot in the magmatic region. Data from well 84-30, located outside of the field, plot in the magmatic region.

The use of the N_2-Ar-He ratios applied to the bulk analysis provides information about specific fluid types in much the same way as analyses of individual crystals. Inclusions from lower temperature systems and lower temperature wells in high-temperature systems typically indicate meteoric fluids with minor contributions of crustal and magmatic fluids (high N_2). Although N_2/Ar ratios of ASW and air

(34 and 84, respectively) cannot be used to identify shallow meteoric waters, bulk analyses that have relatively high percentages of Ar can be assumed to be meteoric. Based on the El Centro and Hawthorne wells in which meteoric waters are expected to dominate, the Ar concentrations are 30 percent or more. FIT ratios of N_2/Ar are in the range of 100 to 450 in these systems.




N2/100
Salton Sea Elmore 16
He*1000
Ar


N2/100
Coso Well 38D-9
He*1000
Ar

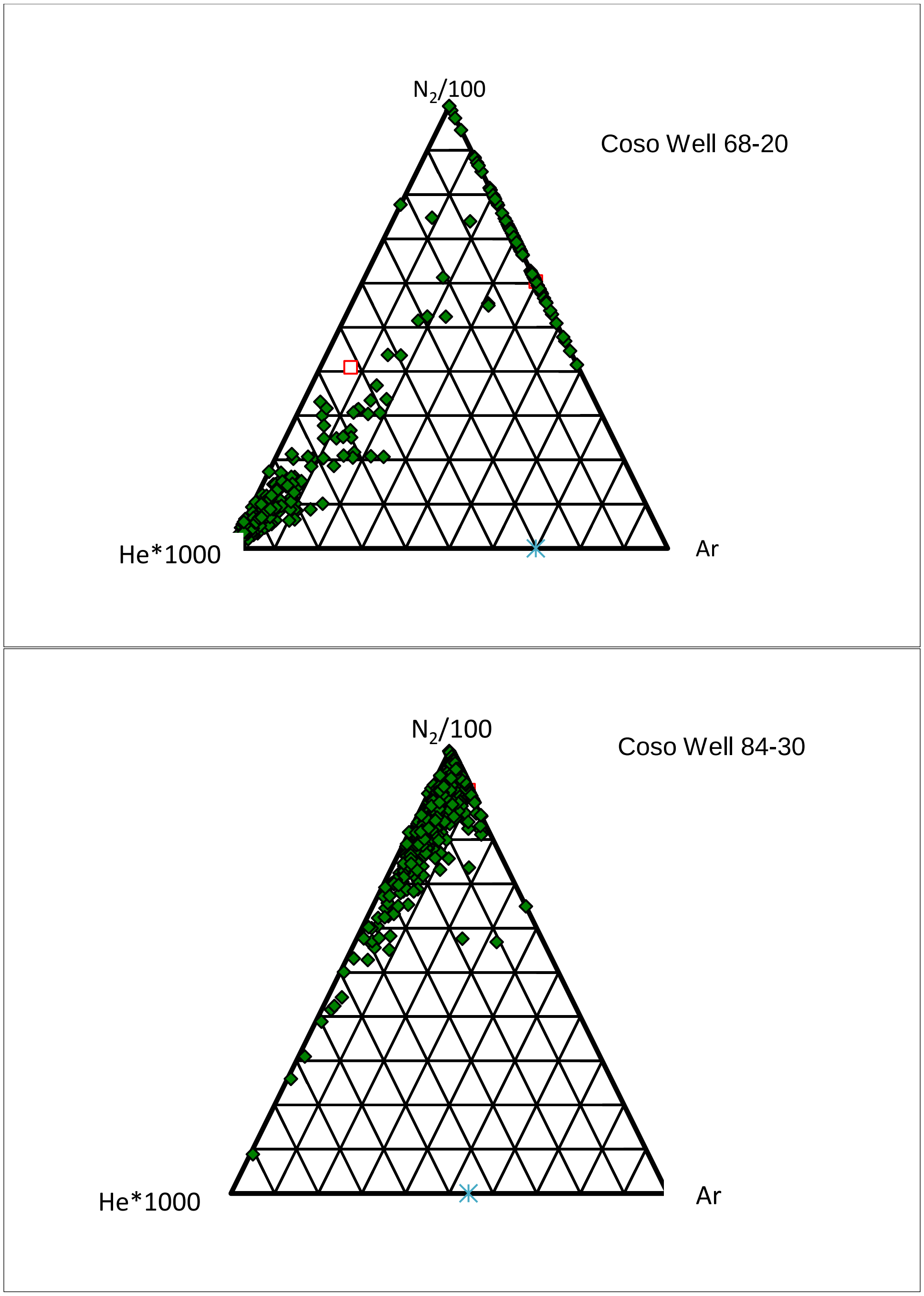


Figure 23: N_2-Ar-He diagrams for wells showing different fluid types: Beowawe B57-13, Fallon FOH3 , Salton sea Elmore 16, and Coso Well 38D-9 all show mixing of deep crustal fluids with meteoric fluids. there are some magmatic components as well with those analyses that plot near the N_2 apex such as in Coso Well 84-30. Coso Well 68-20 indicates deep crustal fluids by the analyses plotted near the He apex and meteoric fluids with little mixing.

6.3.2 CO_2-CH_4-H_2 relationships

CO_2-CH_4-H_2 ratios have been useful for identifying fluids that have undergone boiling by a progressive increase in the CO_2 concentration relative to CH_4 and H_2. Appendix D presents this ternary diagram for the wells. Vapor-rich inclusions can be recognized in an analysis by gas contents that are too high for a liquid phase(e.g. >2 mole percent). The ratio of these gases are controlled by reactions such as the following:

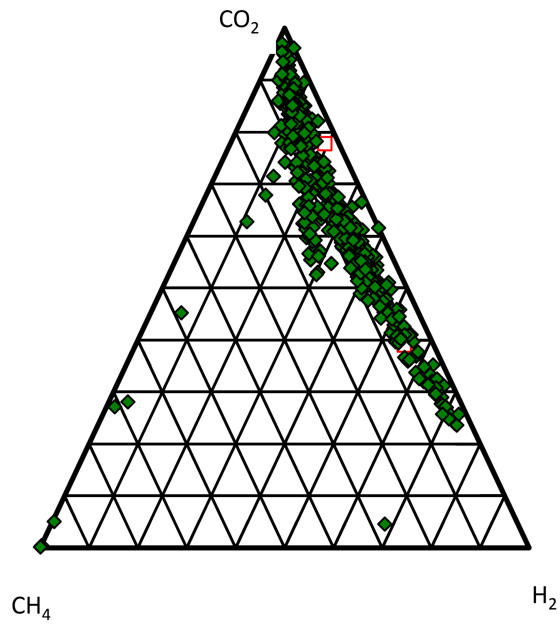
$$CH_4 + 2H_2O = 4H_2 + CO_2$$

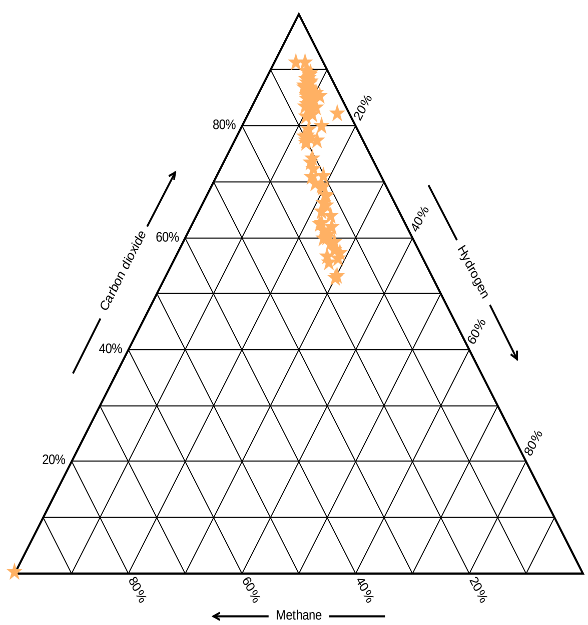
Boiling models indicate that the CH_4 to H_2 ratio remains approximately constant as the steam fraction (y) increases and that open-system boiling will produce a much greater range of gas compositions than closed-system boiling. (Moore et al, 2000). CO_2-CH_4-H_2 ratios were used successfully to describe boiling trends at Tiwi (Moore et al., 2000) and The Geysers (Moore et al., 1998).

Plots of analyses of low-temperature systems unexpectedly yielded trends typical of boiling at high H_2/CH_4 ratios. Fallon Well CL82-36 (Figure 24) is a low temperature well that encountered sediments to about 2,400 ft and andesite flows, metamorphic rocks and tuffs at greater depths. The present day temperatures are too low for boiling to occur and petrographic analyses of the samples show no evidence of boiling. Plotting the data in 2000 ft intervals reveals that the fluids do not show a boiling trend above 8,000 ft. This is the depth the well encountered tuffs and andesitic flows.

Plots from the Salton Sea also show similar trends, with Elmore 16 having a relative high percentage of CH_4 compared to the other wells at Salton Sea. Lower temperature wells at Salton Sea have higher percentages of H_2 than CH_4 (Figure 25). There is no evidence of boiling but petrographic studies have documented dissolution of the carbonate cement in the sandstones and its replacement by epidote. The released CO_2 in solution could have been trapped in fluid inclusions, producing a trend towards higher CO_2 that would mimic a boiling trend.

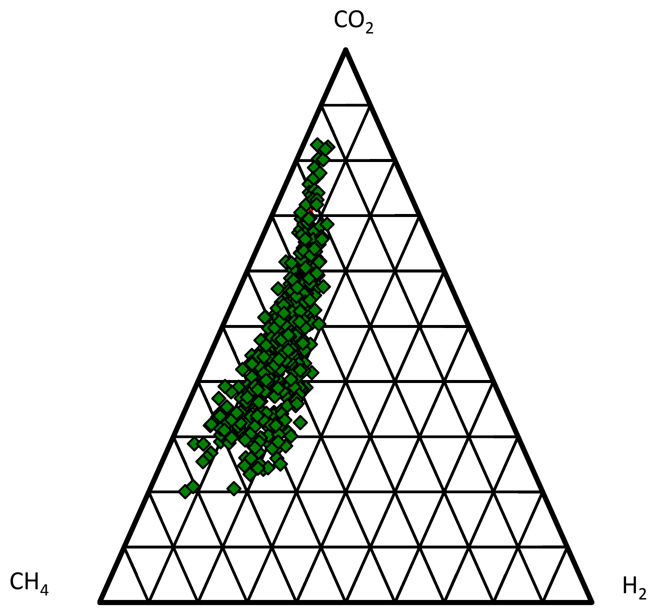
Widespread boiling that led to the formation of a vapor-dominated regimen has been documented at Karaha-Telaga Bodas FIT analyses, when compared to NMT analyses show major differences in the CO_2-CH_4-H_2 plot (Figure 26). The NMT data for T-2 displays a linear trend with a high CH_4/H2 ratio. The FIT data suggests a lower CH_4/H2 ratio. FIT data for K33 is more clustered than that for the NMT data and has higher CH_4/H_2ratio. We suggest these differences are due to the material sampled and not to fragmentation of H_2O to H_2 or other machine differences. The NMT data was obtained on hand picked vein minerals whereas the FIT data was obtained on mixtures of wall rock and vein minerals. Thus the differences may reflect differences in the compositions of rock dominated (the wall rock) and fluid dominated environments.



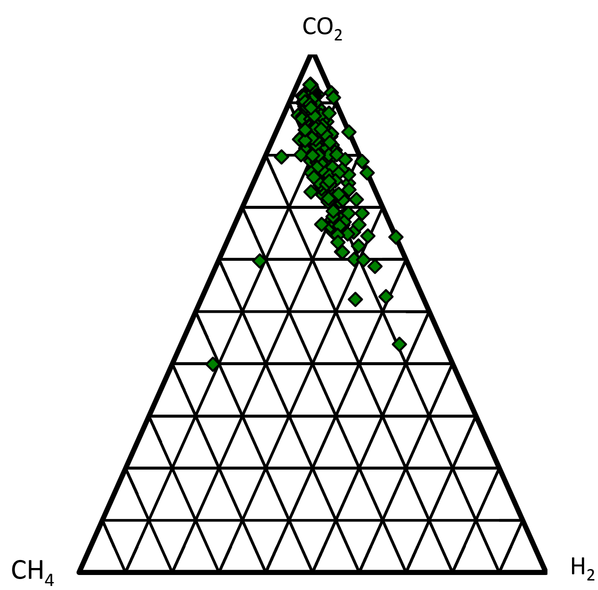


8000 ft to TD

Figure 24: CO_2-CH_4-H_2 ternary diagram for Fallon Well CL82-36. The diagram shows a trend that could be interpreted in terms of boiling, particularly below 8000 ft. No petrographic evidence of boiling was observed. Thus other processes must be considered to explain the trend in gas ratios.

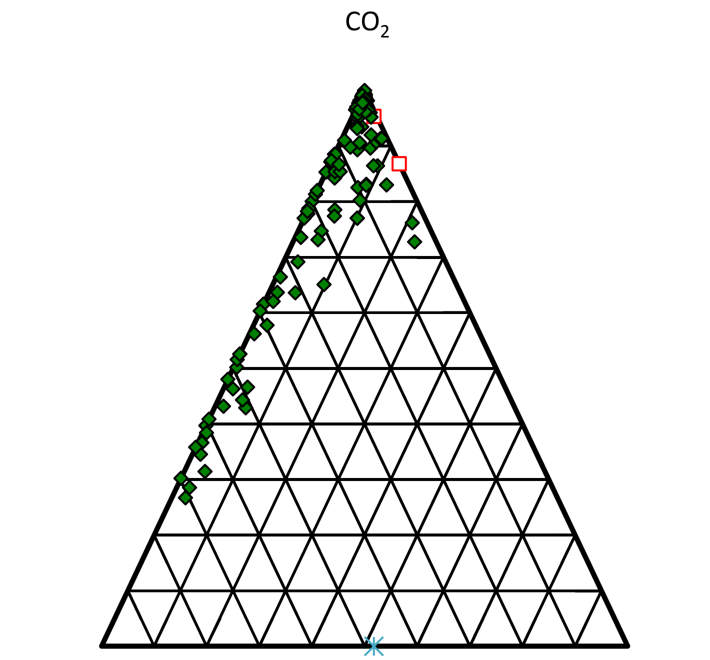


Salton Sea Elmore 16

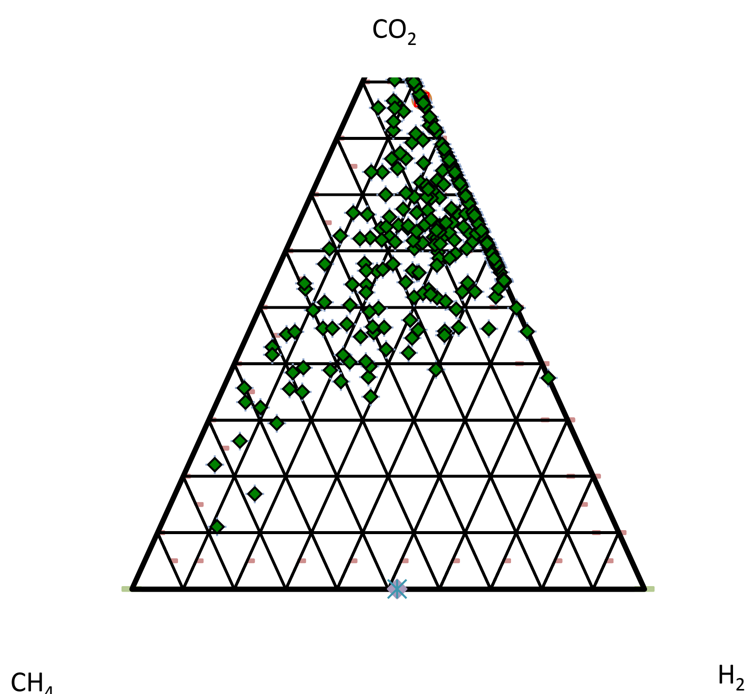


Salton Sea River Ranch 5

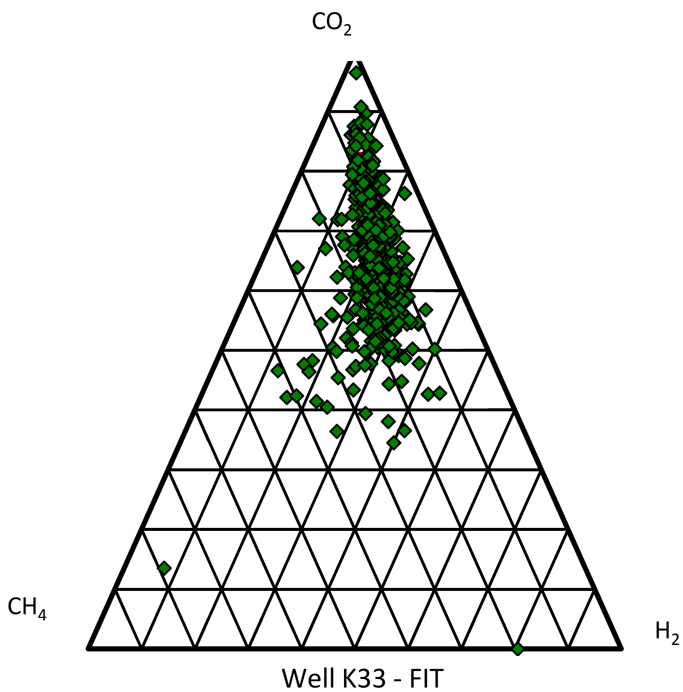
Figure 25: Ternary plots for two wells at Salton Sea. Elmore 16 is hotter than River Ranch 5. Salton Sea does not show evidence of boiling, however there is CO_2 migration which produces the variations in CO_2.



Ternplot T2   NMT DATA



Ternplot T2 FIT



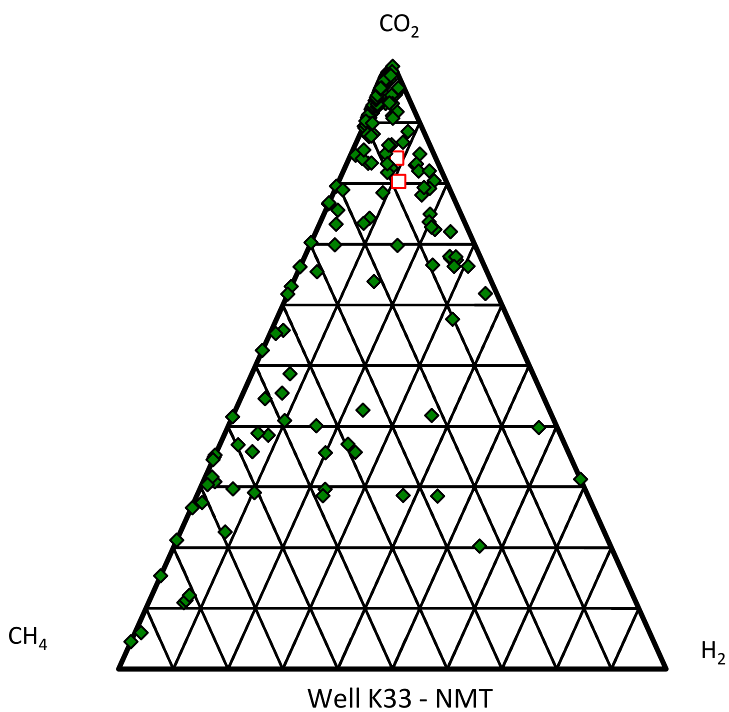
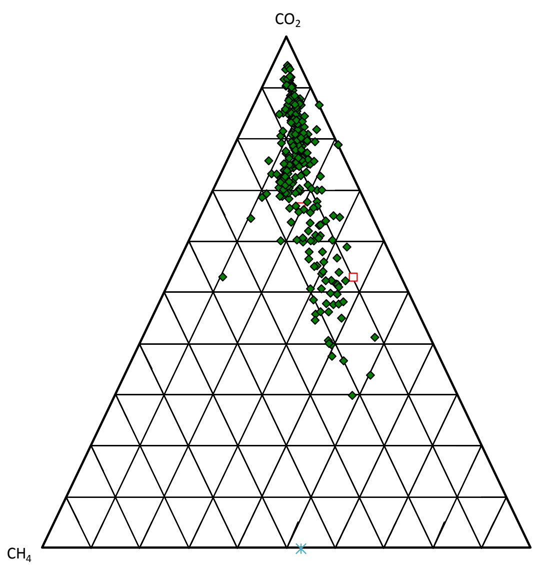
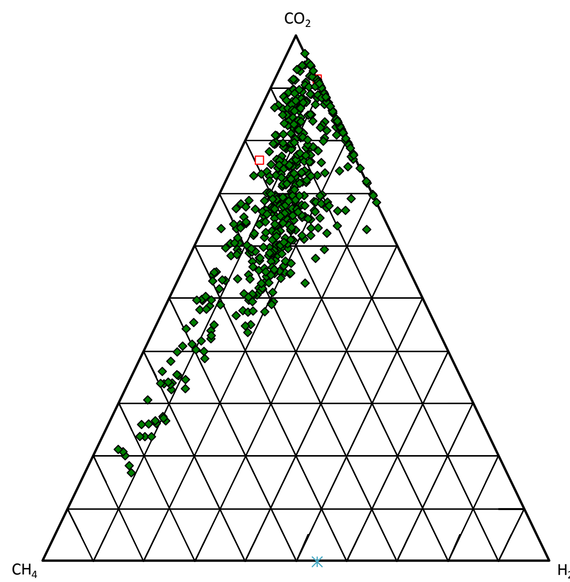


Figure 26: Distribution of CH_4, CO_2 andH_2 for Karaha-Telaga Bodas wells T2 and K33 . The NMT data is based on the analysis of vein minerals whereas the FIT is based on bulk samples that includes both wall rock and vein minerals.

Figures 27 shows the relative CO_2, CH_4 and H_2 contents of fluid inclusions determined by bulk analysis for Coso wells. The data plots as a linear trend with a broad range of CO_2 contents. The H_2/CH_4 ratio appears to vary with temperature. Fluid inclusions from Coso 68-20 are enriched in H_2 compared to CH_4. This well encountered temperatures, below 350^0F. Coso 83B-16 is enriched in CH_4 relative to H_2 51B-16 is characterized by equal amounts of CH_4 and H_2. Coso 83B-16 is one of the hottest wells whereas 51B-16 is intermediate in temperature. This variability in the ratio may be due to hydrogen being less soluble than methane and therefore during boiling is the first in a vapor phase and thus is trapped at lower temperatures compared to methane. Appendix E presents data for all of the Coso wells and their temperature profiles.



Well 68-20



Well 83B-16

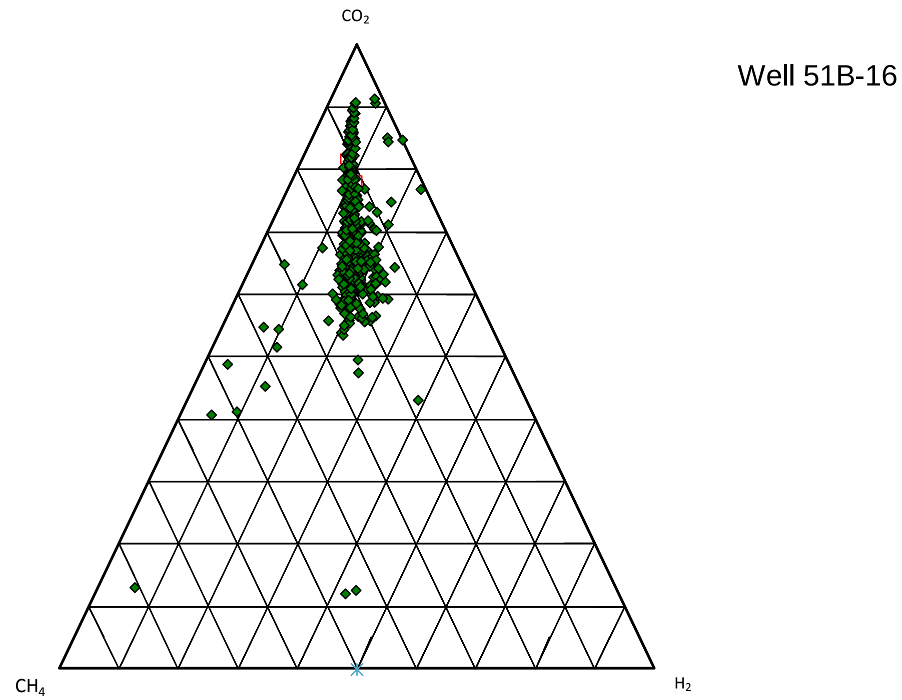


Figure 27: Three CO_2-CH_4-H_2 diagrams for three Coso Wells. Well 68-20 is a low-temperature well with temperatures generally below 350°F. Well 83B-16 encountered temperatures of 500°F and above. Well 51B-16 has temperatures between 300 and 550°F.

The use of the CO_2-CH_4-H_2 diagrams does not appear to be a useful tool for identifying boiling systems. The results suggest several processes can result in trends that mimic those produced by boiling, including CO_2 migration, may be a result of CO_2 migration, trapping of CO_2-rich metamorphic fluids or past boiling. Differences in the CH_4/H_2 ratios within a single field may be related to temperature differences, with the lower temperature wells having lower CH_4/H_2 ratios

Based on the less than definitive nature of the CO_2-CH_4-H_2 diagram to indicate boiling additional gas ratios and cross-plots were investigated. These are discussed in the following sections.

6.3.3 Gas/Water Ratio

In systems where boiling is known to occur (Karaha and The Geysers), fluid inclusions commonly have high gas contents, reflecting the presence of vapor-rich inclusions. As noted above, the maximum gas contents of liquid-rich inclusions cannot exceed a few mole percent under geothermal conditions. Gas/water ratios for Karaha-Telaga Bodas wells T2 and K33 are plotted against their CO_2/N_2 ratio based on NMT data in Figure 28. This plot indicates that gas/water ratios above 0.02 can be used to indicate those crystals that have trapped vapor rich inclusions and therefore boiled fluids. The plot of gas/water ratio versus CO_2/N_2 ratio for the bulk analysis of Karaha-Telaga Bodas well T2 is presented in Figure 29. A gas/water ratio of about 20 appears to correspond to 2 mole %. Appendix F presents data for other systems, as well as the total gas versus CO_2/N_2 ratio for comparison.

Fallon FOH3 has high gas/water ratios even though this is a moderate-temperature system. With moderate temperature systems, we hypothesize that alteration is not strong enough to cause destruction of the existing fluid inclusions.

Coso wells do not have high gas/water ratios except for Well 46-19RD (Figure F35 in Appendix F). High temperature wells have gas/water ratios that are below 20. Low temperature wells have gas/water ratios that are typically below about 10.

Nitrogen is a less soluble gas species than CO_2. We plotted N_2 versus CO_2 for the Karaha-Telaga Bodas wells using NMT data in order to determine if boiling could be identified (Figure 30). The data includes inclusions that have high N_2/CO_2 ratios, which could represent the early stages of boiling. Those inclusions with high CO_2 contents could represent late-stage boiling or in the case of the lower temperature systems and the Salton Sea wells, indicate CO_2 migration or earlier events. Plots of N_2 versus CO_2 were made for a number of wells including Fallon CL82-36 and Salton Sea Elmore 16 (Figure 31). Both of these wells have few inclusions with high N_2 (values above about 1.5E6) and low CO_2 (values below about 2E6). The Salton Sea well in particular has many inclusions with high CO_2 but except for 5 data points, values are below 1.5E6 for N_2. The trend towards increasing CO_2 on the CO_2-CH_4-H_2 plot, high gas/water ratios and low N_2 are consistent with gas migration.

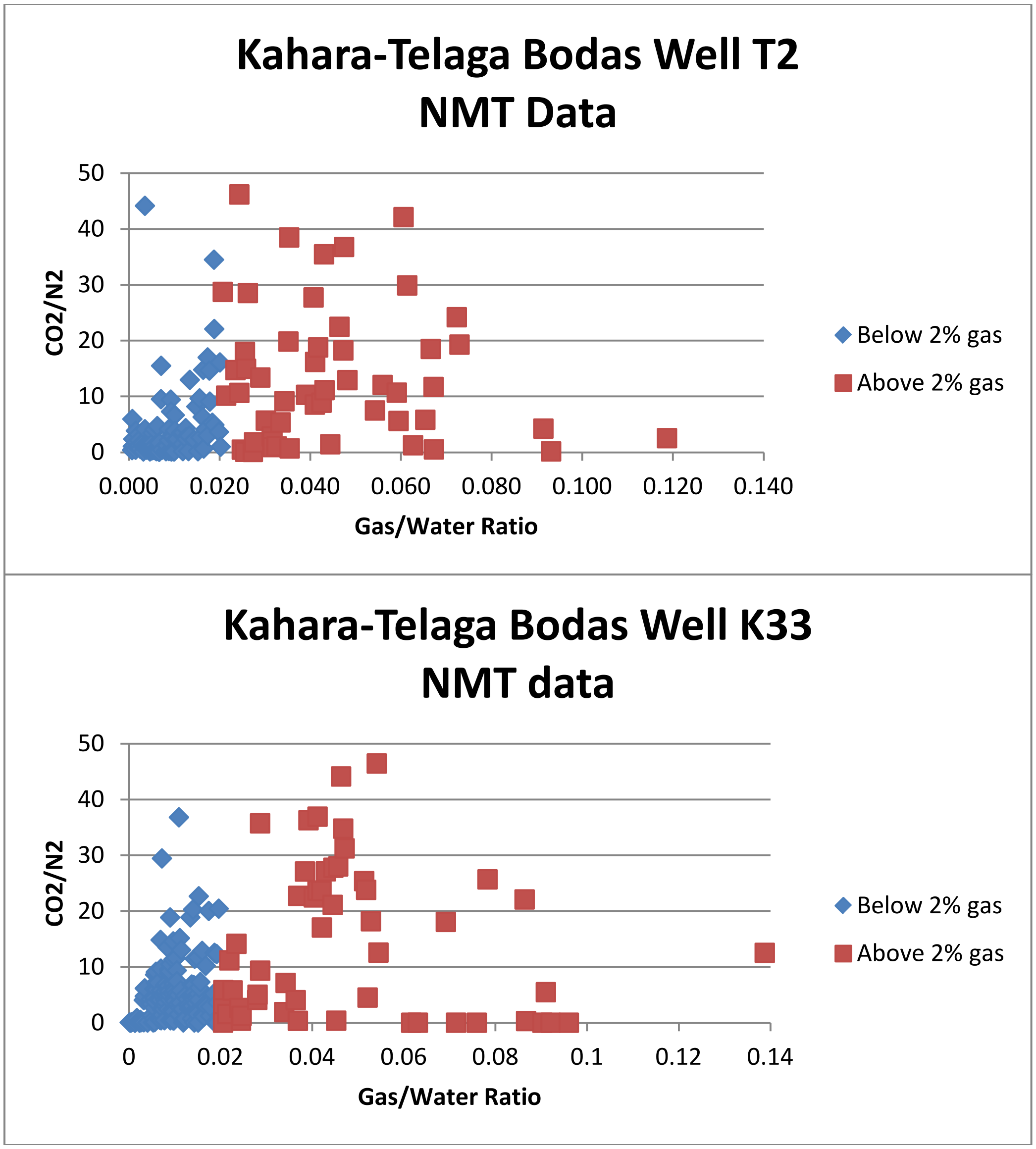
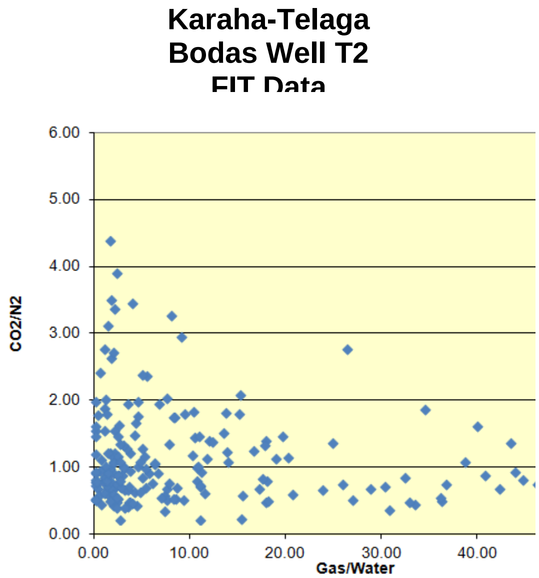
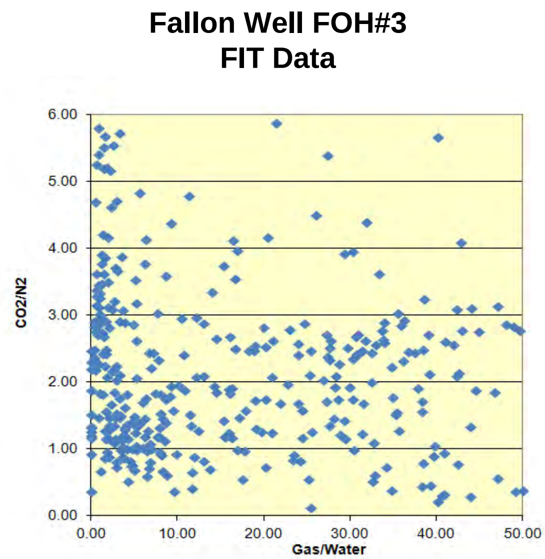


Figure 28: Plots of gas/water ratio versus CO_2/N_2. Inclusions with more than 2% gas are interpreted to have trapped steam and gas.





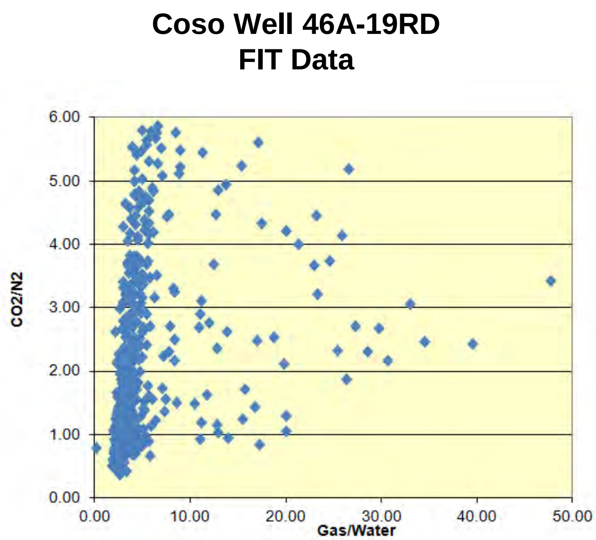
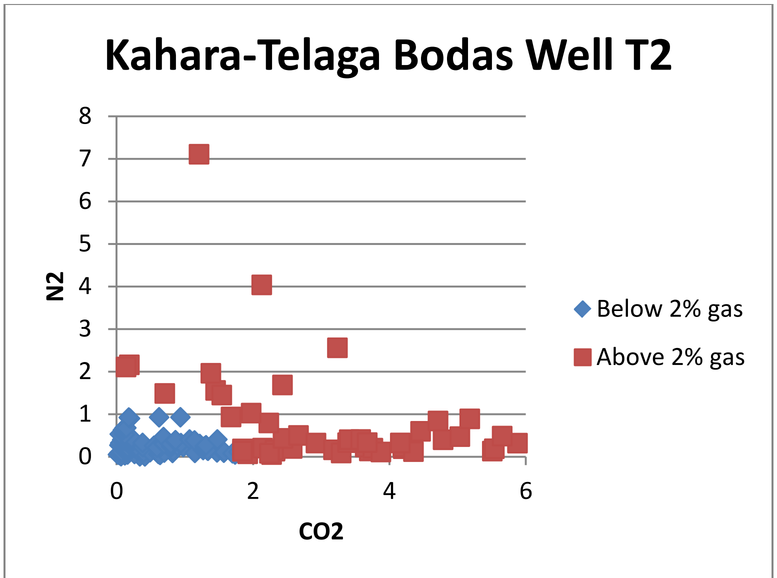
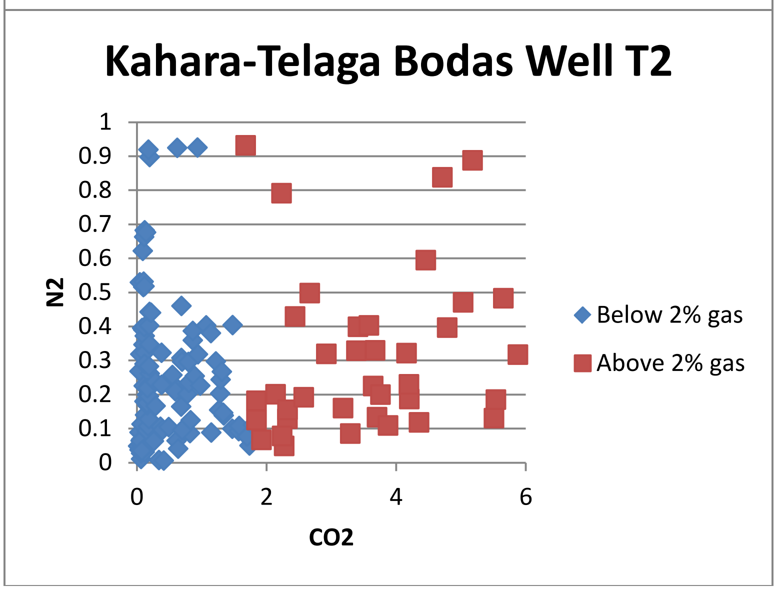


Figure 29: Gas/Water ratio versus CO2/N2. Note that for Karaha-Telaga Bodas well T2, FIT data is similar to NMT data. Low temperature well FOH3 (Fallon) also shows high gas/water ratios, most likely from previous events. Coso well 46A-19RD has a few intervals of high gas/water ratios indicating possible boiling.


Kahara-Telaga Bodas Well T2
N2
CO2
Below 2% gas
Above 2% gas


Kahara-Telaga Bodas Well T2
N2
CO2
Below 2% gas
Above 2% gas

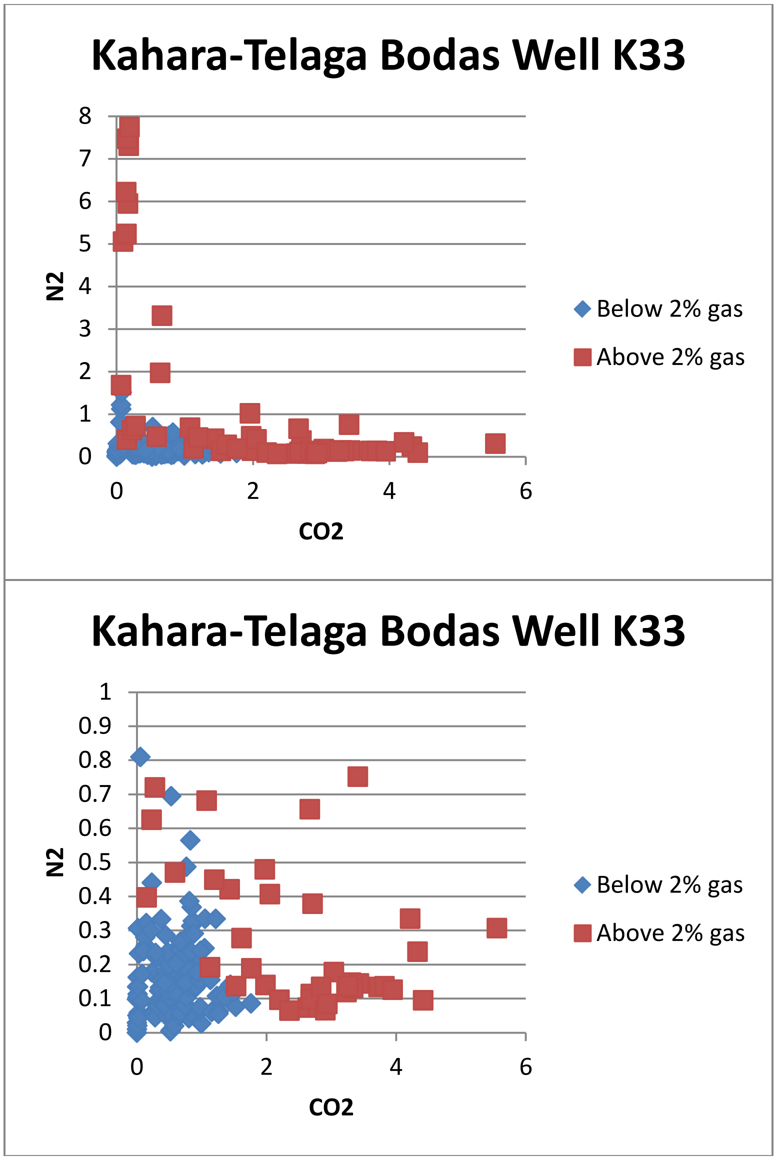
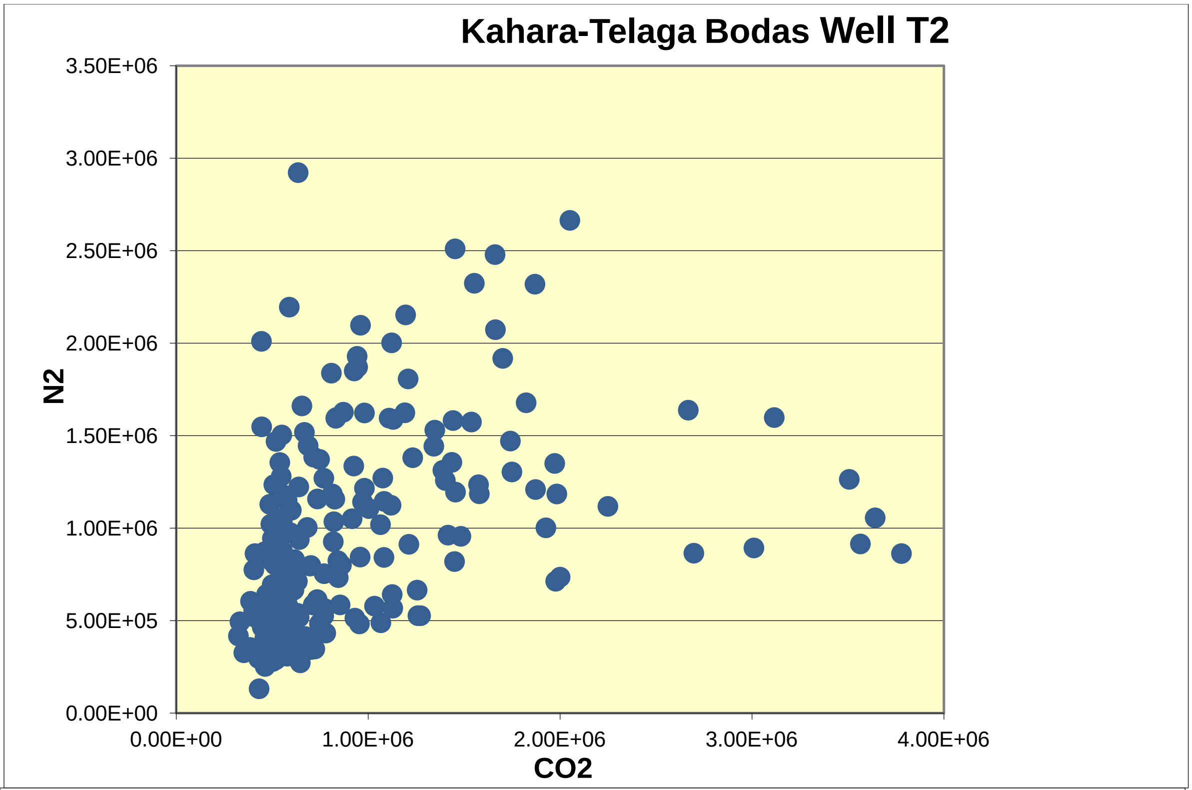
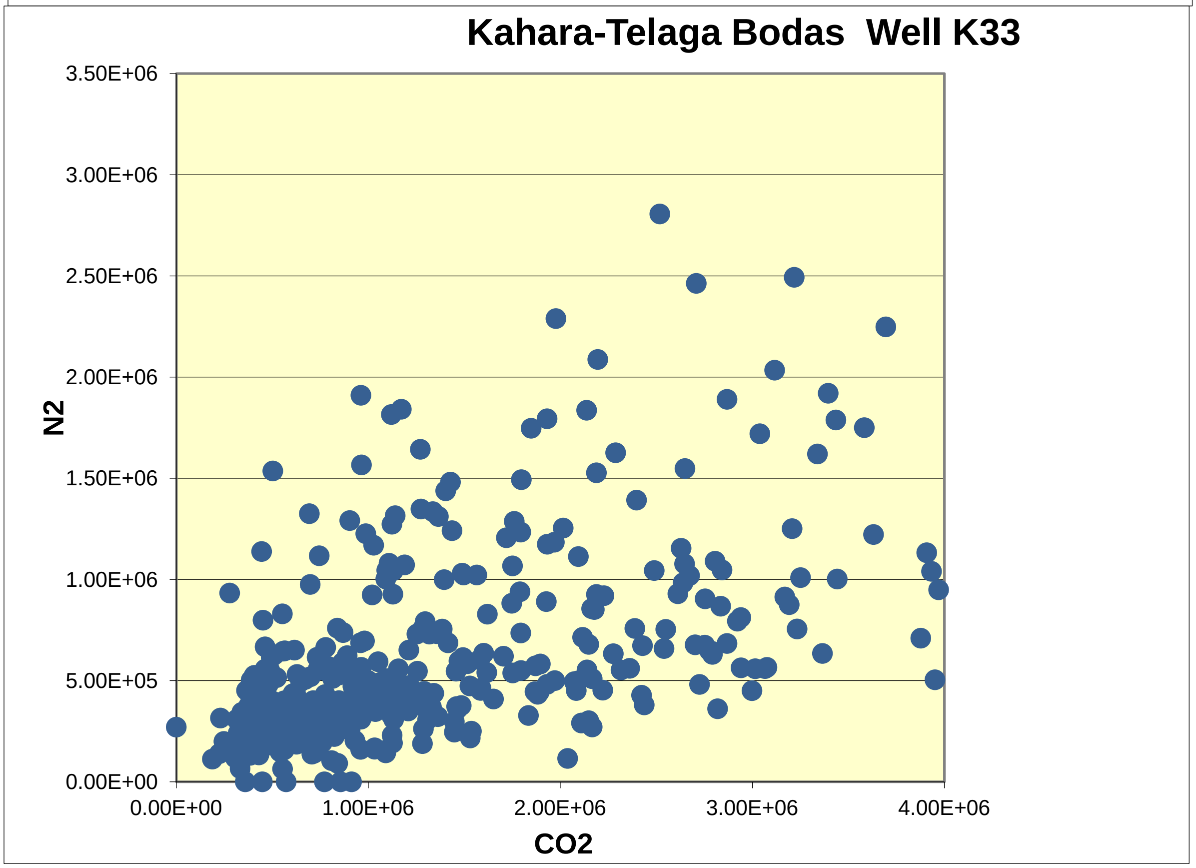
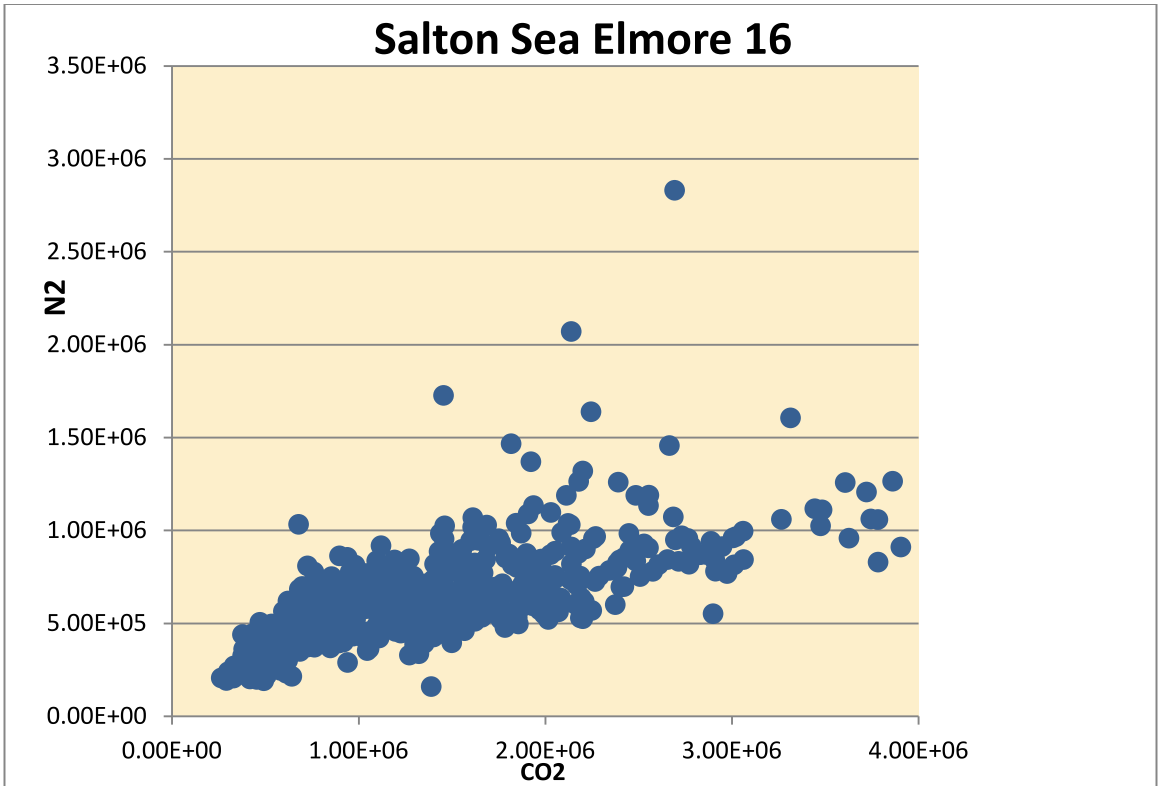
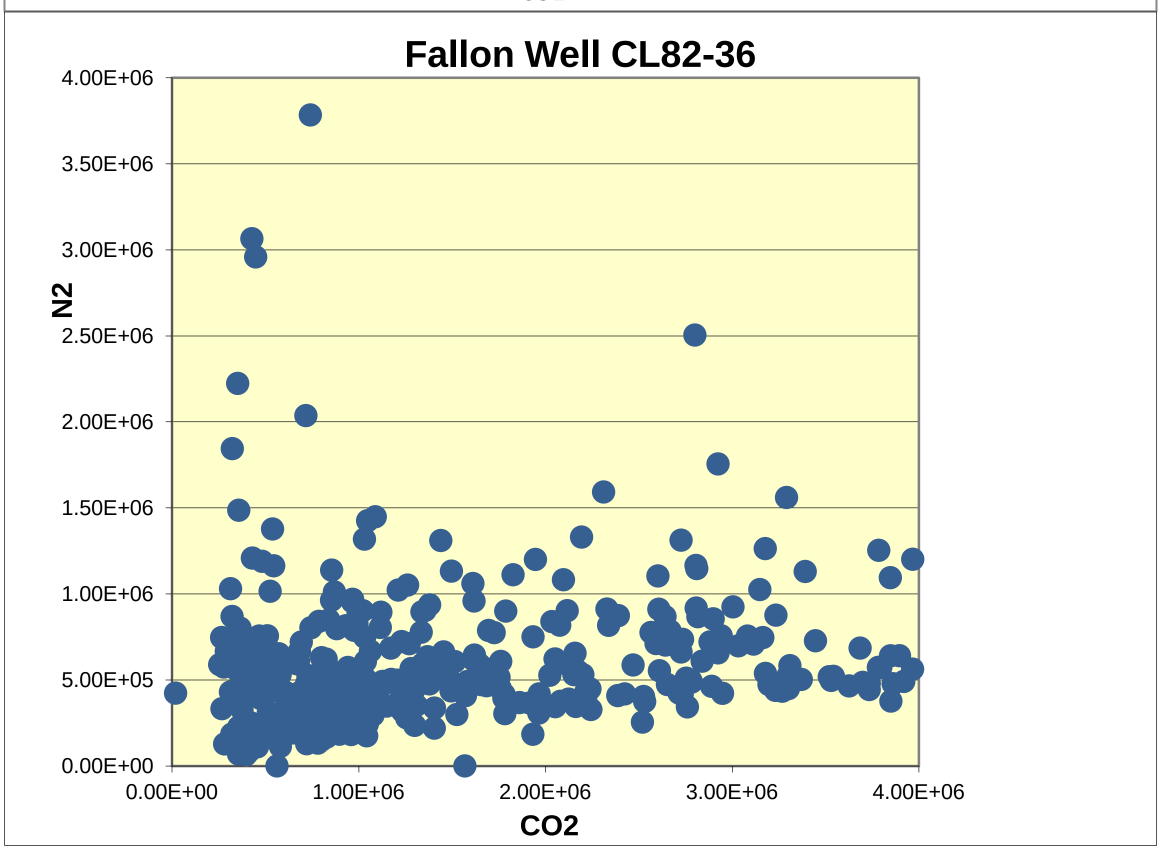


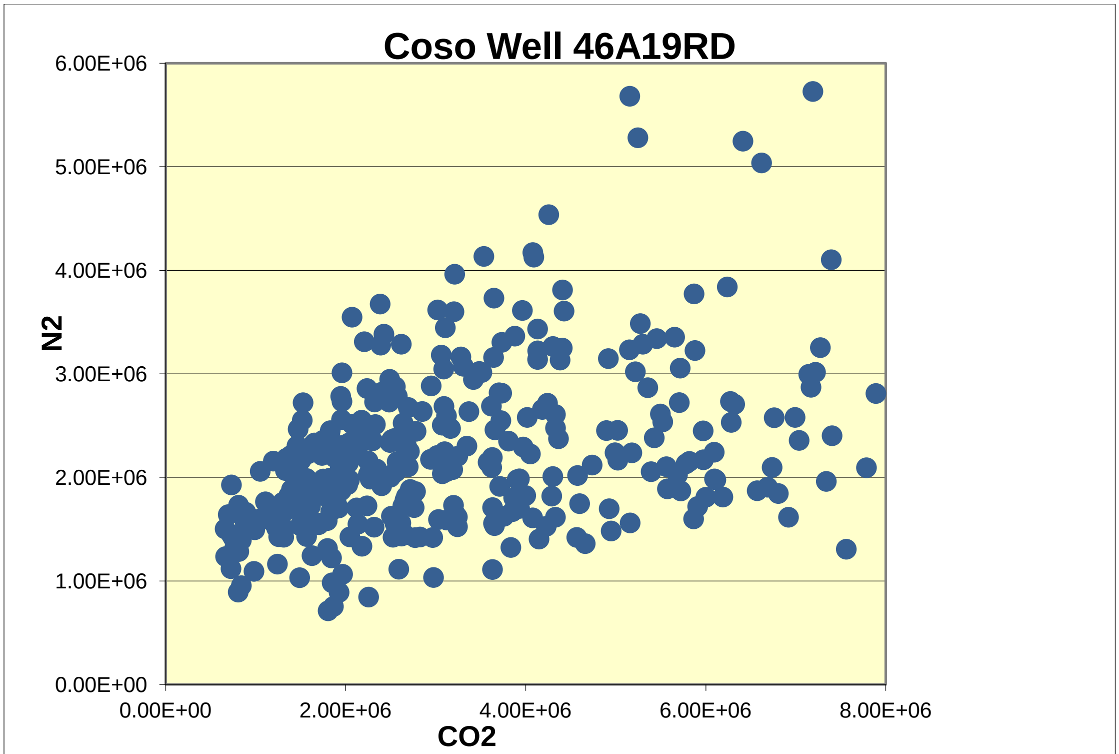
Figure 30: Plot of CO_2 versus N_2 for Karaha wells T2 and K33 at different scales using NMT data. Note the presence of high N_2. low CO_2 inclusions, which are interpreted as an indication of early boiling.


Kahara-Telaga Bodas Well T2
3.50E+06
3.00E+06
2.50E+06
2.00E+06
1.50E+06
1.00E+06
5.00E+05
0.00E+00
N2
0.00E+00
1.00E+06
2.00E+06
3.00E+06
4.00E+06
CO2


Kahara-Telaga Bodas Well K33
3.50E+06
3.00E+06
2.50E+06
2.00E+06
1.50E+06
1.00E+06
5.00E+05
0.00E+00
N2
0.00E+00
1.00E+06
2.00E+06
3.00E+06
4.00E+06
CO2


Salton Sea Elmore 16
N2
CO2
3.50E+06
3.00E+06
2.50E+06
2.00E+06
1.50E+06
1.00E+06
5.00E+05
0.00E+00
0.00E+00
1.00E+06
2.00E+06
3.00E+06
4.00E+06


Fallon Well CL82-36
N2
CO2
4.00E+06
3.50E+06
3.00E+06
2.50E+06
2.00E+06
1.50E+06
1.00E+06
5.00E+05
0.00E+00
0.00E+00
1.00E+06
2.00E+06
3.00E+06
4.00E+06



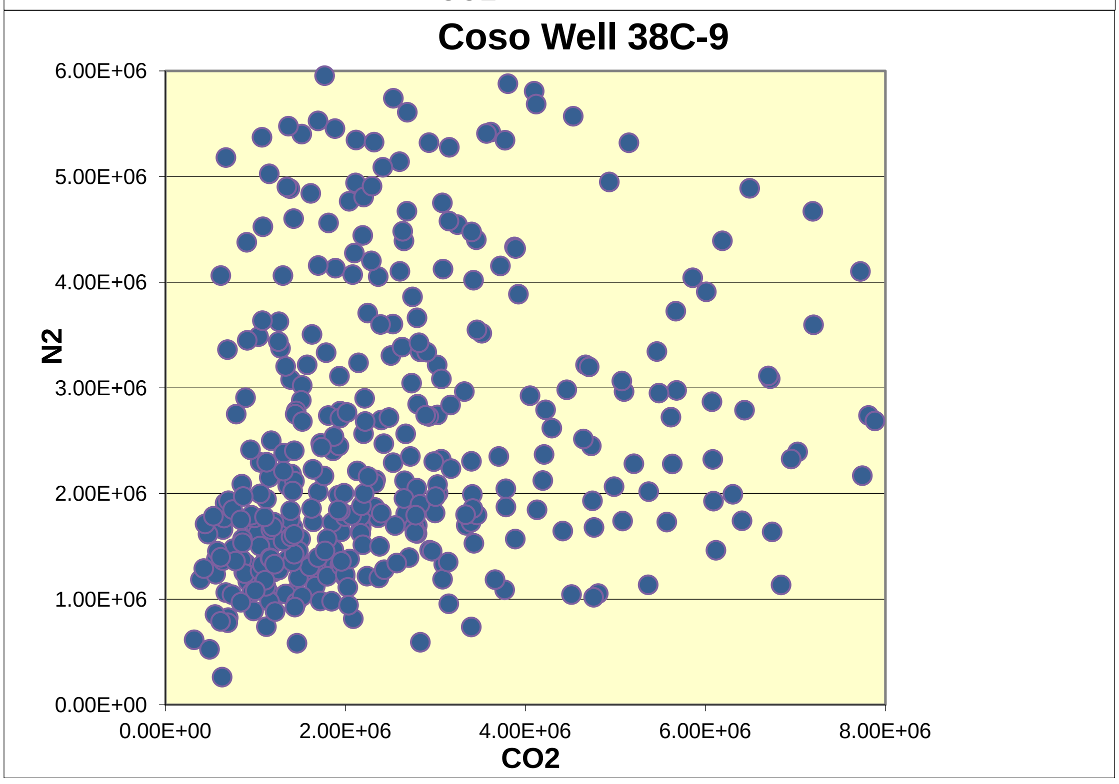


Figure 31: Plots of N_2 versus CO_2. High N_2 and low CO_2 are interpreted to indicate early boiling.

Plots of N_2 versus CO_2 appears to provide information on early boiling. Based on the solubility of various gases, other plots such as H_2 versus CO_2 and CH_4 versus CO_2 may also provide evidence of progressive boiling. Figure 32 presents this idea for Karaha-Telaga Bodas T2. Early boiling is represented in the upper left while later boiling in the lower right with CO_2 rich inclusions. High N_2/CO_2 and H_2/CO_2 ratios maybe used to indicate boiling.

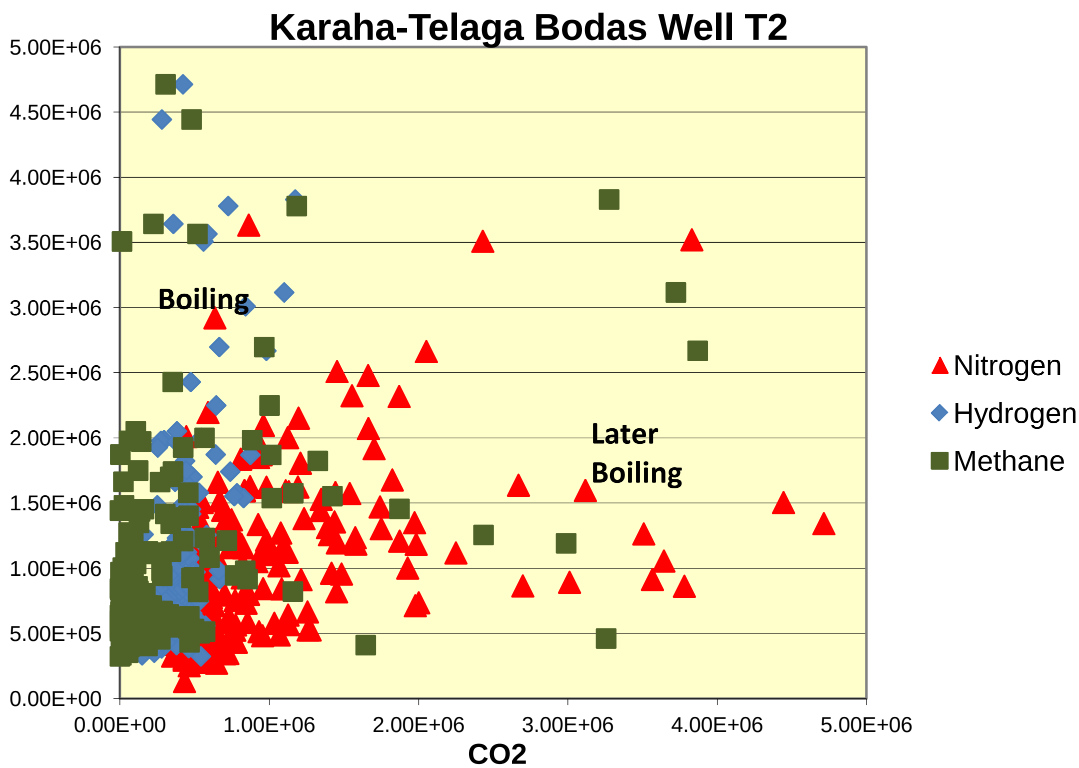


Figure 32: Plot of N_2, $H_2$and CH_4 versus CO_2 can indicate progressive boiling. Early boiled-off gases will have the highest N_2 and H_2 , later boiling will produce gases richer in CH_4 and still later boiling will produce fluid inclusions enriched in CO_2 (and H_2S) and then finally just carbon dioxide.

6.4 ORGANIC COMPOUNDS

Light organic compounds (LOC) other than CH_4 occur in geothermal fluids. The occurrence of LOC's may be related to Fischer-Tropsch processes, or degradation of organic material. Observations indicate that the nature and distribution of hydrocarbon species is more consistent with thermal degradation of kerogen. The primary feature of the alkane distribution produced by Fischer-Tropsch reactions is a maximum at a carbon number between 3 and 5. This is known as the Shultz-Flory distribution. Ethane production is minimal and is actively consumed in the synthesis. We plotted the concentration of the alkanes and alkenes at depth for the Coso wells and the major constituents, by several orders of magnitude, are CH_4) and C_3H_8 (propane), (Figure 33). This is a Shultz-Flory distribution suggesting an inorganic origin for the hydrocarbons(Norman et al., 2002). C_2H_6 (ethane) and C_4H_{10} (butane) are present in extremely low concentrations. Many of the geothermal systems we have studied, display similar trends. Ethane only occurs in trace amounts in a few of the wells. Appendix G presents similar diagrams for the other wells.

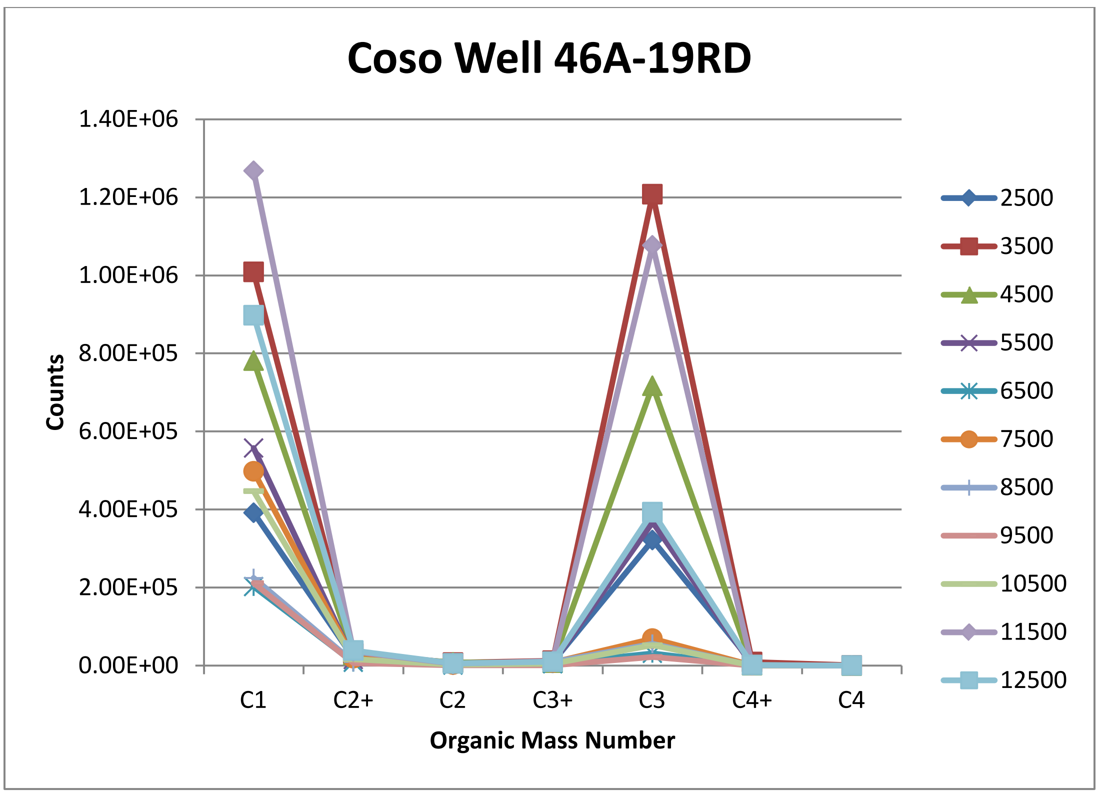
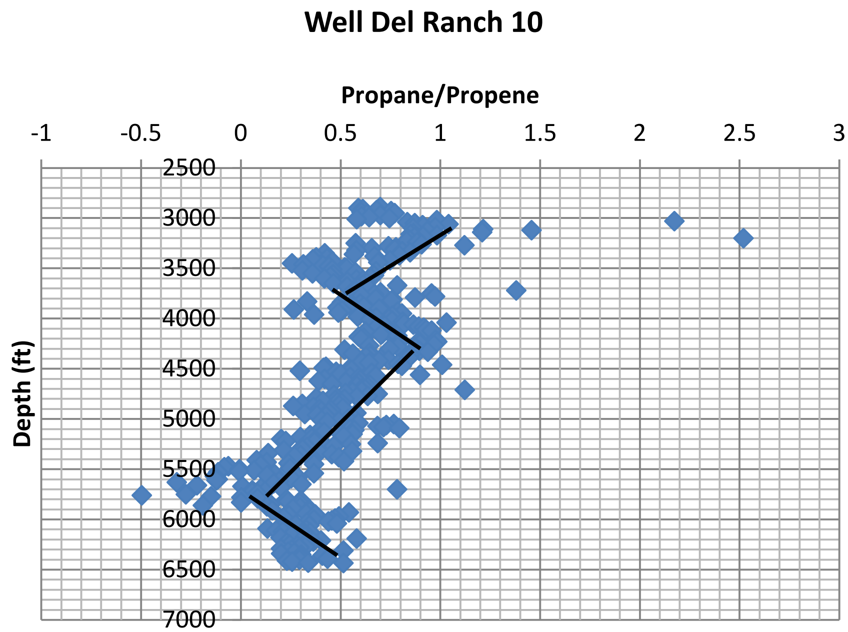


Figure 33: Distribution of light organic compounds for Coso Well 46A-19RD for depths ranging from 2,500 to 12,5000 ft

It can be seen in Figure 33 that high concentrations of C_3H_8 (propane) occur at shallow depths, with the highest concentration occurring at 3,500 ft. The highest concentration of CH_4 occurs at 11,500 ft followed by the 3,500 ft interval.

The alkane to alkene ratio may provide additional information on the history of the fluids. Norman et al. (2002) showed that the alkane to alkene ratio generally decreases with depth (Appendix G). This may be due to the oxidation of alkene to alkane compounds as fluids approach the surface. If this is the case, then the ratio could be used to indicate the presence of cooler meteoric fluids and possibly areas of cold water influx into geothermal wells.

Salton Sea is organic rich geothermal system. We plotted the alkane/alkene ratio with depth to determine if this ratio could be used to indicate fluid types. Figure 34 presents these plots for Elmore 16 and Del Ranch 10. The majority of analyses from both wells show a general decrease in the alkane/alkene ratio with depth followed at the bottom of the wells by a slight increase in the alkane/alkene ratio. The Salton Sea reservoir is characterized by a series of interlayered sandstones and mudstones with varying percentages of sand. The changes in the alkane/alkene ratio could be indicative of the differences in the oxidation state of the in the sandstones (more oxidizing environment) compared to the mudstones (more reducing environment and therefore higher alkenes). Appendix H presents the remaining diagrams.



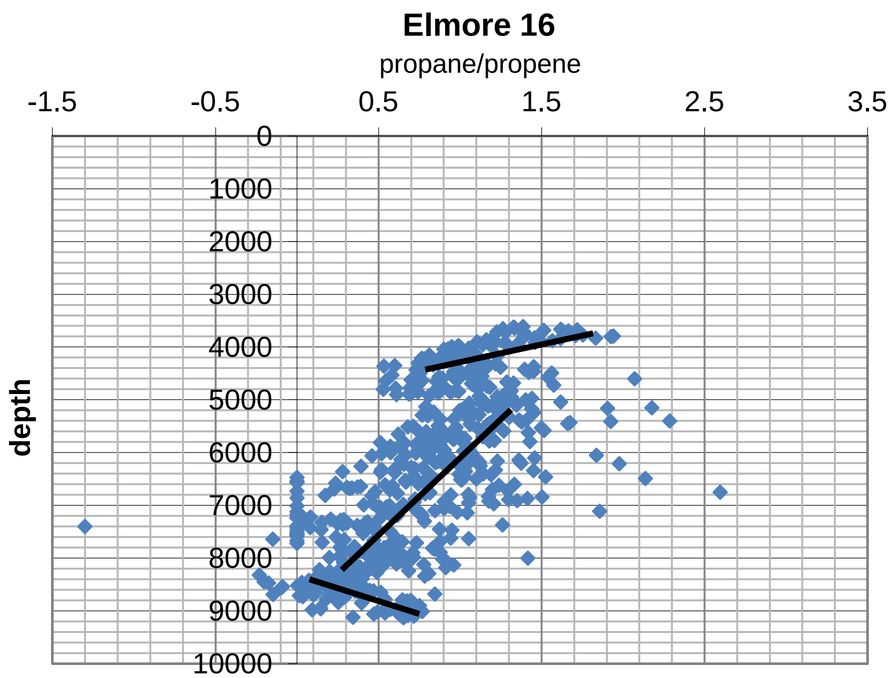
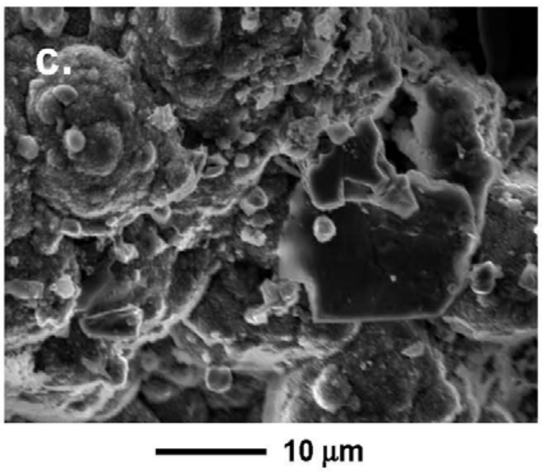


Figure 34: Propane/propene ratio plotted with respect to depth for two Salton Sea wells. The varying nature of the ratio may be due to the occurrence of interlayered mudstones and sandstones.

6.5 TIMING OF INCLUSION FORMATION

Our studies have indicated that fluid inclusions in some systems can persist for long periods of time, whereas in other systems, the inclusion gases appear to reflect current conditions. Investigations of two wells at Coso suggest new inclusions can form relatively rapidly. Analyses were conducted on Coso well 68-20, the original well, and 68-20RD, which is drilled 7 years later were analyzed. Coso well 68-20 was used as an injection well until permeabilities were to the point that the well was no longer useable. Coso Well 68-20 and 68-20RD were drilled adjacent to each other. The injection fluid had a temperature of 230°F and low gas contents. Injection occurred at a depth of about 2,900 ft through (wall rock temperature of 246°F a damaged well casing joint and at about 5000 ft (wall rock temperature of 320°F).

McLin et al. (2006) examined cuttings from both wells and concluded the loss of permeability was due to the deposition of amorphous silica, which was not present in the original well. (Figure 35) .



Well 68-20RD Silica scale

SEM images show aggregates of colloidal opal A spheres

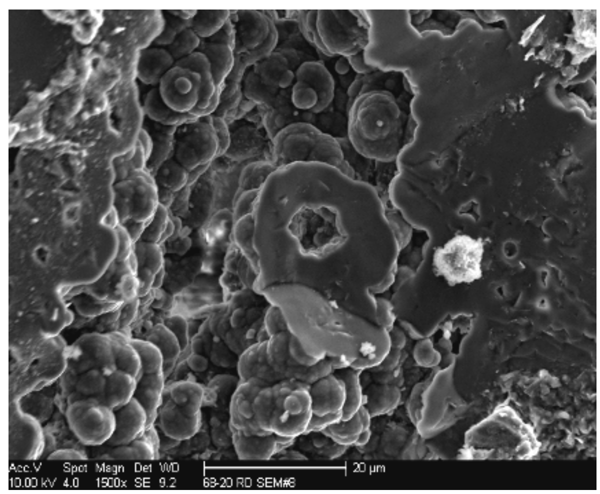


Figure 35. Photographs of scale in Well 68-20RD (from McLin et al, 2006).

Differences in fluid inclusion composition are presented in Figure 36. Negative values indicate more of that species in the original well. The differences in the compositions of the inclusions indicates new fluid inclusions formed prior to drilling of argues that new fluid inclusions have been formed in the redrill. The location of the largest differences is at approximately 2700 feet and 3000 feet. This corresponds to the break in the well casing in 68-20 RD.

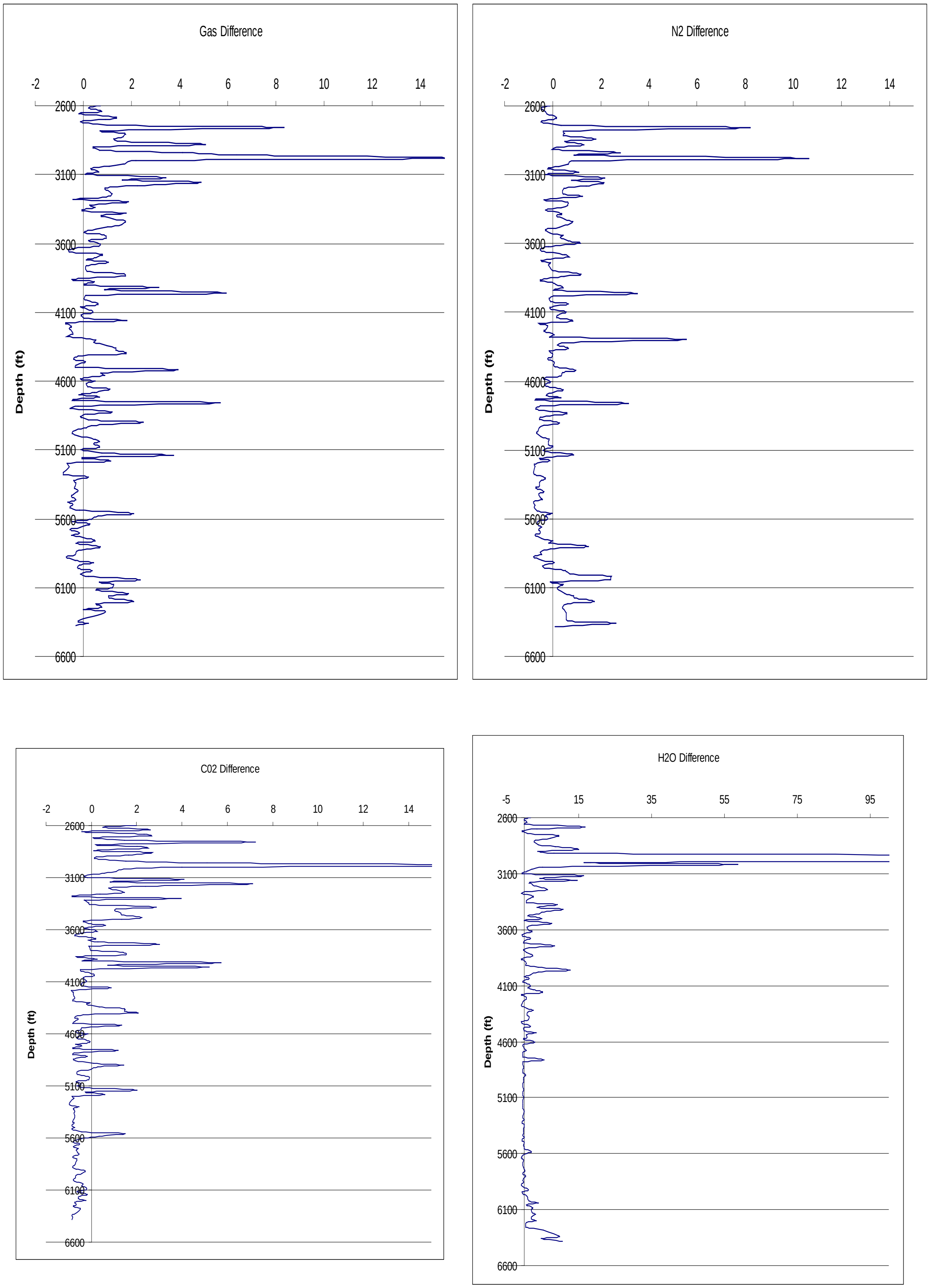


Figure 36: Differences in fluid inclusion compositions between 68-20RD and 68-20. Note the significant peak at about 2900 ft , where a break in the casing allowed fluid to exit the well

Table 6 shows the percent change in the overall average concentrations and the average concentration at the break in the casing between the 68-20 and 68-20 RD for H_2O and for CO_2. There is a 74% difference in the H_2O and a negative 18% change in CO_2 overall average concentration. The negative change in CO_2 is indicated in Figure 21 where the CO_2 concentration decreases below about 4100 feet in the redrill. In the zone of the break in the well casing there is an 810% change in H_2O and a greater than 110% change in CO_2 concentration

Table 6. Percent change in H_2O and CO_2between 68-20 (original well) and 68-20 RD (redrill).

Species	68-20I	68-20 RD	% Change
H_2O (overall)	$3.3 X 10^6$	$5.7 X 10^6$	+74
CO_2 (overall)	$2.6 X 10^6$	$2.1 X 10^6$	-18
H_2O (break)	$4.68 X 10^5$	$4.26 X 10^6$	+810
CO_2 (break)	$9.92 X 10^5$	$2.11 X 10^6$	+113

The graphs presented for the differences in compositions between 68-20 and 68-20RD argue that the FIT analyses are recording recent changes in the fluid inclusion compositions

The largest changes in the ratios occur at depths of fluid injection identified by FIT analyses and petrographic studies that show abundant amorphous silica. The changes also decrease with depth, further suggesting that the changes are a result of the injection creating new fluid inclusions and destroying the gas-rich inclusions that were originally present. The discrete peaks are assumed to represent fractures that control the flow of the injection fluid

A geothermal system, particularly one that is being exploited, is a dynamic environment. Small-magnitude earthquakes occur frequently, resulting in fractures of various dimensions opening and closing (Feng and Lees 1998). Fluid flows either naturally or by being pumped. Pressure, temperature, and chemical changes that occur as the fluid moves through the system lead to an environment of mineral dissolution, chemical movement, and mineral deposition. These minerals would naturally trap new, modern-day fluid inclusions. Older inclusions would be destroyed as older minerals are dissolved. If the older minerals are preserved then the older inclusions would not necessarily be destroyed. Based on the order of magnitude changes in both H_2O and CO_2 concentration at the break in the casing there appears to be enough volume of new inclusions to overprint the older inclusions and produce the change seen on the FIT logs.

Our data shows that geothermal fluid inclusions assemblages can change chemical compositions in a few years and that the changes in inclusion contents are most pronounced in areas of high fluid flux. Thus, bulk fluid inclusion gas analyses of drill cuttings show chemistry of recent fluids. An implication is that all types of geothermal-system bulk-geochemical analyses will be biased toward the most recent hydrothermal event, the last changes in the system.

6.6 Fluid Types

The overall objective of the project is to identify fluid types based on bulk fluid inclusion gas analysis. N_2-Ar-He ratios have proven to be particularly useful in identifying fluid types from the bulk analyses. Meteoric and deep crustal fluids were anticipated for the Fallon system and the N_2/Ar and Ar/He ratios from the bulk analyses indicated these fluid types are present The occurrence of helium provides a measure of the extent of deep circulation of meteoric fluids the fluids. Crustal fluids have low Ar contents. Although the CO_2-CH_4-H_2 ratios of the inclusions could not be used to conclusively demonstrate boiling, the N_2 versus CO_2 plots showed that boiling could be identified. As a first approximation, relatively "high" values can be separated from "low" values by determining the average count for each species. This can be done for each species on a field wide basis. Values above the average can be considered "high" whereas average and below can be considered "low".

Four main fluid types were considered: meteoric, condensate, reservoir, and no fluid or a zone representing a lack of geothermal activity. Condensate is the term used here for both steam-heated waters and condensate. The first step in determining the fluid type represented by the gas analysis was to determine if certain species and ratios were above or below the average concentration for that species, or in the case of ratios, above or below a particular value for that ratio. The species, ratios and tests used were the following:

- H_2O – presence indicates liquid rich inclusions
- Gas/Water - high values indicate potential boiling
- N_2/Ar – high values indicate magmatic components
- Ar/He - low values indicate crustal fluids
- N_2/CO_2 - high values indicate boiling
- Alkane/Alkene - high values indicate oxygen rich - meteoric fluids
- CH_4/H_2- high values indicate high temperatures.

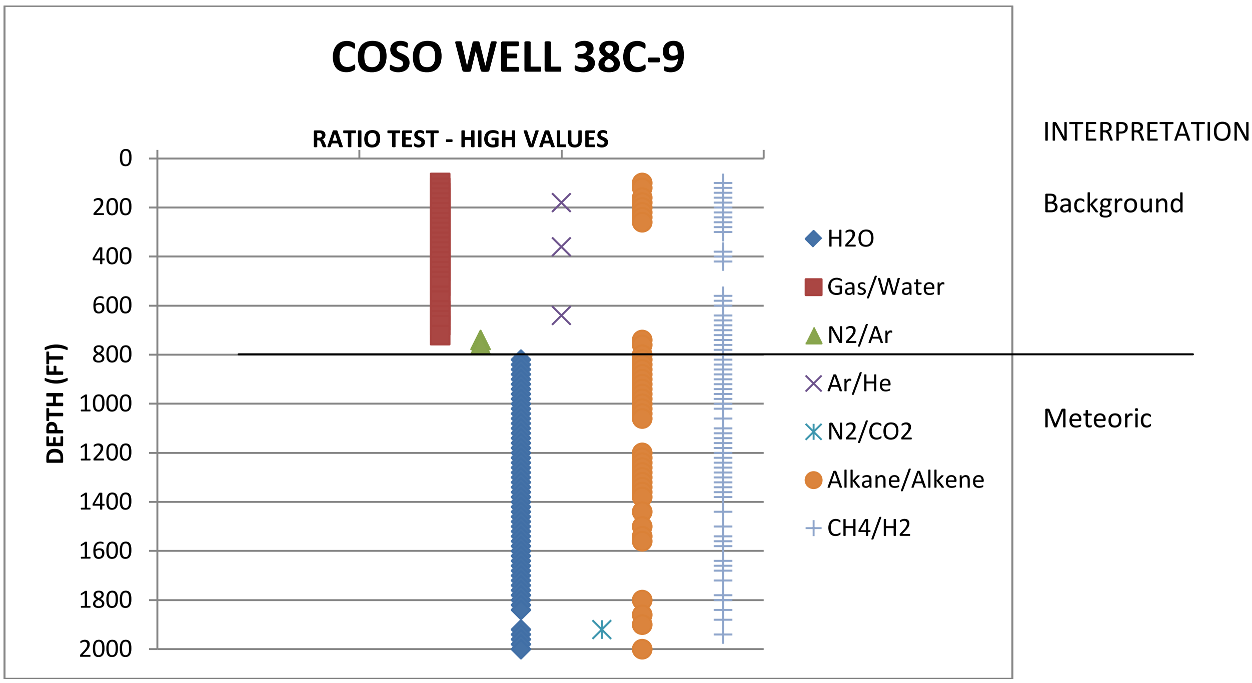
There may be several more species that would assist in indicating fluid types. The above are the ones investigated in this phase of the project. Using these relationships, a series of rules have been developed to distinguish fluid types (Table 7).

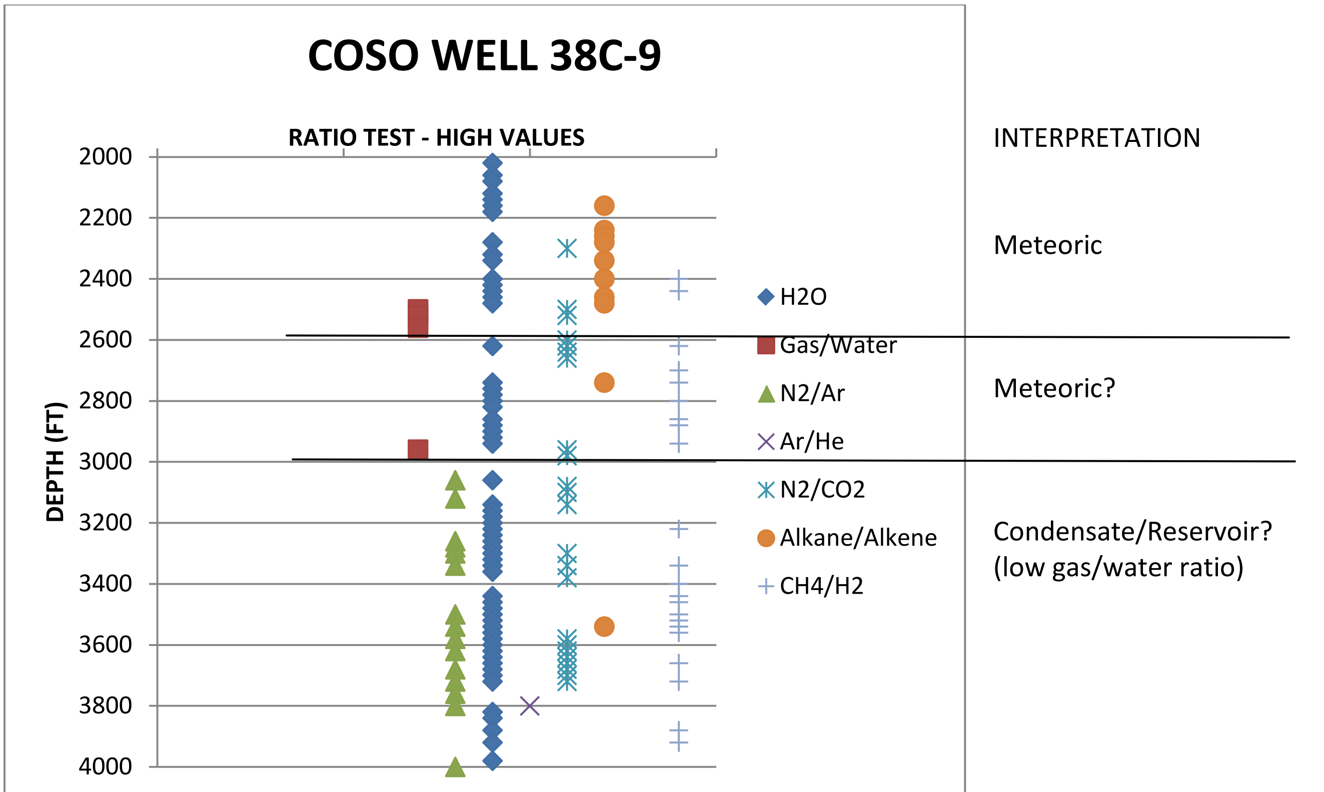
Table 7: Characteristics of fluid types .

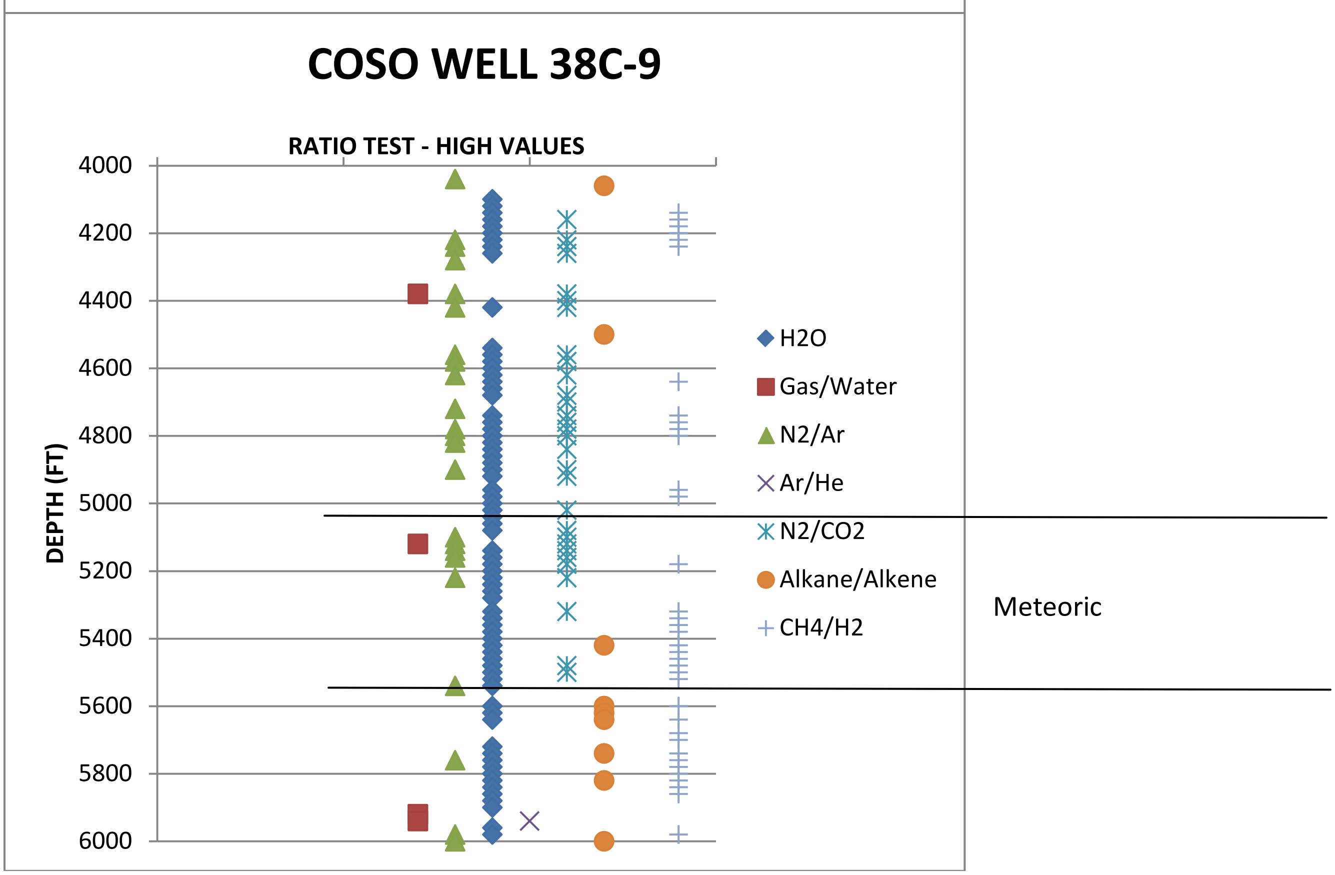
Fluid Type	H_2O	Gas/Water	N_2/Ar	Ar/He	N_2/CO_2	Alkane/ Alkene	CH_4/H_2
Meteoric	Above average	Below average	Below average	Above average	Below average	Above average	Below average
Condensate	Does not matter	Above average	Does not matter	Does not matter	Above average	Does not matter	Above average
Reservoir	Does not matter	Above average	Above average	Below average	Does not matter	Below average	Above average
Background	Below average	Does not matter	Below average	Does not matter	Below average	Above average	Below average

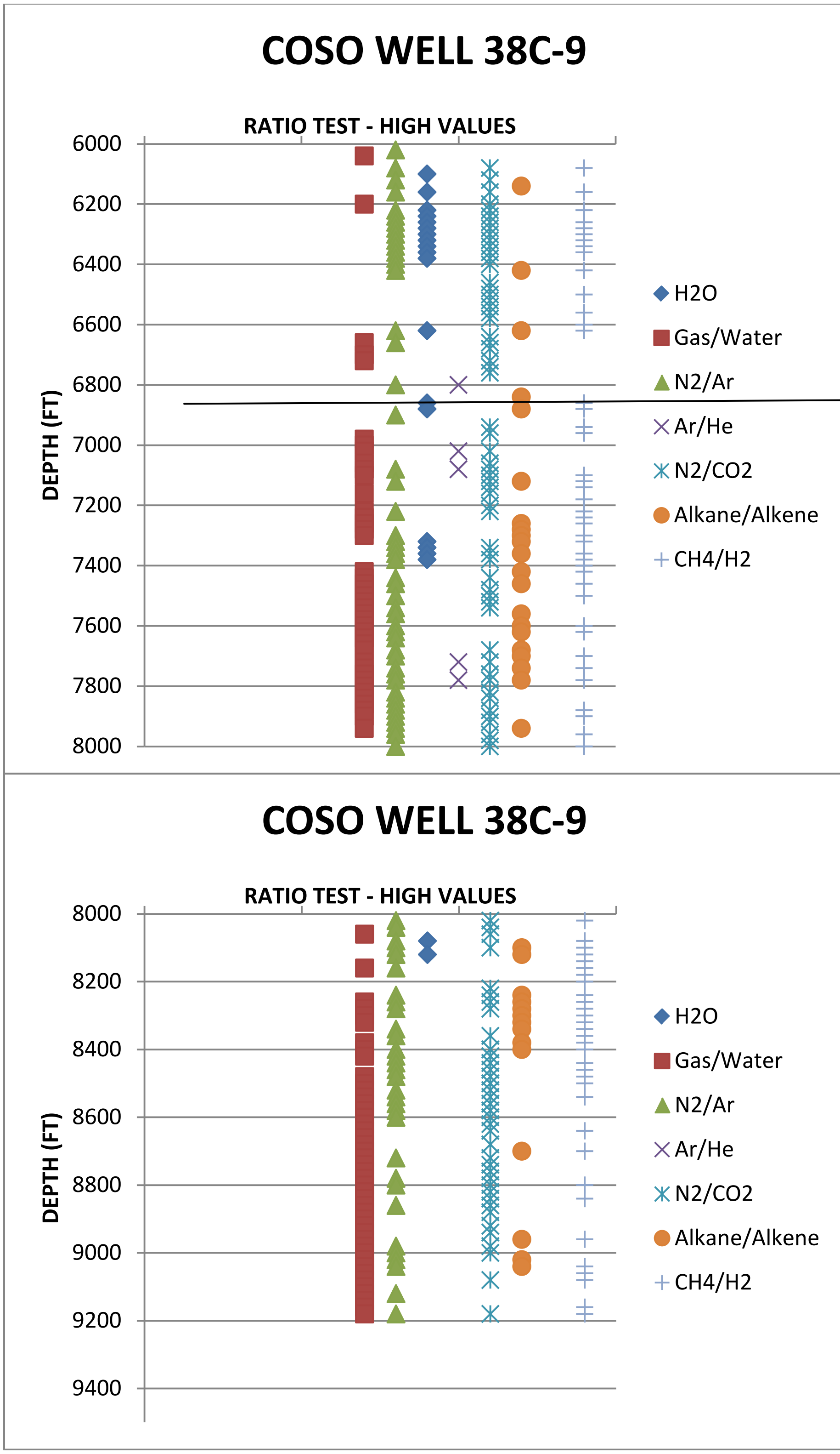
It is difficult to distinguish condensate from meteoric or reservoir fluids. Analysis of individual crystals has shown that condensates may be enriched in H_2S has been shown to be relatively high concentrations in condensate fluids and this may also be the case for the bulk analysis.

We have applied these "rules" to Coso Well 38C-9, a 8 MW production well with temperatures up to 570°F. Figure 37 shows the data and interpreted fluid types for successive 2000 ft intervals   The graphs indicate which species and ratios were above average. Above average values are plotted as that particular species such as red squares for gas/water ratios. Where there is a blank space such as from about 800 to 2,500 feet for the gas/water ratio this is the depth at which the gas/water ratio is below average value.




COSO WELL 38C-9
RATIO TEST - HIGH VALUES
DEPTH (FT)
2000
2200
2400
2600
2800
3000
3200
3400
3600
3800
4000
H2O
Gas/Water
N2/Ar
Ar/He
N2/CO2
Alkane/Alkene
CH4/H2
INTERPRETATION
Meteoric
Meteoric?
Condensate/Reservoir?
(low gas/water ratio)


COSO WELL 38C-9
RATIO TEST - HIGH VALUES
DEPTH (FT)
4000
4200
4400
4600
4800
5000
5200
5400
5600
5800
6000
H2O
Gas/Water
N2/Ar
Ar/He
N2/CO2
Alkane/Alkene
CH4/H2
Meteoric



INTERPRETATION

Condensate/Reservoir? Low gas/water ratios

Condensate/Reservoir? High gas/water ratio, Note: Ar/He highs may indicate possible cold water entries. The Alkane/alkene ratio is above average in a number of locations indicating either possible cold water entries particularly when it corresponds with the Ar/He highs or another inorganic origin for the alkanes.

Figure 37: Fluid types for Well 38C-9 based on various ratios. Fluid types were based on the occurrence of above average values for particular ratios following the rules in Table 6.

The graphs for Coso Well 38C-9 indicate meteoric fluids occur at shallow depths in the well followed by condensate/reservoir fluids. The N_2/Ar ratio has above average values beginning at about 3,000 ft and continuing to depth with some narrow intervals (such as 5250-5550 ft) where there are below average values. The alkane/alkene ratio is interesting in that it has above average values at shallow depths and then again starting at about 5,400 ft. The CH_4/H_2 ratio is above average for most of the well suggesting a high temperature well (Figure 27). Production from this well occurs at approximately 7,200 ft to TD (McCulloch, personal communication). Figure 38 presents the temperature log for this well. The well encounters temperatures from 400 to 570^{0}F starting at about 4,500 ft. The break in the fluids between meteoric and condensate/reservoir fluids begins at about 6,000 ft. At 7,000 ft is another break in the fluid types, with increase gas/water ratios.

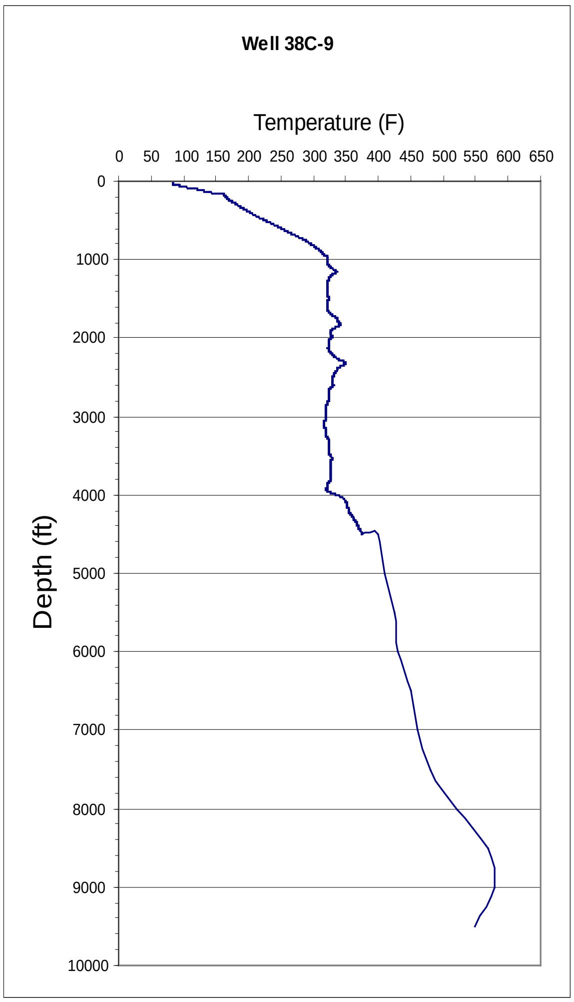


Figure 38: Temperature log for Coso Well 38C-9.

7.0 TASK 4: GEOLOGICAL INTERPRETATION

In this task, the FIS data was evaluated with respect to the temperatures, rock type, grade of alteration, and the permeability distributions encountered in the individual wells that were studied. Different geological environments should be characterized by different gas signatures if the fluid inclusions mainly record the local geology. Geothermal systems regardless of the local geology would produce fluid inclusions that reflect the geothermal system and not the local rock package.

7.1 Correlation to Temperature Logs

Temperature logs are a primary source of information about a well. The fluid inclusion gas ratios of N_2/Ar, CO_2/CH_4 and 43/39 were plotted against temperature for select wells in a few different fields to evaluate the potential correlations. N_2/Ar ratios are high when there is more N_2 which is assume to be derived from magmatic sources. Argon is high based on its ability to saturate near surface waters. The hypothesis was that cooler waters would have a low N_2/Ar ratio while hotter fluids would have a higher ratio since higher ratios would be derived from magmatic sources. Boiling may create more CO_2 than CH_4 and may correspond to higher temperatures. Propane (43) is the oxidized propene (39). Propane would be high in oxygenated, young meteoric fluids whereas propene (39) would have higher concentrations in more evolved, reduce connate waters. Based on the discussion the following table was created as to what would be expected for the ratios versus temperatures:

Table 8: Temperature correlation to gas ratios

RATIO	HIGH TEMP	COLD TEMP
N_2/Ar	High ratio	Low ratio
CO_2/CH_4	High ratio	Low ratio
43/39	Low ratio	High ratio

Temperature logs were provided for the Coso, Hawthorne, Fallon, and Hawaiian geothermal fields. A cross-section indicating temperatures was provided for Karaha geothermal system. The following wells were chosen:

Table 9: Wells with temperature profiles

FIELD/WELL	CRITERIA
Coso Field	One main rock type, multiple wells with different temperatures and production, two parts of the field
33-7	3 MW producer on western side of field
38C-9	8 MW producer on eastern flank

46A-19RD	Impermeable, believe to represent the upwelling zone on the western side of field
58A-18	Multiple entrances of cold water in the eastern basin
58A-10	Deep well in the Navy eastern basin
73-19	3 MW producer, one of the hottest producing wells, on western side
68-20	Cool, non-producer, used as injection well in middle of field
84-30	Non-producer, on the outside of the field to the south
Hawthorne Field - HAD#1	Basin & Range rock package, low to moderate temperature field
Hawaii Field	Basaltic in nature, high temperature field
SOH1	Coolest well in the field
SOH4	Hottest well in the field
Karaha Field	Active volcanic field, large steam cap, NMT data
T2	Hotter well near magma source
K33	Petrographic evidence of boiling

The plots are shown in Appendix I for the above wells. A few are presented in the text to illustrate the findings.

For Coso Well 38C-9 (Figure 39a) it can be seen that the temperature increases at about 4,000 feet. CO_2/CH_4 ratio increases at depth of approximately 5,500 feet, whereas there is an increase in N_2/Ar ratios at about 3,000 feet and reduction in 43/39 ratio. There are distinct peaks in both the N_2/Ar and 43/39 ratio at 6,000 feet, 7,200 feet,7,800 feet, 8,400 feet and at 9,000 feet. These peaks suggest young, oxidized, meteoric fluids have flowed into the well via fractures around these locations. The N_2/Ar ratio is most likely high due to nitrogen from biogenic sources as oppose to magmatic gases. As seen in Figure 39 it can be seen that the 43/39 ratio is low while the N_2/Ar ratio is high in areas between the distinct peaks. This suggest that the N_2/Ar ratio in these areas are high due to the nitrogen being derived from magmatic sources. This coupling of the N_2/Ar and 43/39 ratios can allow for distinquishing between zones of young, oxidized meteoric fluids and fluids that have a magmatic component. The distinct peaks in the ratios coupled together further suggests fractures or changes in rock type. Well log indicates felsic dikes were encountered at about 6,000 feet, 7,300 feet and 7,800 feet and a no return and altered zone from about 9,000 to 9,2000 feet. The well log does not note any major change around 8,400 feet except for interstial calcite at 8,350 feet.

Well 58A-18 (Figure 39b) is known to have multiple entrances of cold water. As seen in Figure 39b, peaks in both N_2/Ar and 43/39 ratios parallel each other and are followed by decrease in temperature (4,500 feet, 5,500 feet, and 7,500 feet). The two ratios and temperature decrease suggest that the peaks correspond to fractures where the cold water enters the well. The CO_2/CH_4 ratio has peaks that occur at these same depths.

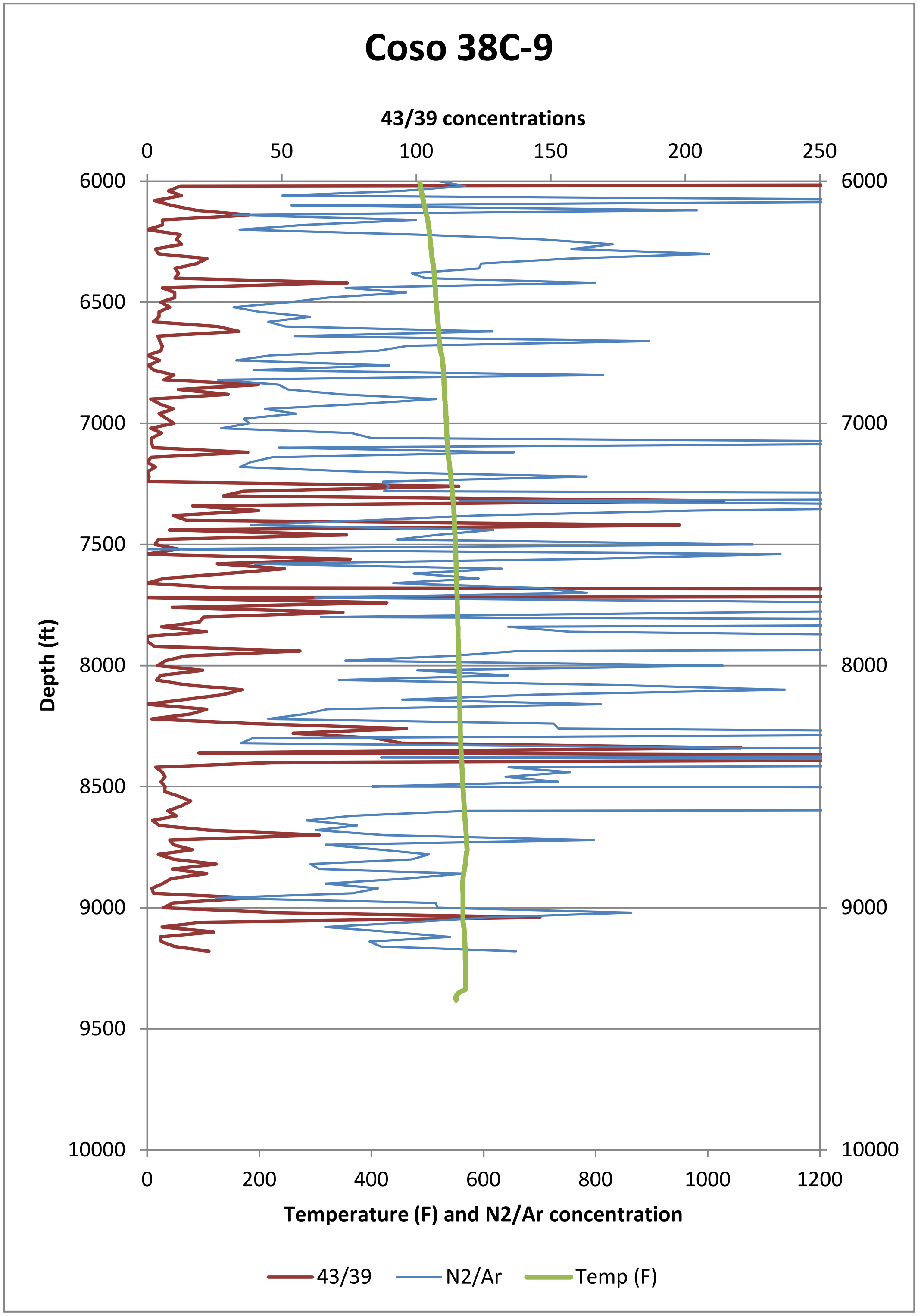


Figure 39a: Select gas ratios versus temperature for Well 38C-9

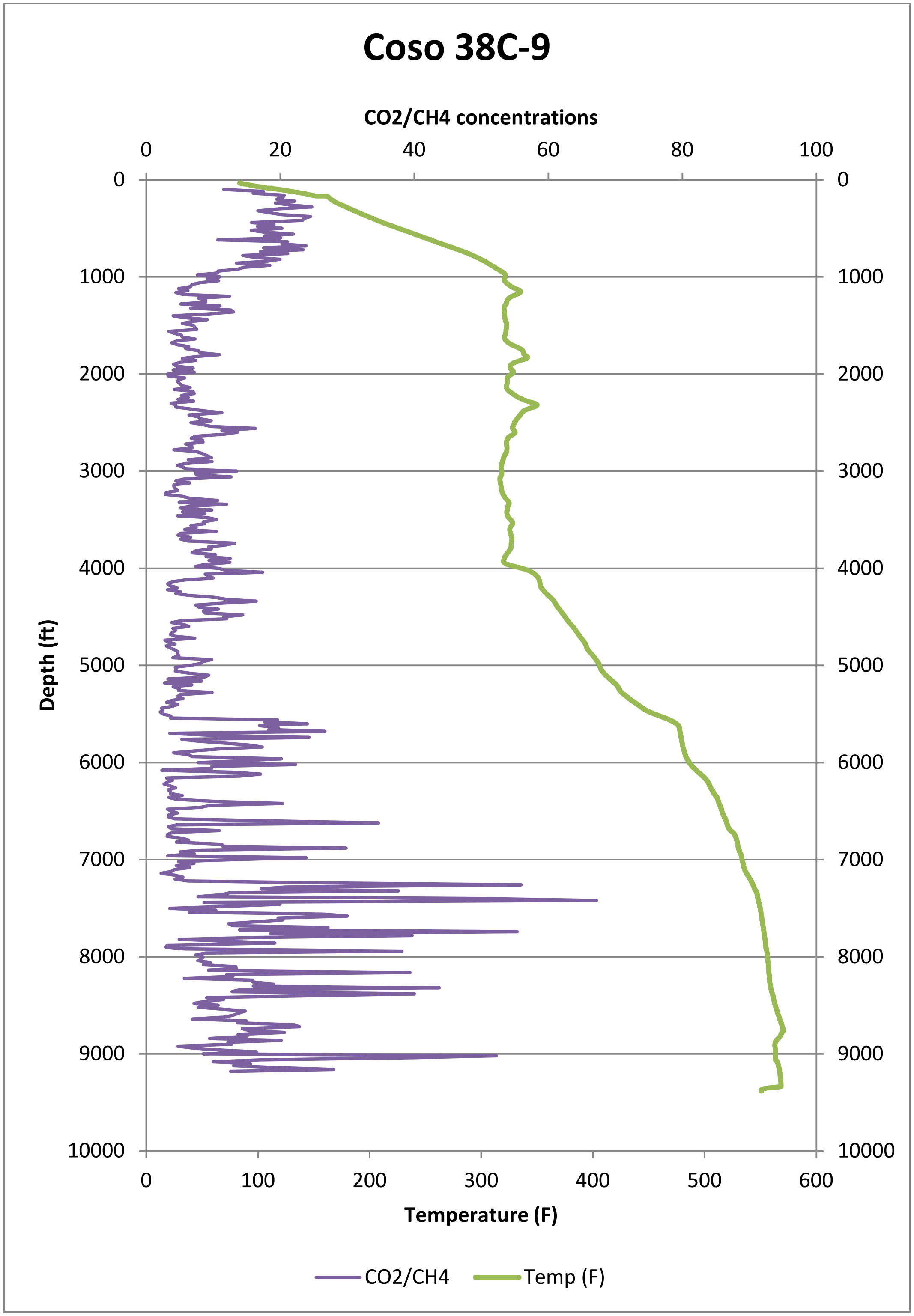


Figure 39a: continued

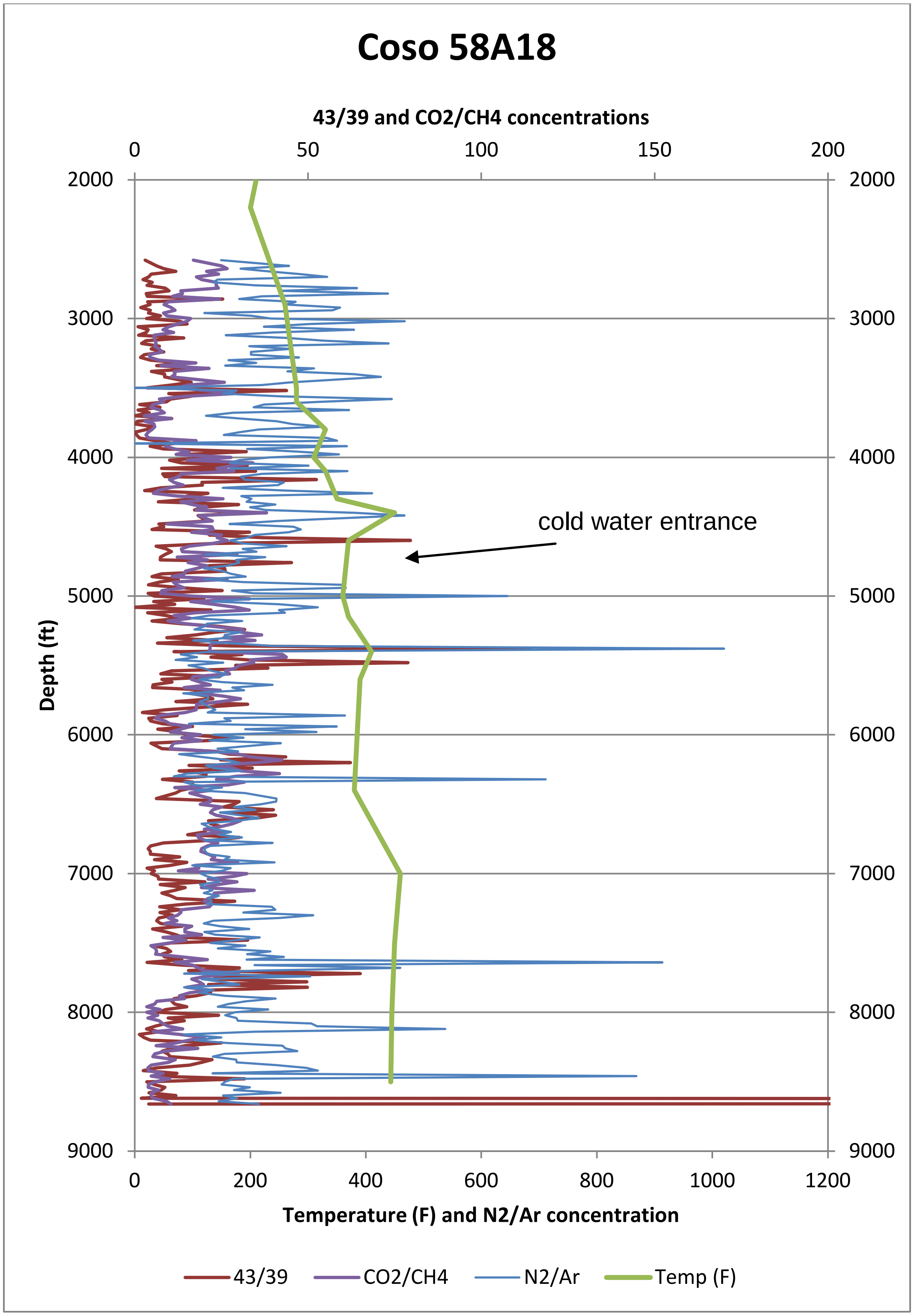


Figure 39b: Select gas ratios versus temperature for Well 58A-18

Coso Well 84-30 is to the south of the field and is believed to be outside of the present day geothermal field. The 43/39 ratio is overall low however it parallels the N_2/Ar ratio throughout most of the well. There are a few peaks in the N_2/Ar ratio particularly between 2000 to 3000 feet which are out of sync with the 43/39 ratio. Since this is a relatively shallow depth for the Coso field, it is difficult to interpret these peaks in N_2/Ar ratio as due to magmatic components. Since the temperature is below 200^0F the peaks may be due to the rock type (granodiorites and granites) being magmatic in origin. Starting at about 4,000 feet to the depth of the well, the 43/39 ratio and N_2/Ar ratio parallel each other suggesting young, oxidized, meteoric fluids. The CO_2/CH_4 ratio appears to parallel the 43/39 ratio.

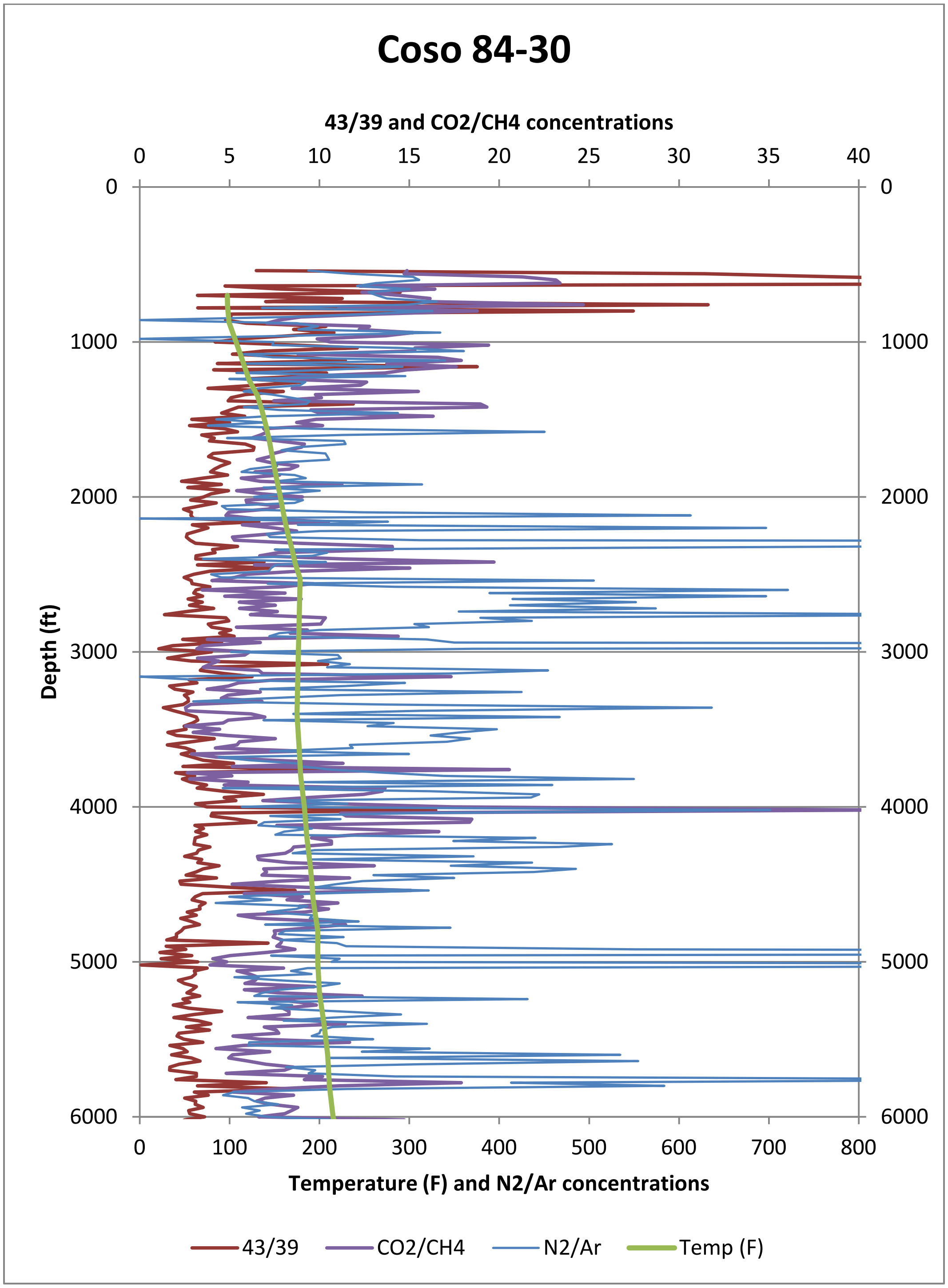


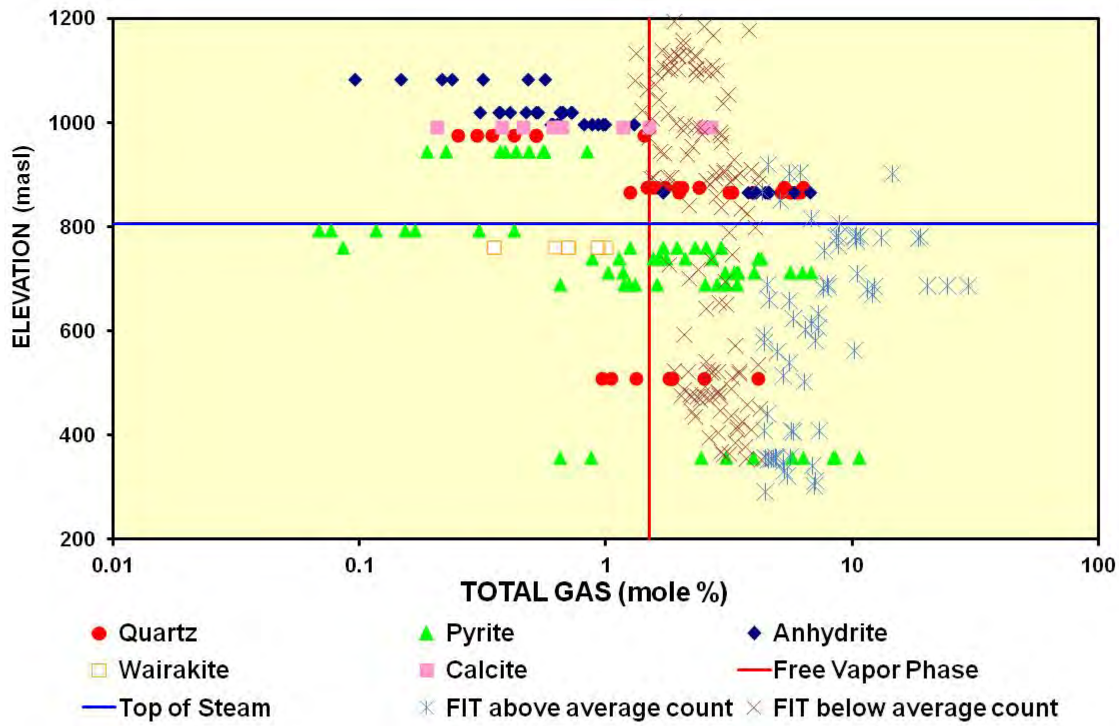
Figure 39c: Select gas ratios versus temperature for Well 84-30. Note 43/39 and N_2/Ar parallel each other throughout the depth of the well.

Well 33-7 located on the western side of the field is a moderate producer. Appendix I presents the ratios versus temperature graphs for this well. To about a depth of 5,500 feet, the 43/39 ratio has multiple peaks and has a overall higher concentration than in the bottom portion of the well. Although there are several peaks in the N_2/Ar ratio above 5,500 feet, there are many more peaks below this depth and the overall ratio appears to have a higher concentration. The CO_2/CH_4 ratio is overall low and has lower values from about 6,000 to 8,000 foot depth. None of the ratios appear to correlate with each other except 43/39 and N_2/Ar above about 1,500 feet.

Hawthorne Well HAD #1 has N_2/Ar and 43/39 ratios that parallel each other to a depth of about 1,800 feet (Appendix I). From that depth to the bottom of the hole, the ratios are almost opposite of each other. The ratios including CO_2/CH_4 are overall lower in concentration than the ratios for many of the Coso wells. There are multiple peaks in the 43/39 ratio at depth indicating influx of young, meteoric waters and the downhole temperatures are relatively low and consistent ranging from about 175 to 250 F.

The ratios for the Hawaiian wells are generally lower in value than the ratios for the other fields. All three ratios generally parallel each other in both wells however in Well SOH4 (the hotter well) there appears to be several instances where the N_2/Ar ratio has peaks in concentration while the other two ratios are low particularly at depth (5,500 ft to 6,100 feet and 6,300 feet to the depth of the well at 6,500 feet).Given the relatively young geologic history of the field, the waters are most likely young, oxidized fresh or salt waters. The basaltic magma source may not provide much nitrogen gases like the continental systems.

For Wells T2 and K33 the top of the steam is show through petrographic evidence and NMT fluid inclusion gas data to occur at about 2600 feet (800 masl) in T2 and 5200 feet (-200 masl) in K33 as shown in Figure 40. As seen in Appendix I, these depths correspond to when the ratios diverge from each other.



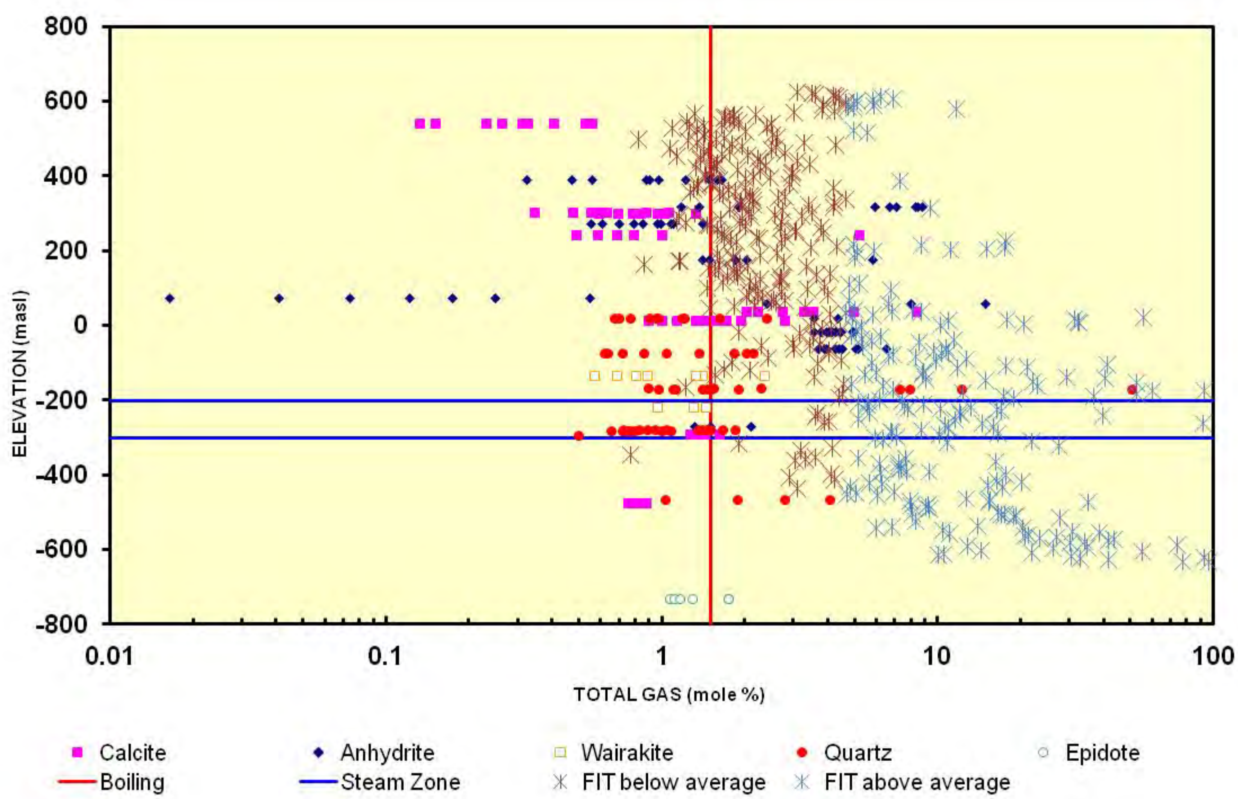


Figure 40. Total gas versus Elevation for T2 (top graph) and K33 (bottom graph). The FIT data was divided into below average concentration and above average concentration in both wells.

Plotting N_2/Ar and 43/39 on the same graph shows that the two ratios appear to parallel with each other in the colder wells. For higher temperatures wells (~>300^{0}F) the ratios did not parallel to each other but were in several cases opposite of each other, with high N_2/Ar and low 43/39. Closer examination of the break where the ratios correspond and then are opposite each other occurs near the top of systems. Where the two ratios track each other, the nitrogen is possibly derived from biogenic sources whereas when the ratios are opposite each other, the nitrogen is most likely derived from magmatic sources.

Although the ratios do not specifically correlate with temperature, they do help to explain the temperatures in wells. For instance the 43/39 ratio was high, the wells tended to have low or lower temperatures. When the N_2/Ar ratios were high and were not paralleling the 43/39 ratios, the temperatures in the wells were generally higher than in wells that had low N_2/Ar ratios, or N_2/Ar ratios that paralleled the 43/39 ratio. One exception to this was the Hawaiian field where the temperatures are on the order of 500 ^{0}F or above and yet all of the ratios are low. This is most likely due in part to the young geologic history the geothermal field has with young, oxidized waters being the primary component of the system. Older connate waters may not have had time to develop on the island.

7.2 GAS CHEMISTRY BETWEEN WELLS AND FIELDS

Fluid inclusion gas chemistry was compared between wells and between fields (Table 10). Table 10 presents a statistical summary of select chemical species and ratios (H_2O, H_2S, Total Gas, Gas/Water, N_2/Ar, CO_2/CH_4, mass 43/mass 39, H_2S/N_2,and CO_2/N_2) analyzed in the fluid inclusions. The highest average for each species and ratio is highlighted in orange while the lowest value is highlighted in green. For all of the species and ratios presented, except total gas, the difference between the lowest and highest average is one order of magnitude. For total gas, the difference is 4 orders of magnitude. The difference between maximum and minimum values were several orders of magnitude for the various parameters. It is interesting that the maximum value for H_2O between the different fields varied by less than one order of magnitude. For the other parameters the difference between the maximum values between fields varied by 3 or more orders of magnitude.

Table 10: Summary statistics for select species and ratios for each field.

FIELD	H2O	H2S	total gas	Gas/ H20	N2/ Ar	CO2/ CH4	43/ 39	H2S/ N2	CO2/ N2
COSO									
average	6.25E+06	1.62E+04	6.89E+10	8.64E+03	4.37E+02	4.36E+01	3.91E+01	6.70E-03	1.90E+00
max	2.69E+07	7.62E+05	6.10E+14	7.61E+07	2.38E+05	5.45E+03	7.74E+03	3.86E-01	2.73E+01
min	0.00E+00	0.00E+00	8.82E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
std dev	4.38E+06	2.60E+04	6.44E+12	8.03E+05	2.76E+03	1.22E+02	1.25E+02	1.03E-02	1.78E+00
KARAHA									
average	3.47E+06	1.36E+04	5.48E+10	3.01E+03	2.04E+02	2.71E+01	1.09E+01	2.14E-02	2.28E+00
max	2.43E+07	3.57E+05	2.40E+13	3.06E+05	1.27E+04	1.11E+04	7.93E+02	7.93E-01	1.76E+01
min	0.00E+00	0.00E+00	7.68E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
stddev	5.49E+06	3.60E+04	9.48E+11	2.45E+04	6.24E+02	4.32E+02	3.27E+01	6.13E-02	1.82E+00
BEOWOWE									
average	9.18E+05	1.37E+03	3.97E+07	4.21E+02	3.44E+02	8.68E+00	3.26E+01	1.33E-03	3.31E+00
max	1.32E+07	4.77E+04	1.87E+10	2.30E+05	3.56E+04	2.04E+02	5.81E+02	4.67E-02	1.53E+01
min	5.38E+03	0.00E+00	1.65E+04	6.77E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.53E-01
std dev	1.70E+06	4.30E+03	7.51E+08	9.24E+03	1.94E+03	1.07E+01	5.43E+01	4.07E-03	1.92E+00
GLASS MTN									
average	2.52E+06	7.28E+03	3.37E+06	1.14E+01	7.12E+02	1.72E+01	3.82E+01	6.73E-03	1.84E+00
max	1.20E+07	1.07E+05	2.18E+07	1.16E+02	5.53E+04	1.31E+03	5.32E+02	6.32E-02	9.49E+00
min	0.00E+00	0.00E+00	1.01E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.20E-01
std dev	3136295	17056.27	2913978	19.89407	5034.937	119.7469	56.84038	0.010442	1.585538

FIELD	H2O	H2S	total gas	Gas/ H20	N2/ Ar	CO2/ CH4	43/ 39	H2S/ N2	CO2/ N2
STEAMBOAT SPRINGS									
average	7.63E+06	6.27E+04	1.43E+07	3.91E+00	1.33E+02	8.43E+00	2.82E+01	4.12E-02	2.83E+00
max	2.06E+07	9.01E+05	8.28E+07	2.55E+02	7.31E+02	4.08E+02	2.17E+02	3.99E-01	1.29E+01
min	0.00E+00	0.00E+00	2.02E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
std dev	5.08E+06	1.04E+05	1.39E+07	1.55E+01	7.54E+01	3.01E+01	2.90E+01	4.91E-02	1.67E+00
ICELAND									
average	4.75E+06	2.57E+03	4.36E+06	4.07E+00	1.67E+02	3.81E+00	1.16E+01	1.76E-03	2.741411
max	1.52E+07	4.89E+04	1.99E+07	2.18E+01	1.43E+03	1.20E+01	8.74E+01	2.59E-02	10.12811
min	1.20E+05	0.00E+00	1.90E+06	3.81E-01	0.00E+00	4.22E-01	4.25E+00	0.00E+00	0.422132
std dev	4.37E+06	7.34E+03	3.11E+06	5.67E+00	2.05E+02	2.37E+00	1.13E+01	3.93E-03	2.314967
HAWAII									
average	7.03E+05	1.35E+03	4.28E+06	3.56E+01	1.03E+02	7.72E+00	4.16E+00	1.30E-03	9.39E-01
max	1.71E+07	6.76E+04	5.51E+07	7.49E+02	1.74E+03	3.53E+02	2.86E+01	1.16E-01	6.88E+01
min	0.00E+00	0.00E+00	6.71E+05	0.00E+00	0.00E+00	0.00E+00	1.52E+00	0.00E+00	0.00E+00
std dev	2.31E+06	7.56E+03	5.25E+06	4.95E+01	1.02E+02	2.38E+01	2.85E+00	8.93E-03	3.45E+00
HAWTHORNE									
average	2.73E+06	5.16E+03	2.12E+08	1.22E+02	1.51E+02	1.60E+01	1.37E+01	2.13E-03	2.35E+00
max	1.47E+07	5.38E+04	1.22E+11	6.62E+04	1.39E+03	1.32E+03	2.02E+02	1.13E-01	3.19E+01
min	2.72E+04	0.00E+00	8.13E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.79E-01
std dev	3.12E+06	7.27E+03	4.91E+09	2.67E+03	9.02E+01	5.34E+01	2.13E+01	4.94E-03	2.02E+00

FIELD	H2O	H2S	total gas	Gas/ H20	N2/ Ar	CO2/ CH4	43/ 39	H2S/ N2	CO2/ N2
FALLON									
average	1.25E+06	4.38E+03	1.48E+10	7.12E+03	4.42E+02	1.16E+01	3.90E+01	4.83E-03	2.87E+00
max	1.44E+07	4.68E+05	9.44E+12	2.13E+06	4.21E+05	1.11E+02	1.76E+04	2.09E-01	3.44E+01
min	0.00E+00	0.00E+00	7.76E+05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
std dev	2.34E+06	1.95E+04	2.50E+11	8.17E+04	1.05E+04	6.69E+00	4.76E+02	1.44E-02	2.14E+00
EL CENTRO									
average	7.11E+05	2.38E+03	4.84E+06	1.98E+01	7.04E+01	7.27E+00	4.34E+00	2.81E-03	1.97E+00
max	1.72E+07	7.58E+04	4.35E+07	9.92E+02	4.51E+02	2.86E+01	1.15E+01	3.72E-02	1.43E+01
min	0.00E+00	0.00E+00	8.56E+05	0.00E+00	0.00E+00	0.00E+00	2.38E+00	0.00E+00	1.73E-01
std dev	1.67E+06	5.95E+03	4.54E+06	5.00E+01	4.20E+01	3.57E+00	1.23E+00	4.60E-03	1.29E+00
SALTON SEA									
average	2.70E+06	3.81E+03	1.07E+07	2.66E+01	2.04E+02	6.54E+00	1.04E+01	4.36E-03	3.06E+00
max	1.48E+07	5.18E+04	4.10E+08	1.52E+03	4.34E+04	1.74E+02	3.94E+02	8.69E-02	1.60E+01
min	0.00E+00	0.00E+00	1.41E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.69E-01
std dev	3.70E+06	7.39E+03	2.12E+07	8.52E+01	1.27E+03	7.07E+00	1.77E+01	7.82E-03	2.00E+00

It can be seen that Coso has the highest average for all of the species and ratios except for the ratios N_2/Ar, and CO_2/N_2. Hawaiian wells had the lowest average for six of the eight parameters. Coso is composed of felsic intrusives and occurs in continental crust. Hawaii is composed of basaltic rocks and occurs due to a hot spot in the Pacific Ocean. However both systems have wells with temperatures exceeding 400 ^{0}F. Table 11 presents the rank form the highest to lowest overall average. Geothermal systems with felsic magma had higher average concentrations for these species and ratios than systems with basaltic magma. Systems occurring in the Basin and Range or Salton Sea had average concentrations between these two magma types. Temperatures do not seem to affect the distribution since Hawaiian field (Puna) and Iceland field has high temperatures like Coso and Karaha.

Table 11: Rank of each system for averages of select species and ratios.

H_2O	TOTAL GAS	H_2S	N_2/Ar	CO_2/CH_4	43/39
Steamboat	Coso	Steamboat	Glass Mtn	Coso	Coso
Coso	Karaha	Coso	Fallon	Karaha	Fallon
Iceland	Fallon	Karaha	Coso	Glass Mtn	Glass Mtn
Karaha	Hawthorne	Glass Mtn	Beowawe	Hawthorne	Beowawe
Hawthorne	Beowawe	Hawthorne	Karaha	Fallon	Steamboat
Salton Sea	Steamboat	Fallon	Salton Sea	Beowawe	Hawthorne
Glass Mtn	Salton Sea	Salton Sea	Iceland	Steamboat	Iceland
Fallon	El Centro	Iceland	Hawthorne	Hawaii	Karaha
Beowawe	Iceland	El Centro	Steamboat	El Centro	Salton Sea
El Centro	Hawaii	Beowawe	Hawaii	Salton Sea	El Centro
Hawaii	Glass Mtn	Hawaii	El Centro	Iceland	Hawaii

Continental - felsic magma	(yellow)
Basaltic magma	(purple)
Sedimentary basin	(light blue)

7.3 ROCK TYPE

One of the main goals of this project was to evaluate how rock type influences fluid inclusion gas chemistry. Is the fluid inclusion gas chemistry a result of the rock history or is the gas chemistry recording geothermal events? Can the geothermal event be separated from the prior rock history? Does the alteration mineralogy or vein assemblage correlate to the fluid inclusion gas chemistry? In order to assess these questions the fluid inclusion gas data was plotted with lithology, and select veins and alteration minerals. The lithology logs for a number of the wells was obtained from previous work conducted by Energy and Geoscience Institute. A few welllogs were available including two logs from Coso Operating Company and drill reports from University of Hawaii for the Hawaiin wells. Not all fields had lithology logs.

Figure 41 presents the log of select species, rock type and alteration minerals for the deeper portion of Karaha Well T2. This log was prepared using RockWare Logger program. This log allows for display of multiple species, ratios, rock types, and alteration minerals. The majority of the rock type is andesite (dark red) and crystalline tuff (pink). The brown bands represent a tuff which is a term used in the logging for variety of rock types that include ash-flow tuff, tuffaceous deposits, and lahars.

The fluid inclusion gas chemistry is shown for H_2O, Total Gas, Gas/Water ratio (in blue), N_2/Ar, CO_2/CH_4 (in red), 43/39 (green), H_2S (orange), and He (purple). These ratios and species are used in the Ternary diagrams discussed in Section 6.3. Each column width was set as the field average concentration plus two standard deviations for that particular species or ratio. These species and ratios are fundamental to understanding the fluid chemistry. Water and gas provides an indication of liquid or vapor rich inclusions, the ratios of N_2/Ar, CO_2/CH_4 and 43/39 have been discussed in previous section, H_2S provides an indication of condensate, and He can indicate magmatic/deep crustal components.

There is much variation in each of the species and ratios within the same rock type. For example from 3,400 to 3,900 feet the rock is classified as the crystalline tuff. There are multiple peaks in each of the species and ratios. A few of them coincide such as at 3,600 feet and again at 3,750 feet. At about 3,750 feet is a layer of tuff which may correlate with the peaks observed in 43/39 and He. Immediately below this depth there is another set of peaks in the N_2/Ar and CO_2/CH_4, H_2S, and He which appear to coincide with increase in the alteration minerals of calcite and pyrite. Although a few of the species/ratios correspond to the tuff, the majority of peaks occur with the alteration minerals suggesting that the fluid inclusion gas chemistry coincides with the alteration minerals, which may have been deposited during the geothermal event(s).

The thick package of andesites at depth also has multiple peaks and dips in the concentrations of the various species and ratios. At approximately 4,300 feet there is a change in the fluid inclusion gas chemistry with the slight increase in H_2O, the increase in the 43/39 ratio and multiple peaks in helium and H_2S. There is also a decrease in calcite at this depth. The fluid inclusion gas chemistry appears to vary within the same rock type but has some correlation to the vein and alteration minerals.

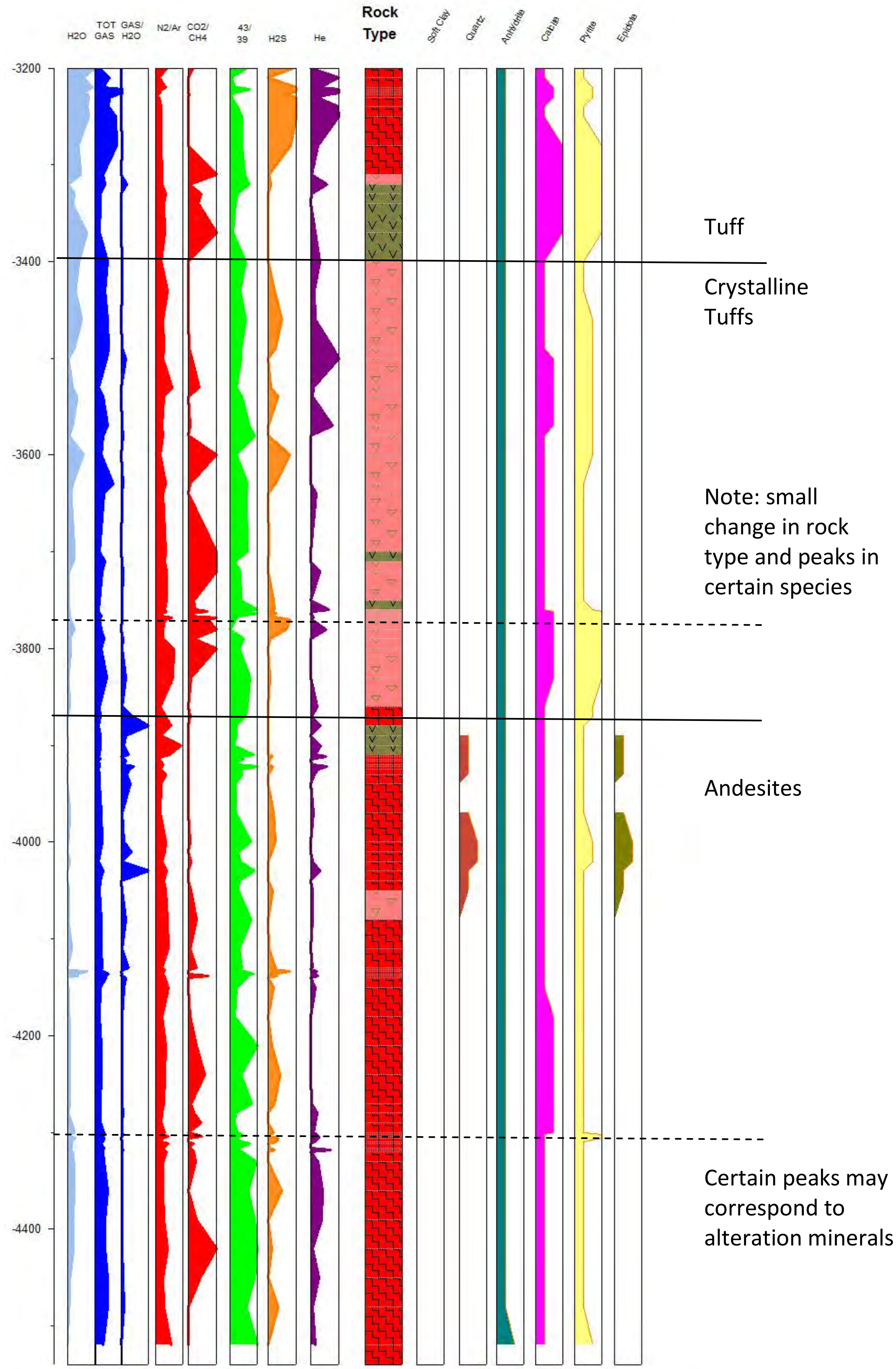


Figure 41: Log of select species, rock type, and alteration minerals for Karaha Well T2

Examining a similar log for Hawthorne HAD#2, a lower temperature geothermal prospect indicates that the fluid inclusion gas chemistry in this well is more influenced by rock type than at Karaha (Figure 42).

Well HAD#2 encountered sands to a depth of 850 feet (1,050 feet on the well log). From this depth to depth of the well at 4,700 feet was the basement intrusive complex. The rocks included amphibolite, metadiorite, and granites. A number of lost circulation zones occurred in this well starting at 1,129 feet to 3,224 feet. There is a significant break in the gas chemistry at approximately 800 feet which corresponds to the change in lithology from sediments to igneous bedrock. The species all decrease in concentration at this depth. Argon and N_2 still have high concentrations but show variability throughout the depth of the well. There are small peaks in several of the species at approximately 1,750 feet and several other depths. At about 2,600 feet there is an increase in total gas, H_2S, and helium that corresponds to rock changes. Peaks in the helium content especially follow the layers of metadiorite interbedded with the granites.

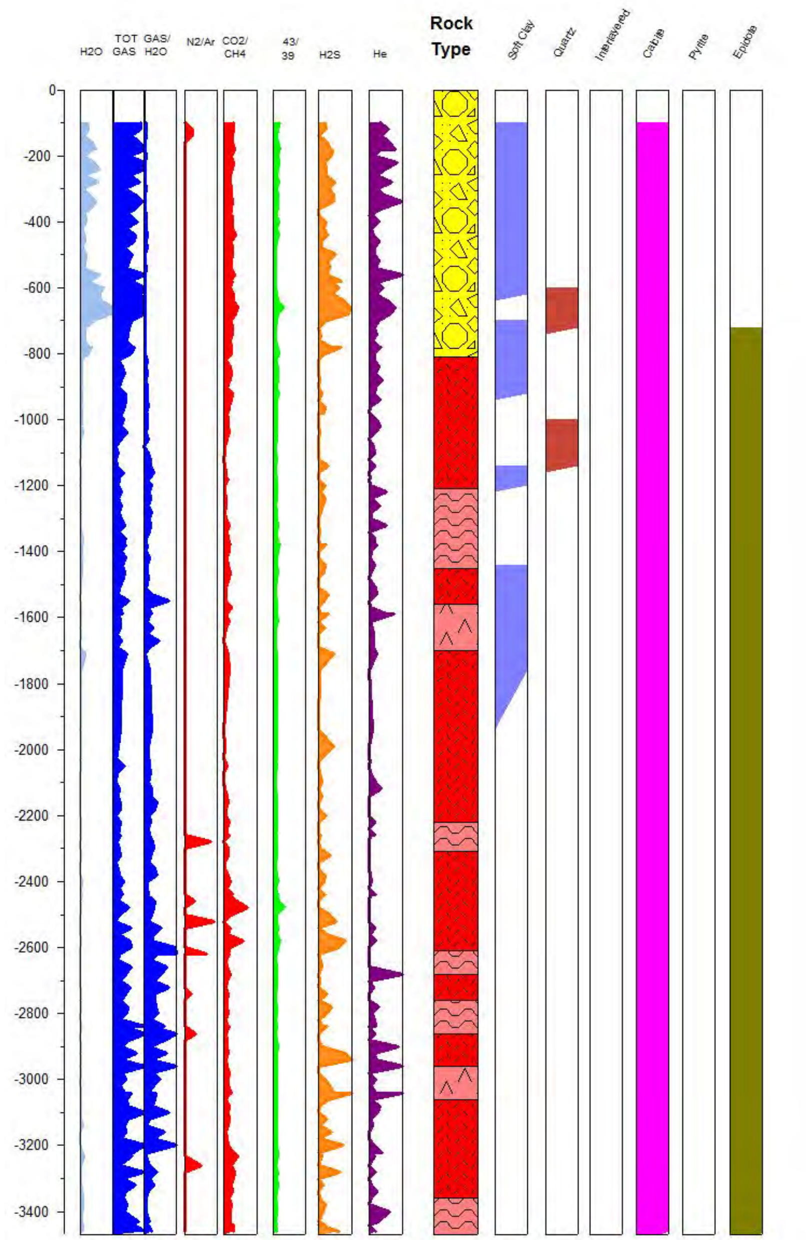


Figure 42: Hawthorne HAD#2 species, rock type and alteration log.

7.4 PERMEABILITY

Previous DOE study titled "Chemical Signatures of and Precursors to Fractures Using Fluid Inclusion Stratigraphy" was conducted in order to evaluate the use of fluid inclusion gas chemistry in identifying fractures in geothermal wells. In summary the project found that there is a statistical difference between fractures and non-fracture areas.

1) Fractures, veins and vuggy areas can be identified on FIS logs by distinct strong peaks (increase concentration) in multiple chemical species.
2) The bulk analysis of volatiles within fluid inclusions corresponds with several types of fracture infilling minerals including quartz, calcite, stibnite, and pyrite. Certain species such as H_2S and CO_2 can be useful fracture indicators depending on the mineral assemblages.
3) There is a statistical difference in the average fluid inclusion gas concentration in select species between fracture and non-fracture areas. Species useful include: H_2, H_2S, CO_2, and SO_2 with other species at a lower confidence.
4) Ratios of CO_2/N_2 and CO_2/H_2 appear to work in wells where boiling is evident.

7.4.1 CO2/N2 Ratio and Permeability

The CO_2/N_2 ratio versus total gas plot illustrates boiling and condensation trends (Norman et al, 2002). Gas partition coefficients for CO_2 and N_2 are considerably different. As steam separates from liquid during boiling gases such as H_2, N_2 and CH_4 preferentially move into the vapor phase and the more soluble gases CO_2 and H_2S stay partially in liquid phase. Nitrogen (N_2) would move into the vapor phase before CO_2 creating a higher CO_2/N_2 ratio with less gas. Condensation would increase both gaseous species concentration and total gas would increase. Figure 43 presents how boiling and condensation would plot on a CO_2/N_2 versus % total gas.

Can this change in the ratio of CO_2 / N_2 be used to indicate fracture zones? As a fracture opens, pressure would drop and boiling would occur. As boiling occurs N_2 would move into the vapor phase and there would be a change in the ratio. Figure 44 are the ratio versus depth for Coso Wells 38C-9 and 46A-19. Well 38C-9 has changes in the ratio that are up to 2E-6 with many peaks above 5E-7. Well 46A-19 has only a few peaks that reach 5E-7 and no over that number. Well 38C-9 is a major producer at Coso with 8MW. Although Well 46-19RD encountered some of the hottest temperatures at Coso it is relatively impermeable and a non-producer. The multiple peaks of the ratio in Well 38C-9 suggest permeability at those locations. The change in ratio was plotted with calcite alteration, felsic dikes and altered zones for two of the Coso wells had well logs available that indicated lost circulation zones, felsic dikes, and altered zones. Figure 45 presents a plot of Coso Well 38C-9 and Coso Well 68-20. The peaks indicate the largest changes in the CO2 / N2 ratio and correspond to logged zones of permeability.

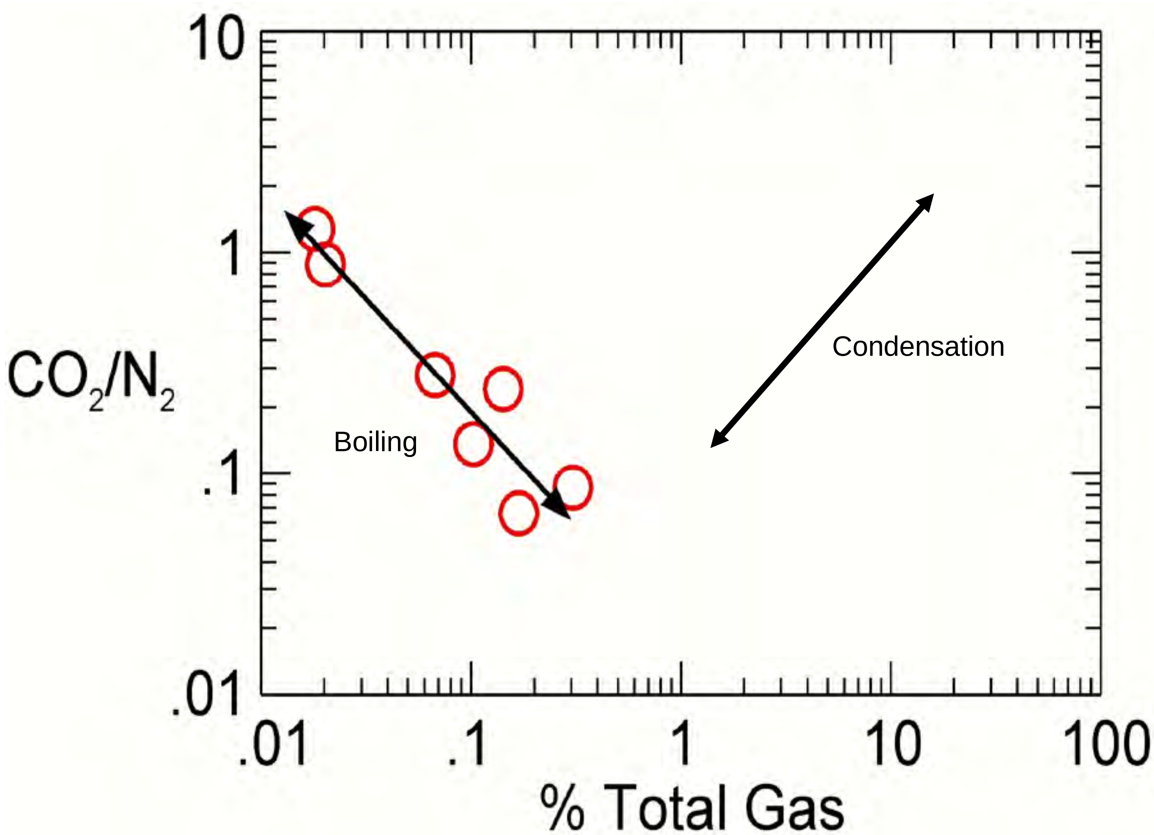
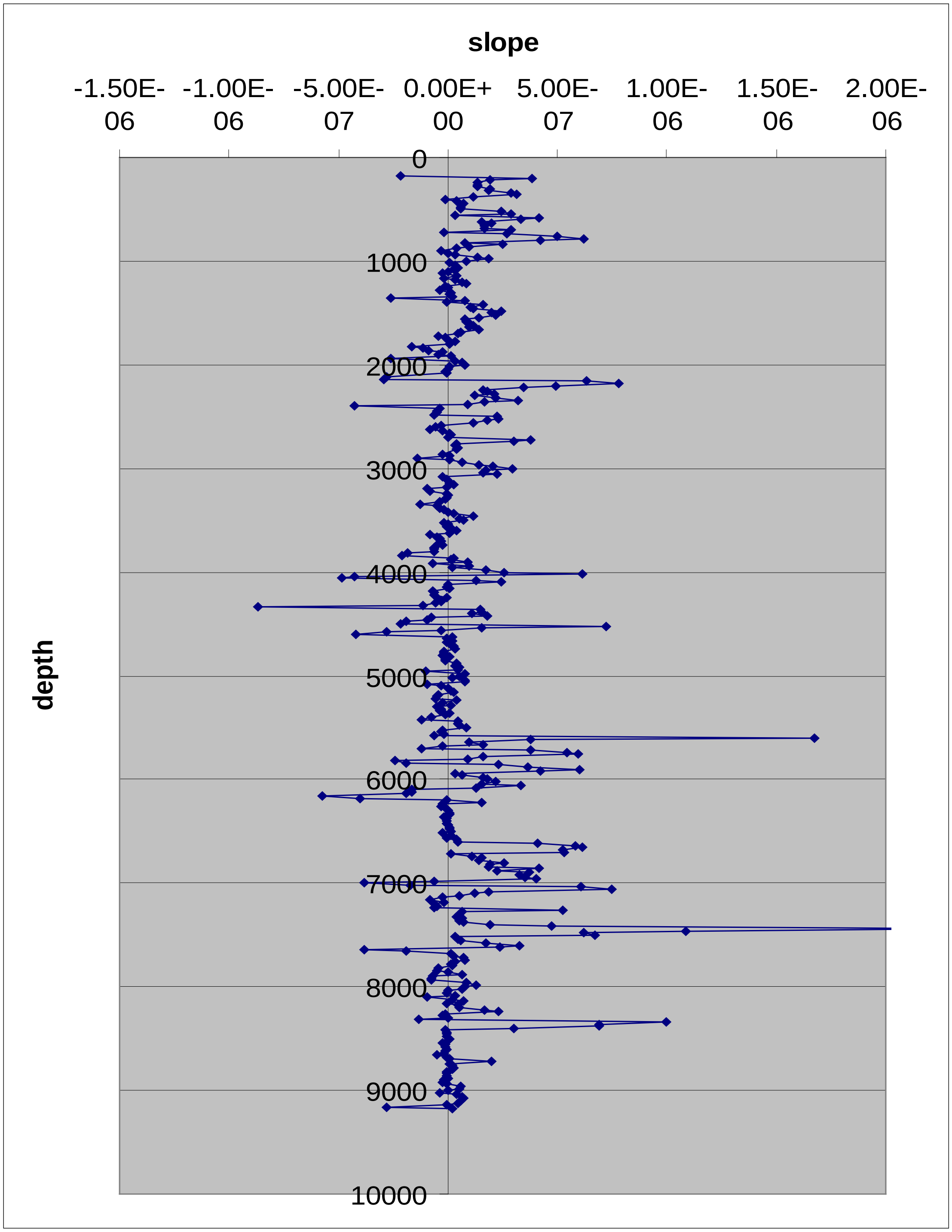


Figure 43: CO_2 / N_2 ratio versus percent total gas plots. Trends for boiling and condensation.

Well 38C-9


slope
-1.50E-06
-1.00E-06
-5.00E-07
0.00E+00
5.00E-07
1.00E-06
1.50E-06
2.00E-06
depth
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000

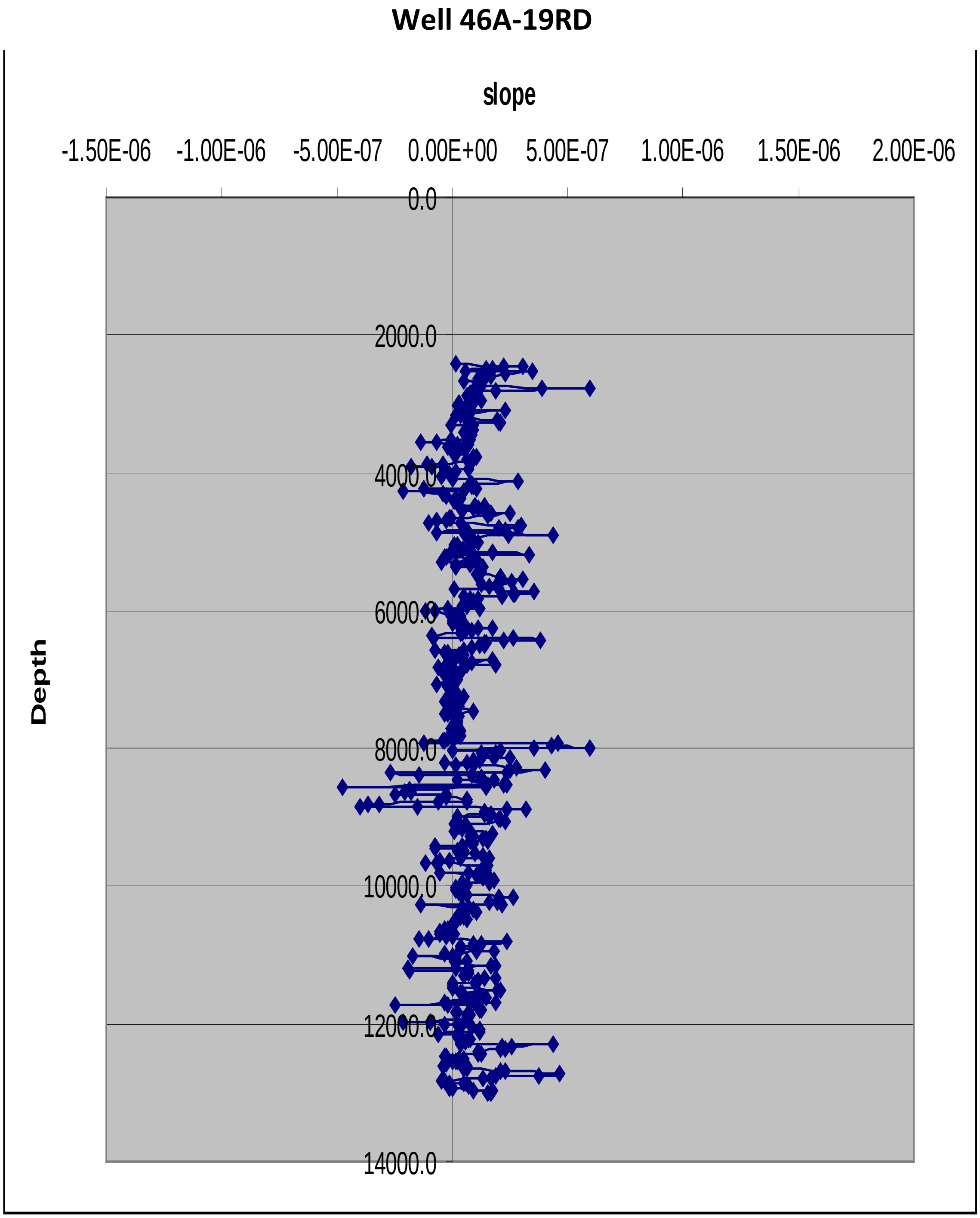
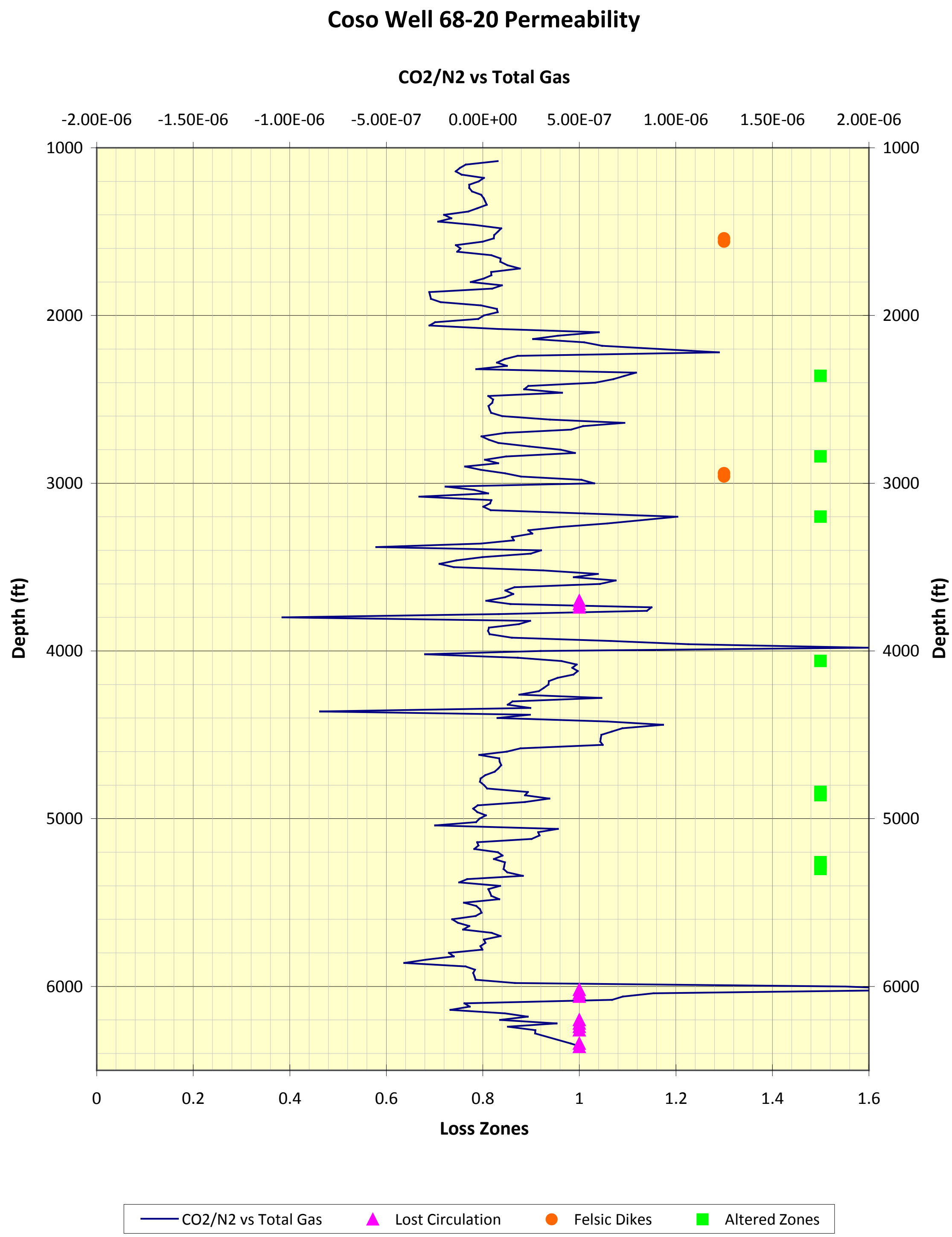


Figure 44: Slope of CO_2/N_2 versus total gas with depth. Note the range in Well 38C-9 is higher than the range in Well 46A-19RD. Well 38C-9 is a 8MW producer whereas Well 46A-19RD is as hot as 38C-9 however it is impermeable.



Coso Well 68-20 Permeability
CO2/N2 vs Total Gas
-2.00E-06
-1.50E-06
-1.00E-06
-5.00E-07
0.00E+00
5.00E-07
1.00E-06
1.50E-06
2.00E-06
1000
2000
3000
4000
5000
6000
Depth (ft)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
Loss Zones
CO2/N2 vs Total Gas
Lost Circulation
Felsic Dikes
Altered Zones

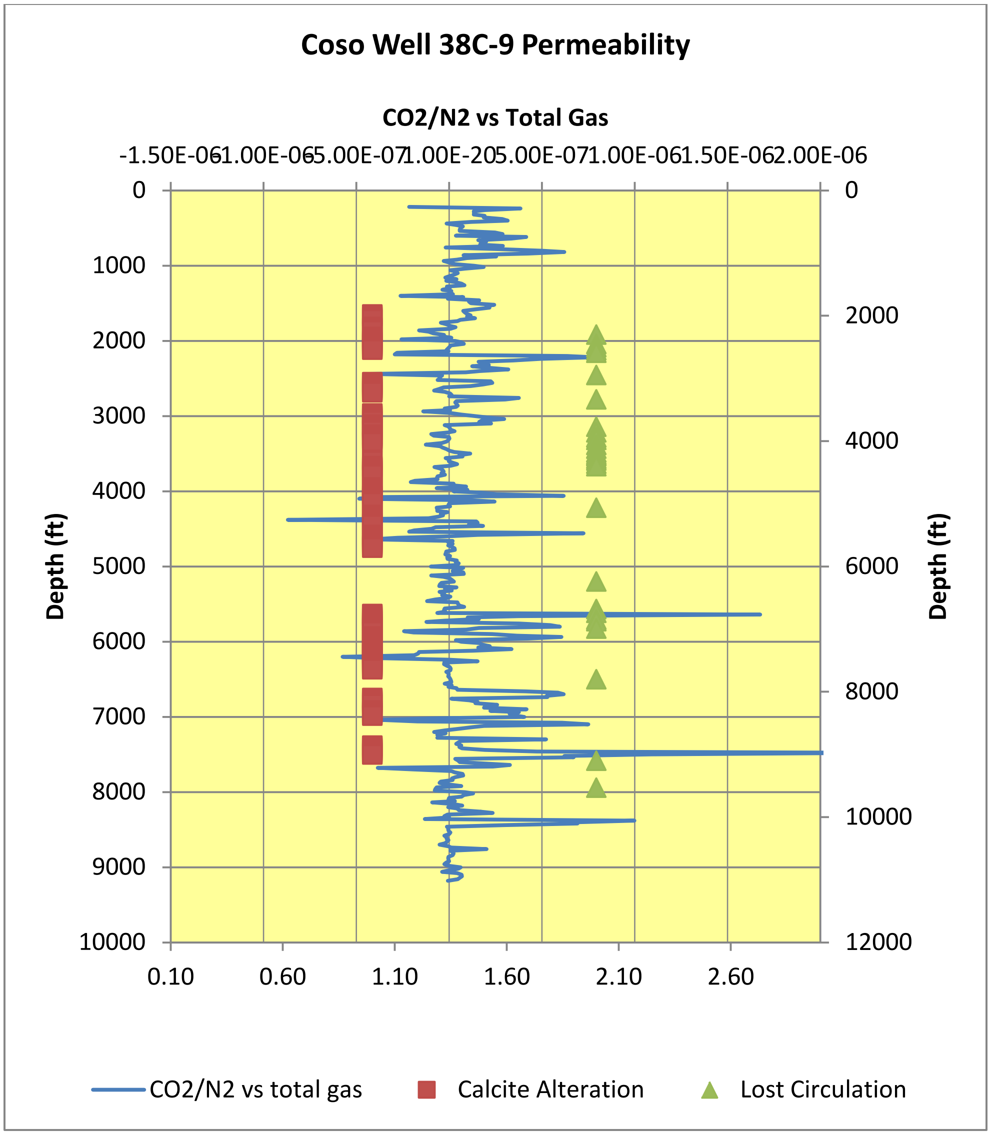


Figure 45: Plot of change in ratio with lost circulation, dikes and altered zones for Coso well 68-20 and 38C-9.

Results of the previous research on the statistical correlations between FIS peaks and fractures indicate that the best species to identify fractures are H_2, CH_4 (mass 16), H_2S, CO_2, and SO_2 (mass 64). The results indicated that to at least a 90 percent confidence interval and in most cases, a 95 percent confidence interval that the average concentration for each of these species was different in fracture areas then in non-fracture areas.

These results were based on already knowing the location of fractures and non-fracture areas. In order to identify fracture locations in a well a routine was developed whereby the average concentration for all the samples for a select species was calculated. This average was subtracted from each sample value and the result was either positive (above the average concentration) or negative (below the average concentration). For each sample and the six species discussed above this was conducted in several wells. The routine through a series of IF/Then statements give a value of 1 to each species that has an above average concentration and a 0 to each species with a below average concentration. The results are summed and range from 0 (no species above the average concentration) to 6 (all species above the average concentration). An ANOVA statistical evaluation was conducted to determine if the results for 2 or more or 3 or more species above the average concentration was statistically similar to the fracture location dataset. Table 12 presents the results of the ANOVA statistical evaluation.

Table 12: ANOVA Statistics for the routine

Well	2 or more	3 or more
87-29	0.058	0.008
T-2	0.132	0.276
K-21	0.366	0.814
K-33	0.026	0.032
88-28	0.0008	0.00002
17A-6	0.00004	0.00001

Yellow	Pr>F <0.05
Orange	Pr>F <0.10
Blue	Pr>F <0.15

For Wells K-33, 88-28 and 17A-6 this routine would give a better than 95 percent confidence that fracture dataset and the routine dataset are similar. For Well 87-29 the confidence interval ranges from 94.2 percent to greater than 95 percent. For Well T-2 the confidence interval ranges from 72 percent to 87 percent. For Karaha's Well K-21 the dataset were not statistically similar.

For predicting the actual location of a fracture using this routine, we evaluated how many times the routine actually located a fracture where there was a fracture and indicated a non-fracture areas. The routine ranged from 42 to 66 percent correct in identifying fracture locations and non-fracture locations. This suggests that there needs to be refinement in the routine in terms of what is the logic test for each species. In other words what would be considered the concentration in a fracture area versus a non-fracture area? In the routine presented it was based on the simplest case: concentration above or below the average for all of the samples. This average would be somewhere between the average concentration for fracture locations and non-fracture locations.

Based on the correlation of peaks in the FIS signature and the occurrence of certain minerals, it seems that CO_2, H_2S, and to a lesser degree H_2O are species that would indicate fracture locations. Generally, H_2S seems to be associated with open fractures and pyrite mineralization, and with the production zone in Steamboat (the depths studied in the other wells do not intersect a production zone). Steamboat has sulfide mineralization (stibnite) occurring as fracture infilling and H_2S has the highest confidence interval (0.001) that the average concentration is different between fracture and non-fracture areas.

Boiling has occurred in Karaha (Moore et al, 2008). For Well K21 which is still liquid dominated, the average concentration of H_2O in fracture areas is higher than in non-fracture areas. In the other two wells in Karaha which are vapor dominated, H_2O average concentrations in fracture areas are slightly lower than in non-fracture areas. Steamboat Springs well has a very low difference in the concentration of H_2O. A similar trend occurs in Glass Mountain as in Karaha where Well 88-28 has a large difference in H_2O average concentration but Well 17A-6.

For Karaha Wells the CO_2/N_2 ratio or the change in the ratio had a 95 percent or greater confidence interval that the ratio average was different in fracture and non-fracture areas. This ratio is based on boiling occurring in the system and there is additional evidence from the vapor-rich inclusions that boiling has occurred in this system.

Based on the above results a similar analysis for Elmore 16 at the Salton Sea was conducted. The species and ratios used were H_2, CH_4 (mass 16), H_2O, H_2S, CO_2, Total Gas, CO_2/N_2, and CO_2/H_2 for a total of 8 species and ratios. The number of species and ratios above average varied with each 10 foot sample. When 4 or less of the species were above average, siltstones were present and sandstones with little alteration and minimal porosity. There were occasionally siltstones with pyrite and/or epidote mineralization that has less than 2 species above average. The above species and ratios were mainly above average when calcite veining or alteration was present. The rhyolitic zone had 5 to 7 (typically 6) species and ratios above average. When 5 or more species were above average, sandstones were predominant and porosity and/or veining was evident. A large zone below about 8,500 feet had several fractures and 6 to 8 of the select species and ratios were above average in this zone.

A routine to estimate permeability would be to plot the slope of CO_2/N_2 vs Total Gas as first approximation, then conduct the above analysis (above average concentration for H_2, CH_4 (mass 16), H_2O, H_2S, CO_2, Total Gas, CO_2/N_2, and CO_2/H_2) to identify possible zones of permeable rocks. When 4 or more of these species and ratios are above average than these may be possible zones of permeability.

8.0 DATA INTEGRATION

The following conclusions were drawn from Sections 6 and 7:

1. Bulk fluid inclusion analyses can be used to define processes that occur in geothermal systems such as mixing, boiling, and condensation.
2. Even though the bulk analyses are qualitative, we have documented systematic trends in the abundances of individual species and ratios that are comparable to trends obtained from quantitative analyses .
3. Ratios of N_2/Ar, Ar/He, CO_2/N_2, alkane/alkene are particularly useful for interpretation.
4. Bulk fluid inclusion analysis can be used for interpreting fluid types within the reservoir.
5. Fluid inclusions in hot, active systems with large fluid fluxes, can provide a record of recent conditions.

Additional conclusions from evaluating rock type, permeability, and alterations.

1. Fluid inclusion gas chemistry has a narrow range of values that are a direct result of the narrow geological conditions which allow for a geothermal system to evolve.
2. In higher temperature systems (Coso, Beowawe, Karaha, Hawaii) the fluid inclusion gas chemistry is a result of the geothermal system and not the host rock. In lower temperature systems (Fallon, Hawthorne, El Centro) previous higher temperature events such as regional metamorphism may result in fluid inclusions with gas chemistry reflecting these previous higher temperature events. This suggest that fluid inclusions are created and destroyed rapidly in higher temperature systems as shown with Wells 68-20 at Coso.
3. Concentrations of many chemical species are lower in geothermal systems in mafic rocks compared to systems in sedimentary environments or felsic volcanic systems.
4. Alteration mineralogy is reflected in the fluid inclusion gas chemistry in geothermal systems.
5. Permeability of wells can be evaluated by determining above average concentrations of select species and using the CO_2/N_2 vs Total gas slope.

This section attempts to integrate the data obtained into a useful methodology in order to define fluid types within a well and permeable zones. Due to the amount of data generated from one well, well logs were developed to ease in presentation and interpretation.

8.1 Data Presentation

The Rockware® program Logger was selected to plot the mass data in a graphic form in order to prepare logs and be able to readily compare a number of concentrations against depth, temperature, rock types, alterations, and fluid type. This program produces graphic strip logs from user-created or imported data files. The format of the logs can be designed by the user. For each well, two types of log diagrams were plotted. One diagram displays mass peaks of various compounds, which provides information on the relative concentrations of a gaseous species with depth. The other diagram plots gas ratios and species that are used to interpret fluid types.

Logger allows for user-defined log plots (Figure 50). For each species and ratio, the size of the graphic strip had to be determined. Each log was plotted to the same scale for each field. A different scale was used for different fields. A technique was developed using two times the standard deviation of the values for each species or ratio as the largest value for the strip. Values outside this value would create large peaks that carried across a number of other strips. To plot the logs, the width of the columns for each volatile had to be determined. For each species and ratio plotted, the minimum, maximum, and standard deviation was calculated. Each of these values was averaged using the wells for only one field at a time. The logs were then developed by setting the column width to two times the average standard deviation for each species. This would allow for 95% of the values to fall within the width of each column for each species. FIT generates mudlog type graphs as seen in Figure 46 and provides a report with interpretations (Hall, 2002).

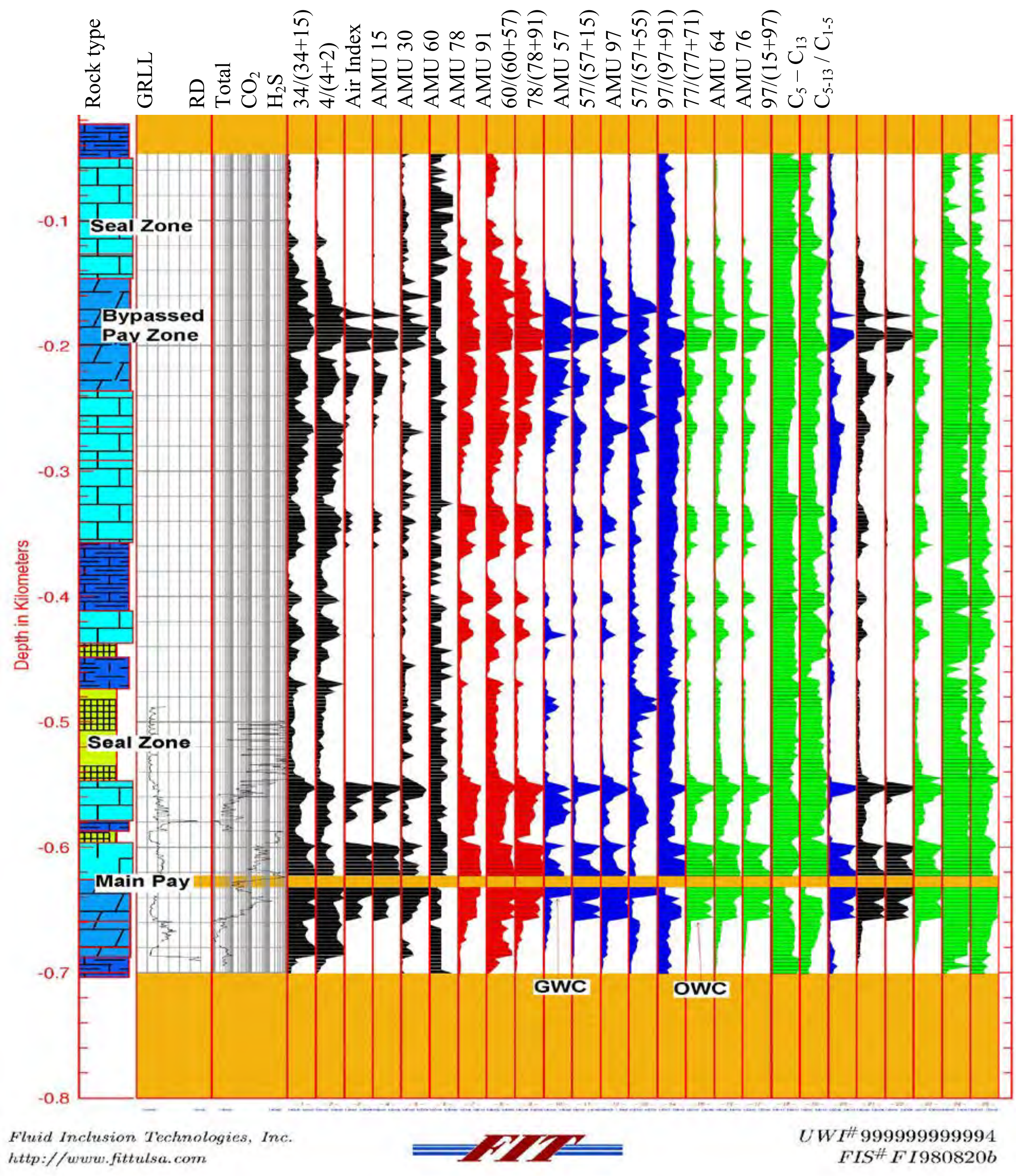


Figure 46. FIT's mudlog type graph presentation of mass spectra

On the logs developed (Figures 47 and 48) the species are grouped by chemical type, which are plotted in different colors. The species plotted (23 total of the 180 mass spectra available) were based on the research described in Section 3 as well as previous research conducted by us and others. Helium and water are plotted in blue with water distinguished by a lighter blue color. Helium is used to distinguish fluids with mantle components. Water is used to determine if the inclusions are water or vapor rich. The inorganic species N_2, Ar, and CO_2 are plotted in red. These species are used in ternary diagrams to determine certain fluid types and processes. The C_2-C_6 straight chain organic species are plotted in green (C_2H_6, C_3H_6, C_3H_8, C_4H_8, C_4H_{10}); the sulfur species are plotted in orange; and organic aromatic peaks are plotted in gray. Sulfur species plotted are H_2S (mass 34), SO_2 (mass 48) and mass 64. Mass 64 is a major peak for SO_2 and CS_2, and it is a minor fragment peak for some organic species. Hence mass 64 is distinguished by a different color than orange used for mass 34 and mass 48. Organic species are useful in determining zones of cold water influxes and tops and sides of geothermal systems. Also organic species are useful in sedimentary hosted geothermal systems such as Salton Sea to determine to a certain extent rock type. The sulfur species are important components in condensate fluids. Mass peaks 70, 78 and 92 are respectively the principal peaks for cyclopentane, benzene and toluene. These compounds are useful in some fields such as Salton Sea which has benzene issues. Mass peak 50 is a common fragment peak for aromatic compounds. Quantitative analysis of fluid inclusion organic species shows concentrations are in the low ppm and ppb range (Norman et al. 2004).

An interpretative log was developed based on the ratios used in the ternary diagrams in Chapter 3. The ratios are group based on fluid source. The blue represents water or gas while the red indicates fluids with magmatic components and the green represents fluids from continental source. Orange represents possible condensate fluids. The same ratios N_2/Ar and CO_2/CH_4 are included in both the magmatic and crustal fluid sources. If the ratios are low then they plot in the crustal fluid source (green). If the ratios are high then they plot in the magmatic fluid source (red). For N_2/Ar the break was set at 200 and for CO_2/CH_4 the break was at 4. Based on the relative concentrations of the various ratios (Figure 48) and species (Figure 47), fluid types can be determined.

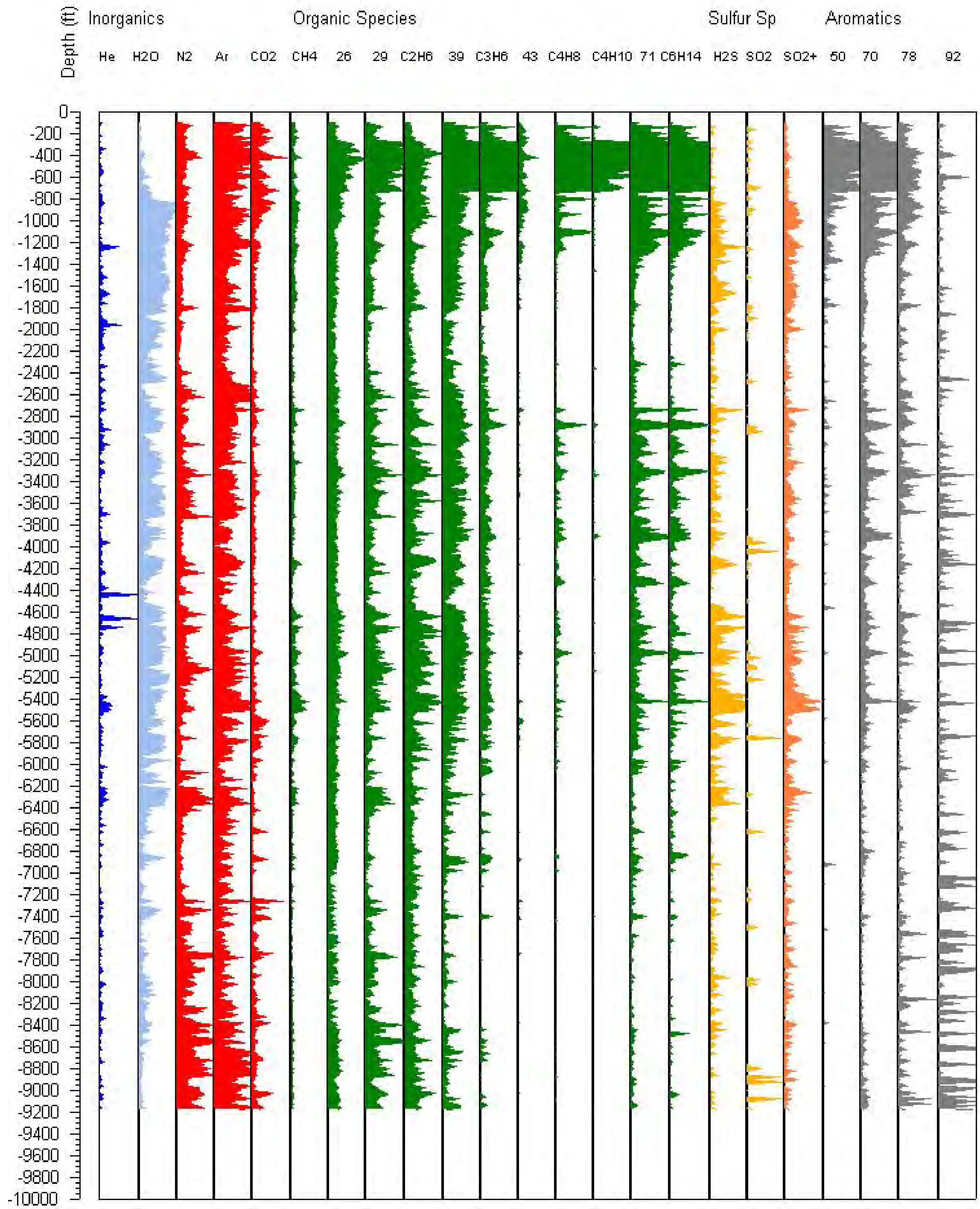


Figure 47. FIS log with select mass spectra plotted versus depth for Coso Well 38C-9 a major producing well.

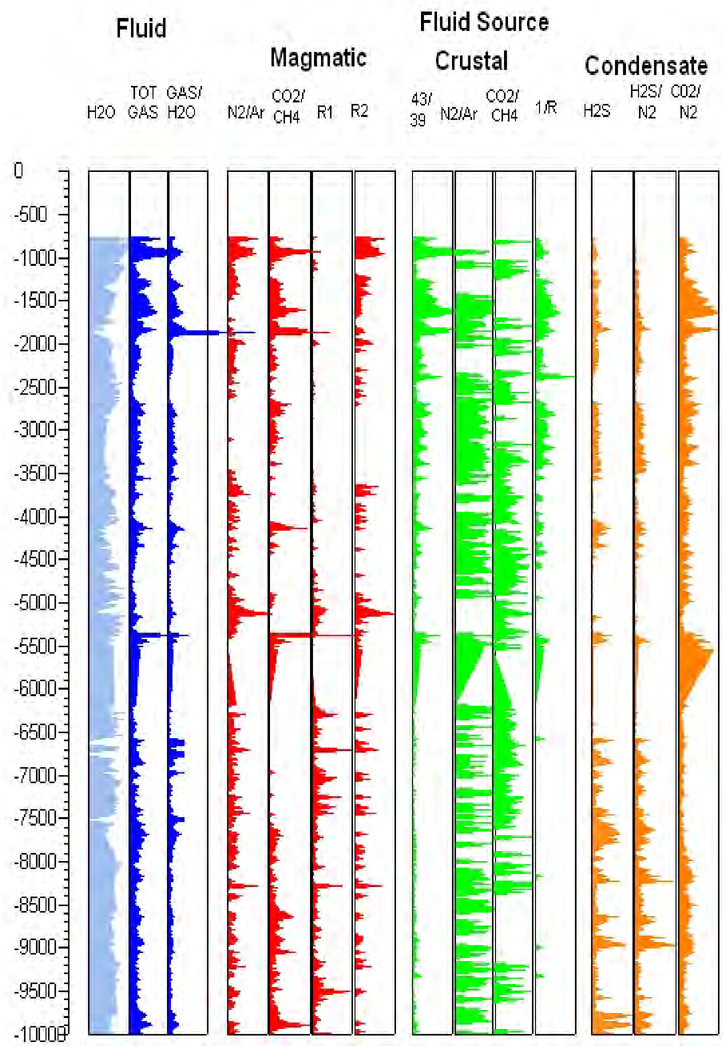


Figure 48: An interpretative log for one of the wells. Ratios are divided into particular source such as magmatic or continental source.

Four main fluid types can be interpreted from the fluid inclusion gas chemistry: meteoric, condensate, evolved or reservoir waters, and no fluid/background.

Meteoric Fluids - fluids in this type would be young, fluids with minimal chemistry. Most of these fluids would be organic rich, and have variable nitrogen/argon ratios. The N_2/Ar ratio would most likely be below 200 since the waters would most likely be near surface and argon would have saturated the fluid. If biogenic nitrogen is present then the N_2/Ar ratio could be higher than 200. The paralleling of 43/39 with N_2/Ar is an indication that biogenic nitrogen is present. H_2O would be high in meteoric fluids.

Condensate Fluids - fluids formed from the condensing vapor. Once boiling starts a drop in water levels occur. Rock are left with heat that is above saturation temperature (boiling point).

Liquid forming as condensate at the reservoir cap flow downward encountering hot rock, and boils. The rock's heat is lost in boiling and a steady-state is achieved, with salinity increasing with time as steam is lost from the reservoir. Condensate at the top is low in salinity and slightly acidic. Near-surface condensation and oxidation of transported H_2S produces sulfate-dominated, steam-heated waters and condensate. Condensate fluids would be characterized by high H_2S, high CO_2 as liquid boils and gases leave, and low to no organics, Total gas should be high since boiling is or has occurred. Steam would be differentiated from condensate fluids by high gas to water ratios.

Connate/Reservoir Fluids - reservoir fluids are the deep circulating fluids that may interact with magmatic fluids and gases from the geothermal heat sources. Based on the ternary diagrams discussed in Section 3, these fluids would be characterized by high nitrogen, low argon, some helium. In addition, high CO_2 will present however CH_4 may be high as well depending upon rock type. Organics would be low. H_2O is present. H_2S is also present.

No Fluids/Low Permeability These are zones were the geothermal fluids have not altered the rocks or areas outside of the geothermal system. Geothermal caps can also be distinguished based on lack of gaseous species. These areas would have below to minimal concentrations in all of the species.

Geology of system

We can use fluid inclusion gas chemistry to identify caps, margins, "magmatic" fluids, fractures, and from this identify possible producing zones. For instance the tops of systems would be characterized by the decoupling of N_2/Ar ratio and the 43/39 ratio. Wells along the margins of the systems would not have overall high concentrations of species and the ratios would be low when compared to average values. Rock types may have more of impact on the fluid inclusion gas data then in the middle of the system. Permeable zones may be identified by using the slope of the CO_2/N_2 versus total gas and select ratios.

9.0 FIS METHODOLOGY

A methodology for identifying fluid types was developed and then refined to include more of the results of the above research.

9.1 First Approximation

The first step in determining the fluid type represented by the gas analysis was to determine if certain species and ratios were above or below the average concentration for that species or in the case of ratios above or below a particular value for that ratio (Giggenbach 1986; Norman & Musgrave 1995; and Moore et al. 2001). The species, ratios and tests used were the following:

- H_2O – above or below average concentration
- N_2/Ar – above or below 200 (see Table 1)
- CO_2/CH_4 – above or below 4 (see Table 1)
- H_2S – above or below average concentration

- Total organics – sum of mass spectra 26 through 86 subtracting the sulfur species and aromatics – above or below average concentration.

There are several more species plotted on the FIS logs, however the above species and ratios appeared to be the strongest indicators of fluid types.

Next a series of rules similar to discussed in Section 6.9, were then developed to identify one of the four fluid types: meteoric, condensate, plume or background. Table 13 presents the rules that were developed (see Figure 49):

Table 13: Fluid type rules.

Fluid Type	H_2O	N_2/Ar ratio	CO_2/CH_4 ratio	H_2S	Total Organics
Meteoric	Above average	<200	<4	Below average	Below average
Condensate	Does not matter	<200	<4	Above average	Does not matter
Plume	Does not matter	>200	>4	Does not matter	Below average
Background	Below average	Does not matter	Does not matter	Below average	Above average

The series of rules were applied to the data in Excel spreadsheets in the form of if/then statements with a return being the fluid type. First the species (i.e. H_2O) concentration for each sample was compared to the average for that species. The if/then statement: If (H_2O > average H_2O, if true return 1, if false return 0) was used for H_2O, H_2S, and total organics. For the ratios N_2/Ar and CO_2/CH_4 the amount was compared against 200 and 4, respectively. A series of columns in Excel was set up using the flow chart in Figure 55 applied to each sample to arrive at a fluid type. Nested if/then statements were used in each column as a test for fluid type. For instance, if H_2O was above average (1) and N_2/Ar was greater than 200 (1) then the fluid type returned from the testing would be plume fluids. This was done for each 20 foot interval sample in each well. The computer generated fluid log was imported into Logger program for plotting. Figures 50 through 52 present the fluid logs developed by this process for the Coso wells. Figure 53 through 56presents the FIS logs for Wells 38C-9, 51B-16, 67-17, and 84-30, resepectively.

The computer generated fluid logs present a fluid type for every sample. Fluid types occur in zones over 1,000 feet thick. In addition there are zones where the fluid types change rapidly with depth. These zones would be considered mixed fluids. As with trying to separate rock units there may be some overlap as to the fluid types and some consolidating of fluid types into one type based on thickness of the unit.

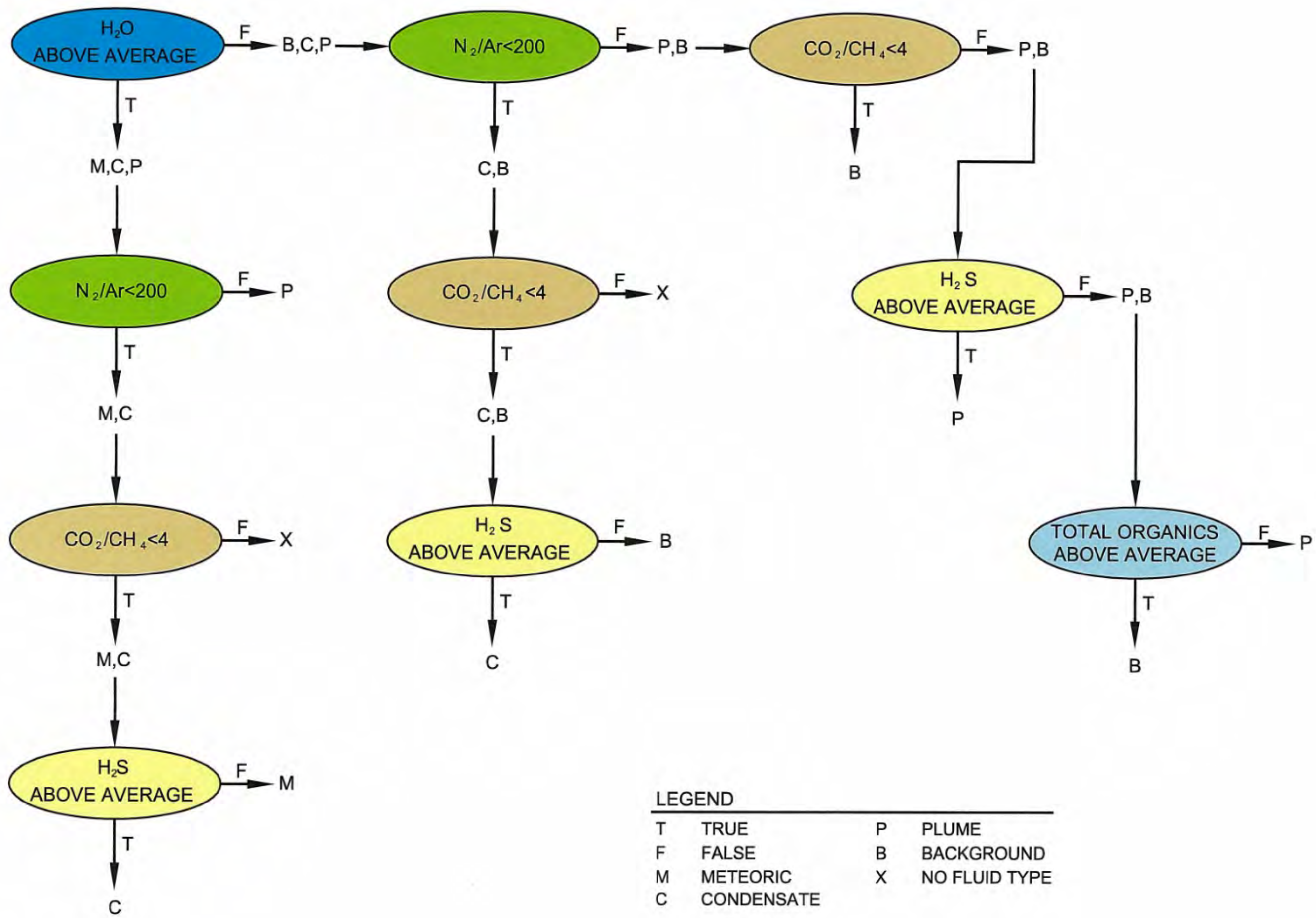


Figure 49. Flow chart illustrating the determination of fluid types.

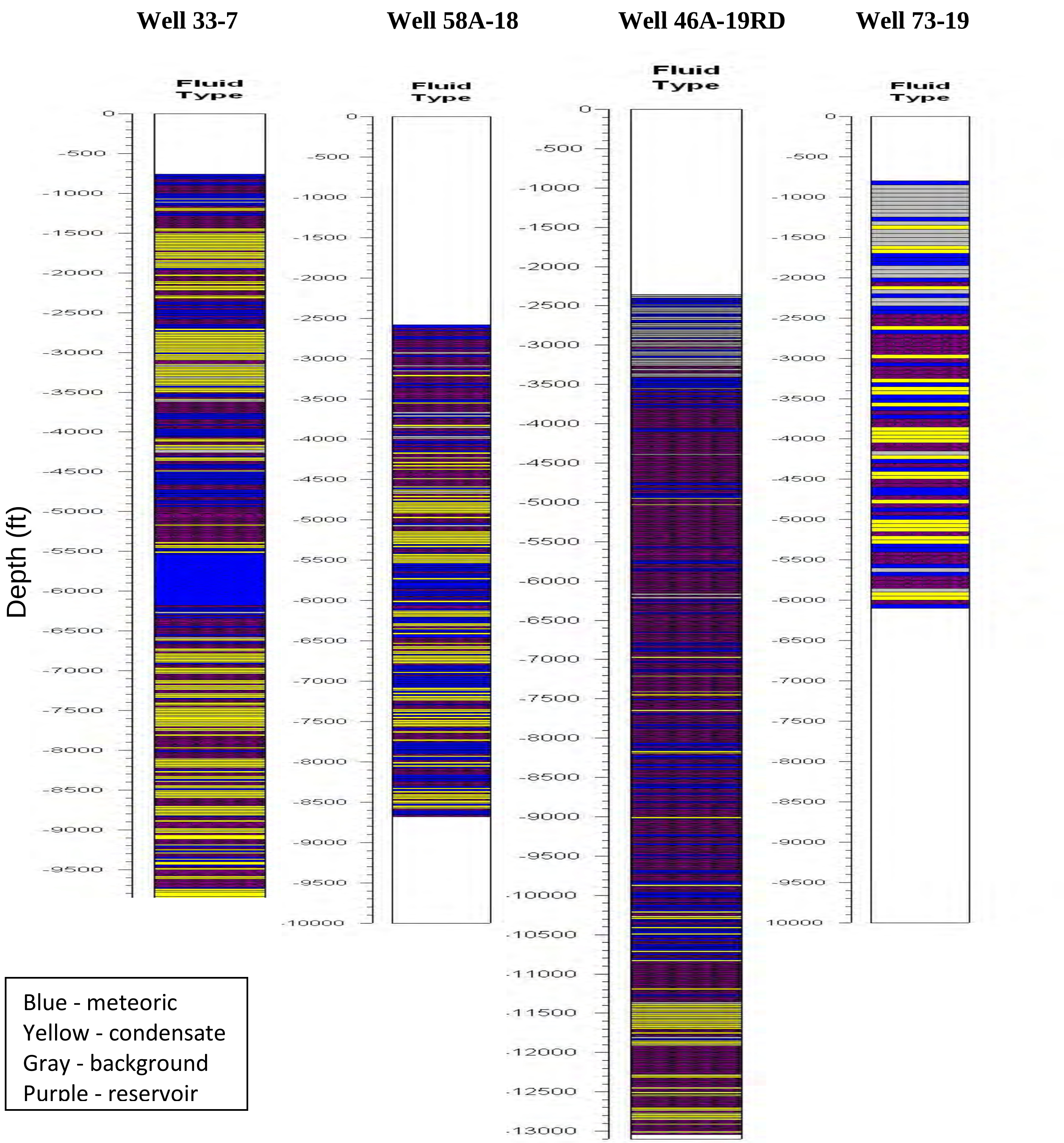


Figure 50. Fluid logs for Wells 33-7, 58A-18, 46A-19RD, and 73-19 that occur on the western side of the Coso geothermal field.

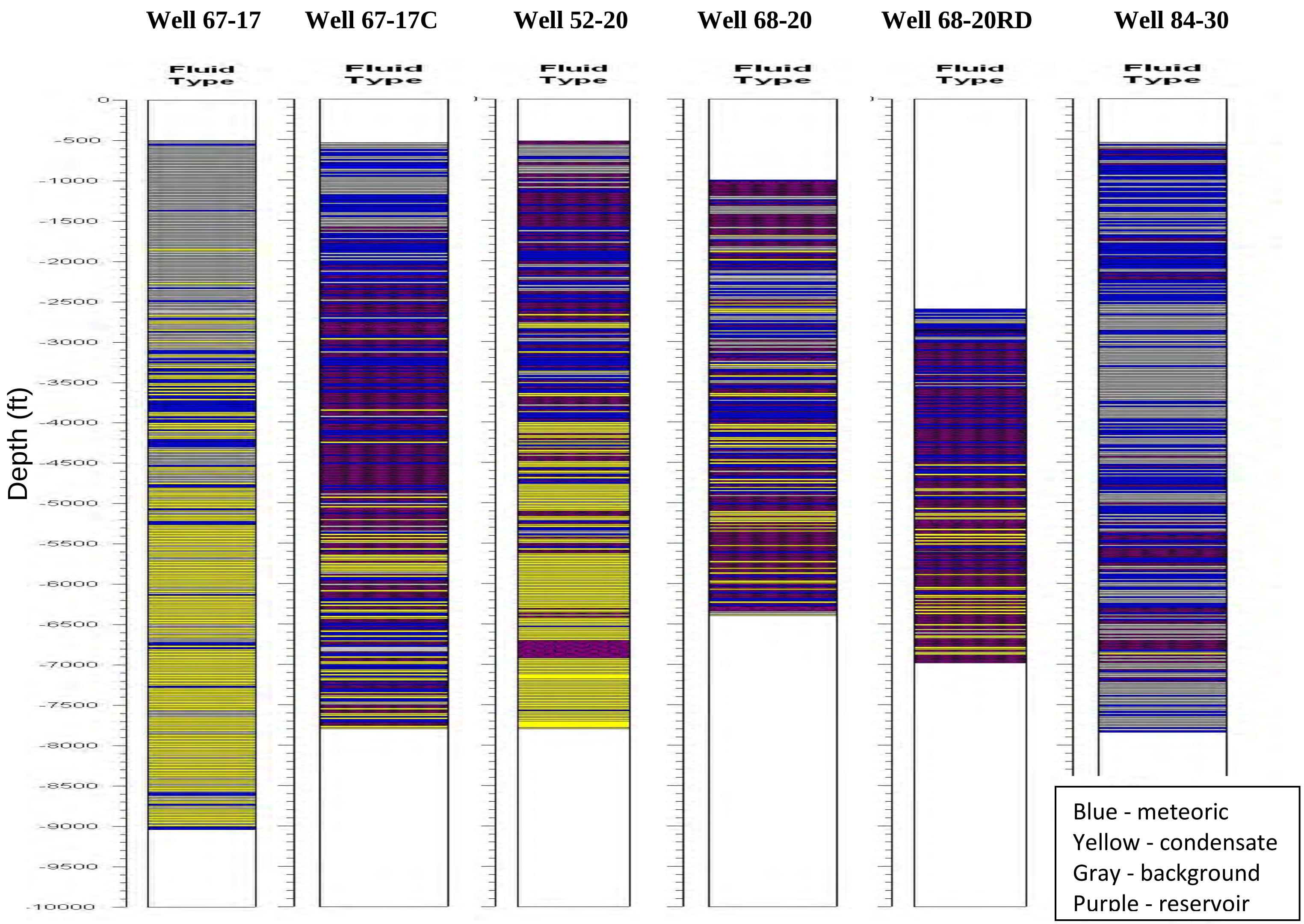


Figure 51. Fluid logs for Wells 67-17, 67-17C, 52-20, 68-20, 68-20RD, and 84-30 that occur on the middle southern portion of the Coso geothermal field.

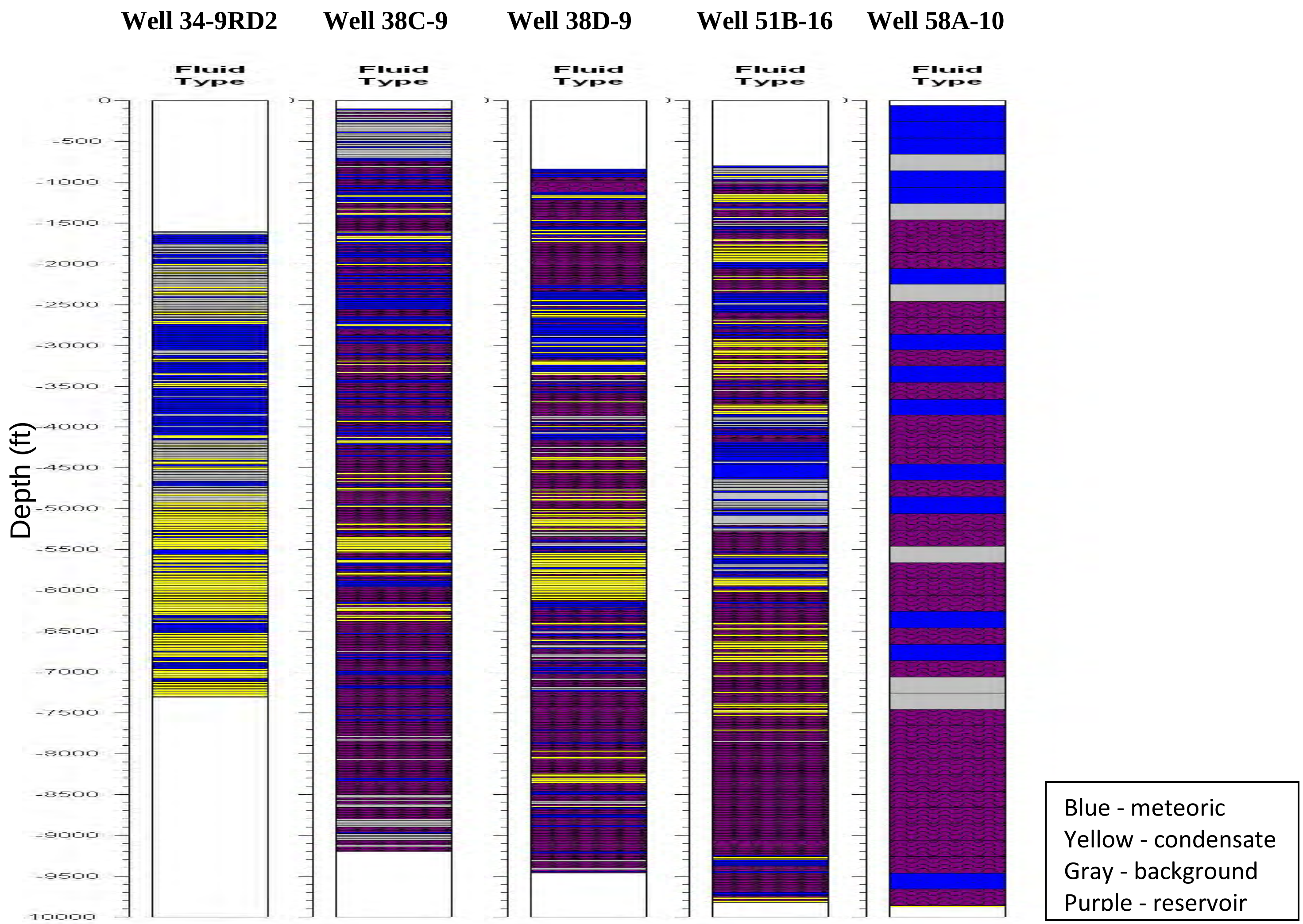


Figure 52. Fluid logs for Wells 34-9RD2, 38C-9, 38D-9, 51B-16 and 58A-10 located on East Flank of the Coso geothermal field.

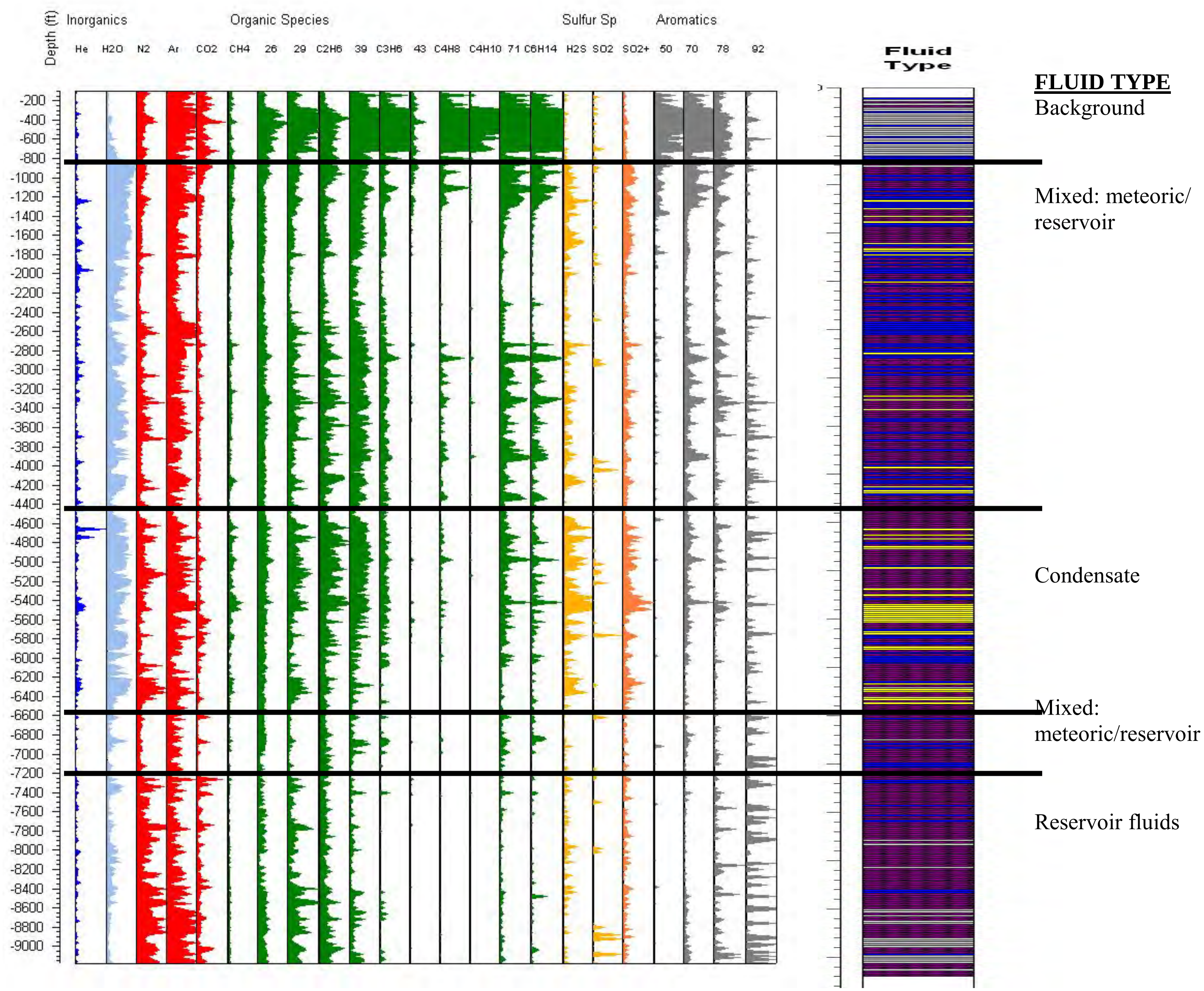


Figure 53. Interpreted fluid types for Well 38C-9.

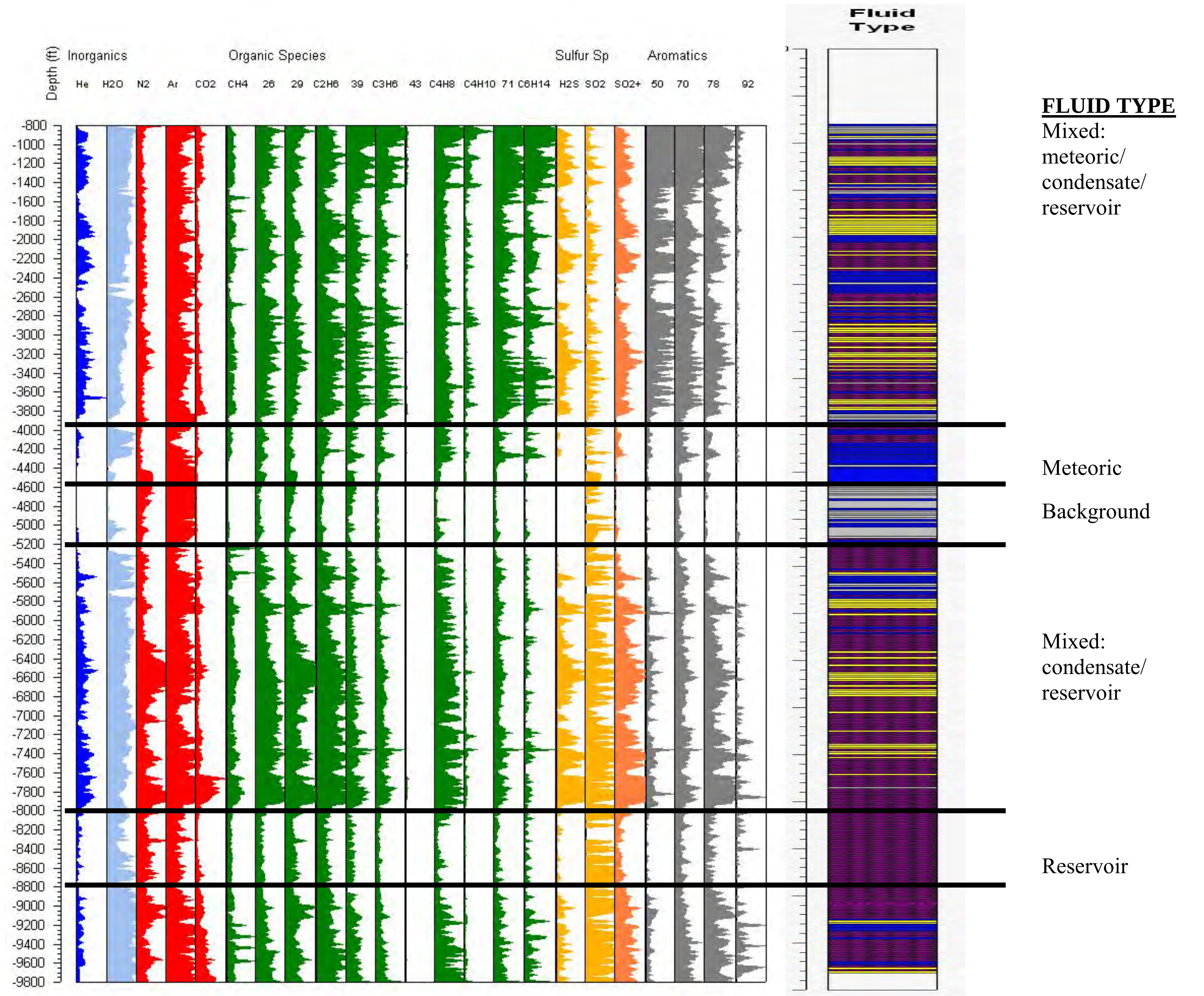


Figure 54. Interpreted fluid types for Well 51B-16.

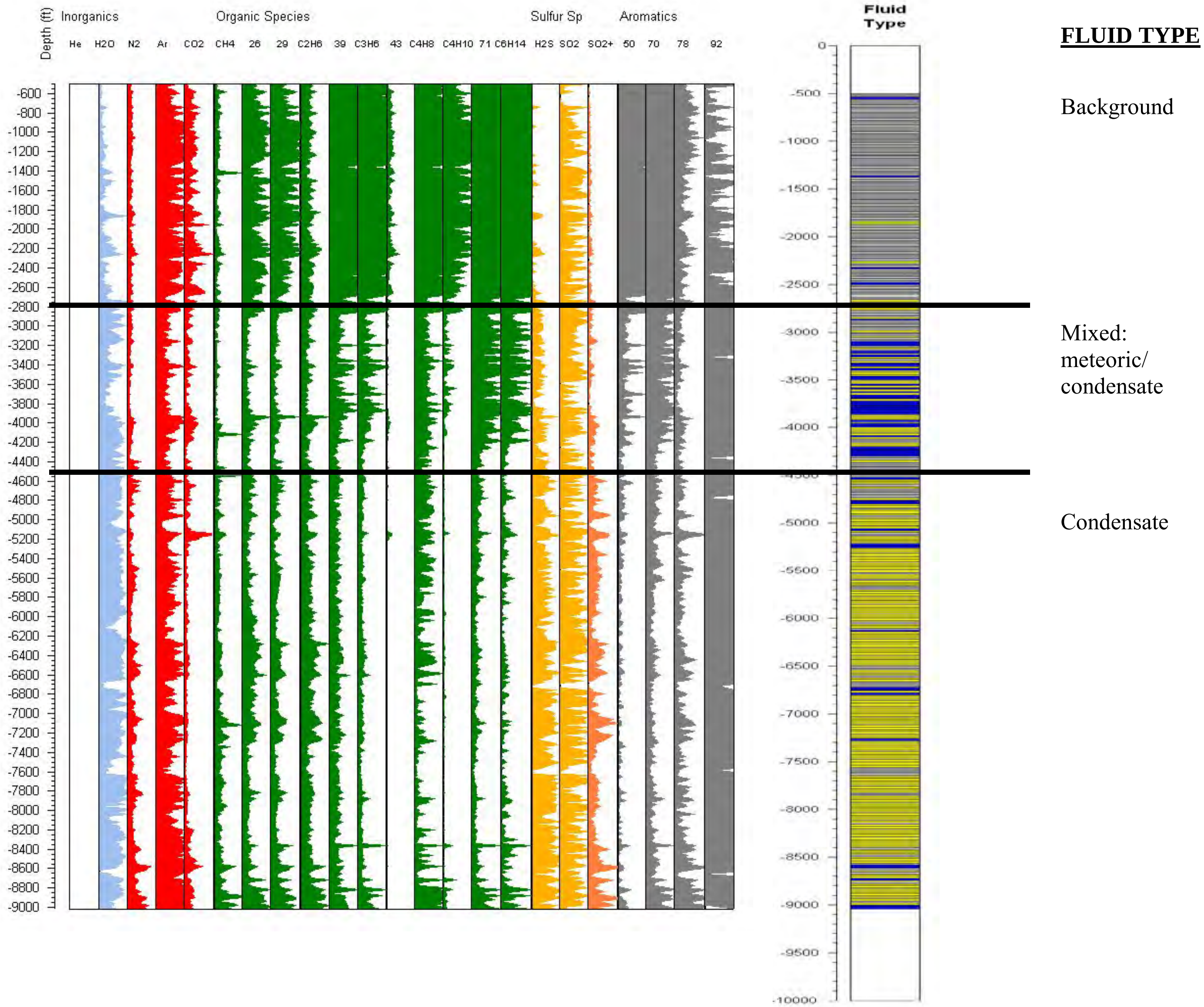


Figure 55. Interpreted fluid types for Well 67-17.

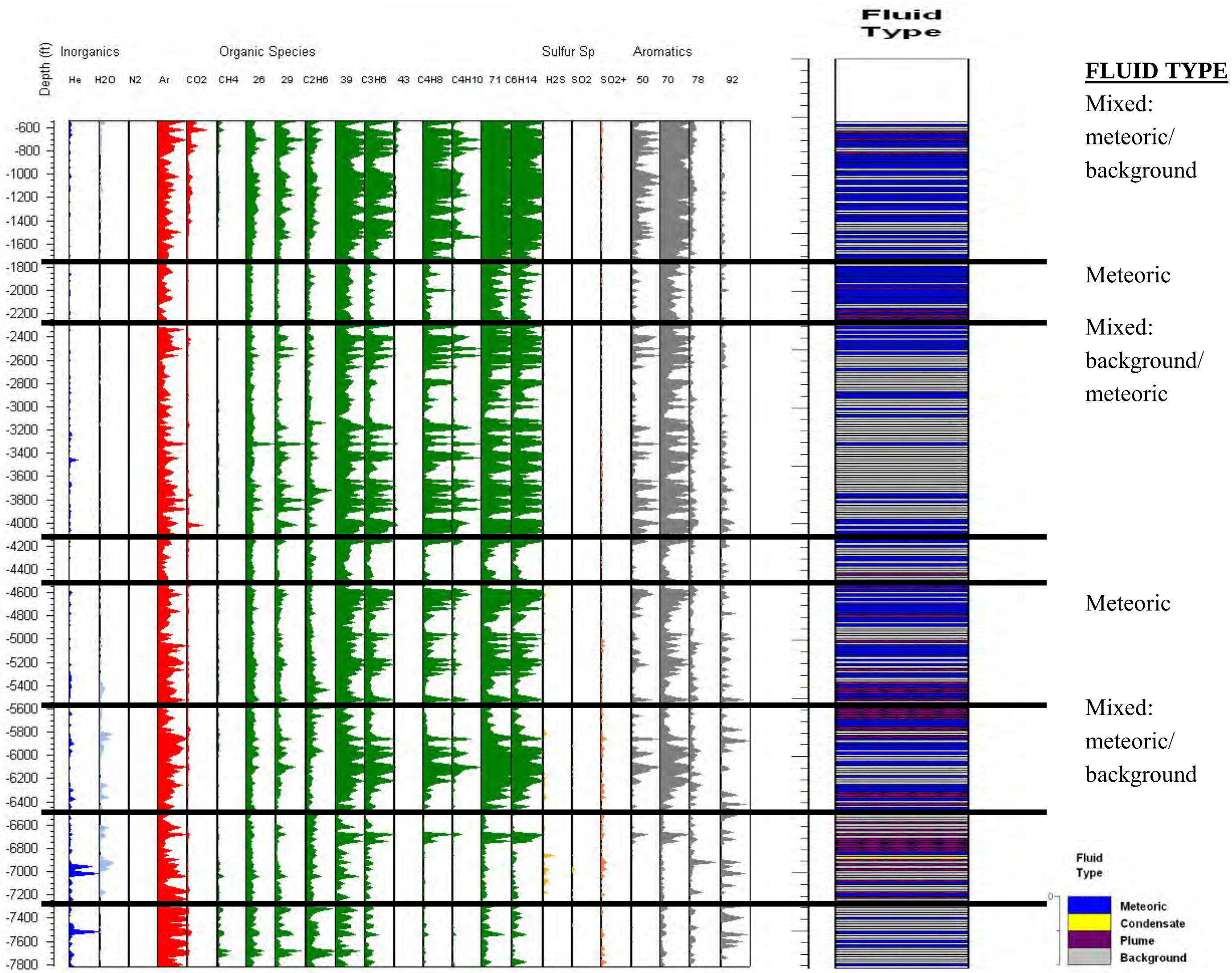


Figure 56. Interpreted fluid types for Well 84-30.

Well 38C-9 is located on the East Flank and is a 8 MW producer. Figure 53 presents the interpreted fluid types for this well. From the surface to approximately 7200 feet is a series of meteoric, condensate and mixed fluids. Background occurs from surface to about 800 feet; the logs in this zone are similar to the logs for Well 84-30. A mixed meteoric/reservoir zone occurs from 800 feet to about 4500 feet. The reservoir end member for this mixed fluid may be due to the high N_2/Ar ratio which suggest magmatic components but at this depth may be due to biogenic sources. Below 4500 feet the H_2S amount increases suggesting condensate fluids. There is a slight transition zone from 6600 to 7200 feet wherein the H_2S decreases, the CO_2 and N_2 amounts increase suggesting a mixed zone with reservoir fluids and meteoric fluids. Below 7200 feet, the mass spectra are interpreted as indicating reservoir fluids. Also note the general lack of organic compounds, and high N_2 and Ar peaks on the FIS log particularly below 7200 feet.

Figure 54 presents the logs for Well 51B-16. Well 51B-16 is a high enthalpy well and the fluid types indicate reservoir fluids at depth and mixed reservoir fluids throughout. Well 38C-9 also has similar fluids at depth. Background fluids occur between 4600 to 5200 feet and correspond to areas of little activity in the gas data except for argon.

Figure 55 presents the combined logs for Well 67-17 with interpreted fluid type. This well presents a series of background and mixed meteoric and condensate fluids. From the surface to about 2800 feet there is a zone interpreted as background. This zone is similar to Well 38C-9 from the surface to about 800 feet and occurs in Well 52-20 from 600 to about 3000 feet; in Well 67-17C to about 2000 feet; in Well 73-19 to about 2500 feet and throughout Well 84-30. There is a peak in the CO_2/CH_4 ratio and lack of water. This zone may represent a cap on the geothermal system where fluids can not move but gas (mainly CO_2) is present. The zone looks similar to Well 84-30 suggesting that this zone may represent the parent rock or background and not the geothermal system. CO_2/CH_4 ratio is high in the magmatic column to about 3000 feet and then decreases to barely there after 5500 feet. The crustal and condensate ratios below the background are high throughout the well indicating mixed fluids of condensate and meteoric which would be consistent with an injection well.

Figure 56 presents the combined logs for Well 84-30 the non-producer to the south of the field. The fluid log indicates that background and meteoric fluids occur throughout the majority of the well. These fluid types are consistent with a well that is non-producing and located on the margin or out of the field.

The routine developed worked well for interpreting fluid types in Coso and similar environments. The same routine was applied to the fields studied. The logs for select wells discussed below are presented in Appendix J.

9.2 High-Temperature Felsic Systems

Karaha

Although the overall mineral relationships suggest the rocks in T-2 and K-33 have undergone similar evolutions the fluid inclusion gases suggest there were significant differences in the geothermal environments at T-2 compared to K-33. Fluid inclusions in T-2 are characterized by higher N_2/Ar concentrations (commonly above 200) and CO_2/CH_4 ratios above 4. These ratios suggest the presence of a significant magmatic component in the inclusion fluids. Two different environments are suggested by the vein minerals whereas the bulk FIT data suggest a third environment developed in the wall rocks at depth. Both data sets indicate the trapping of a gas-poor fluid above 900 masl. Based on the occurrences of anhydrite and calcite and the fluid inclusion salinities and temperatures, the shallow fluid is interpreted to be steam condensate. The veins contain gas-rich inclusions to the total depth of the well, suggesting boiling and gas movement was occurring in these channels. In contrast, FIT analyses of inclusions from elevations below 600 masl indcate lower total gas concentrations than the two-phase fluid above, suggesting these inclusions trapped a degassed and boiled reservoir.

In contrast to T-2, the fluids in K-33 trapped a lower N_2/Ar fluid, K-33 inclusions are also generally less saline than inclusions in T-2. As in T-2, fluids above 200 masl have low gas contents. Veins in these rocks have deposited anhydrite and calcite, suggesting the fluids are downward percolating condensate. However, the relatively low N_2/Ar ratios and the fluid inclusion chemistry suggests the source of the condensate was meteoric water. At greater depths, the chemistry and gas contents indicate the presence of two-phase fluids. The organics are most likely the result of pyrolysis of organic matter in the lake bed deposits.

Figure 57 shows the FIS log for Well K33. Note the depth scale is in elevation in meters. At approximately 100 masl the H_2O increases as well as several other species including the organics, H_2S, and CO_2. A condensate fluid is interpreted from these increases followed by a meteoric fluid zone. Starting at approximately -200 masl, the condensate zone occurs to the depth of the well. Well K33 is known to have a steam zone starting at -200 masl (Figure 40). Figure 58 presents the FIS logs for Well T2. There are several zones in this well designated as reservoir fluids (purple). Well T2 occurs near the magmatic vapor chimney (Figure 12) and has hotter fluids than K33. The condensate zone also occurs at about 800 masl in Figure 58 and corresponds to the occurrence from other evidence in Figure 40.

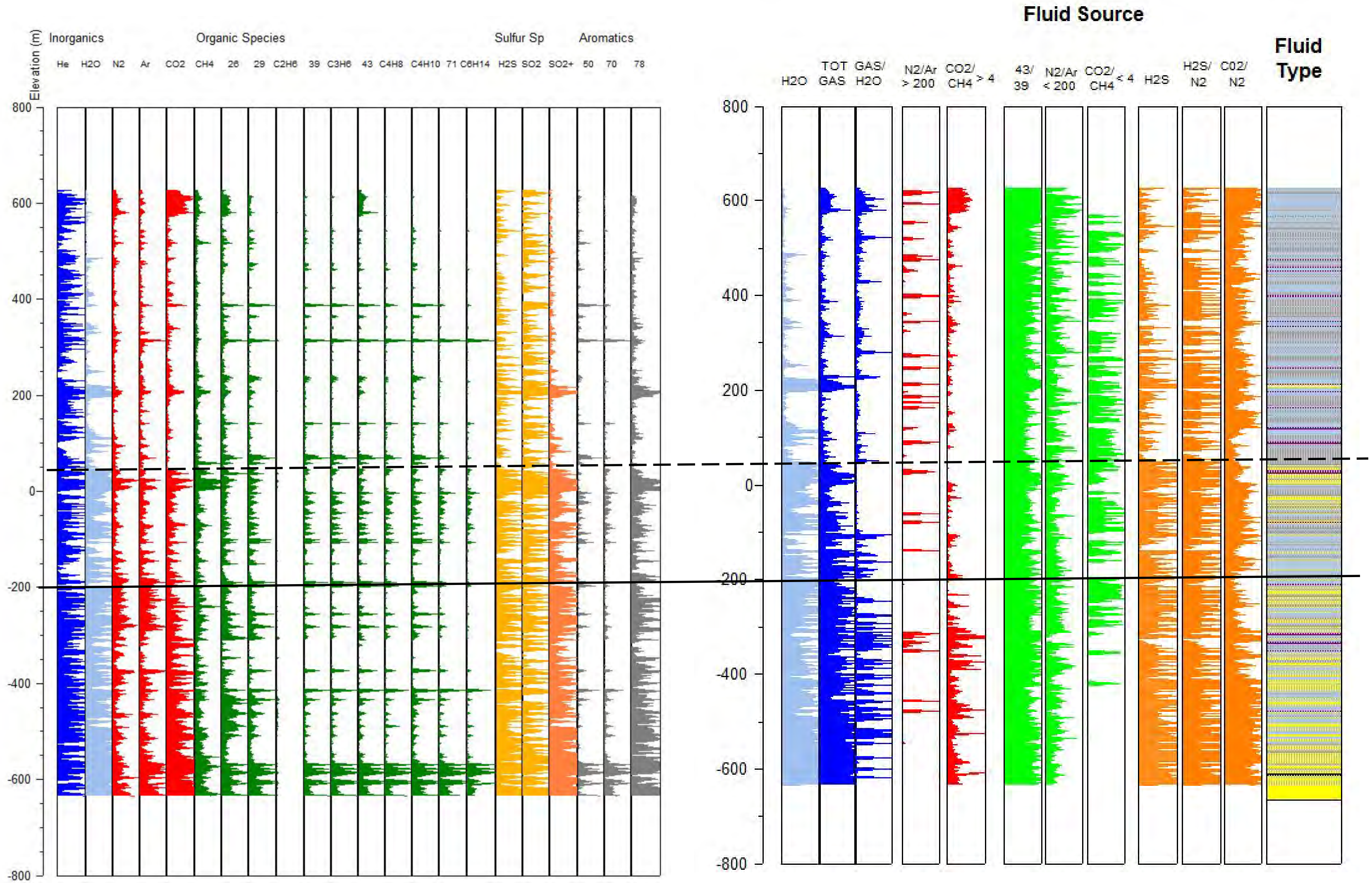


Figure 57. Fluid inclusion log for K33.

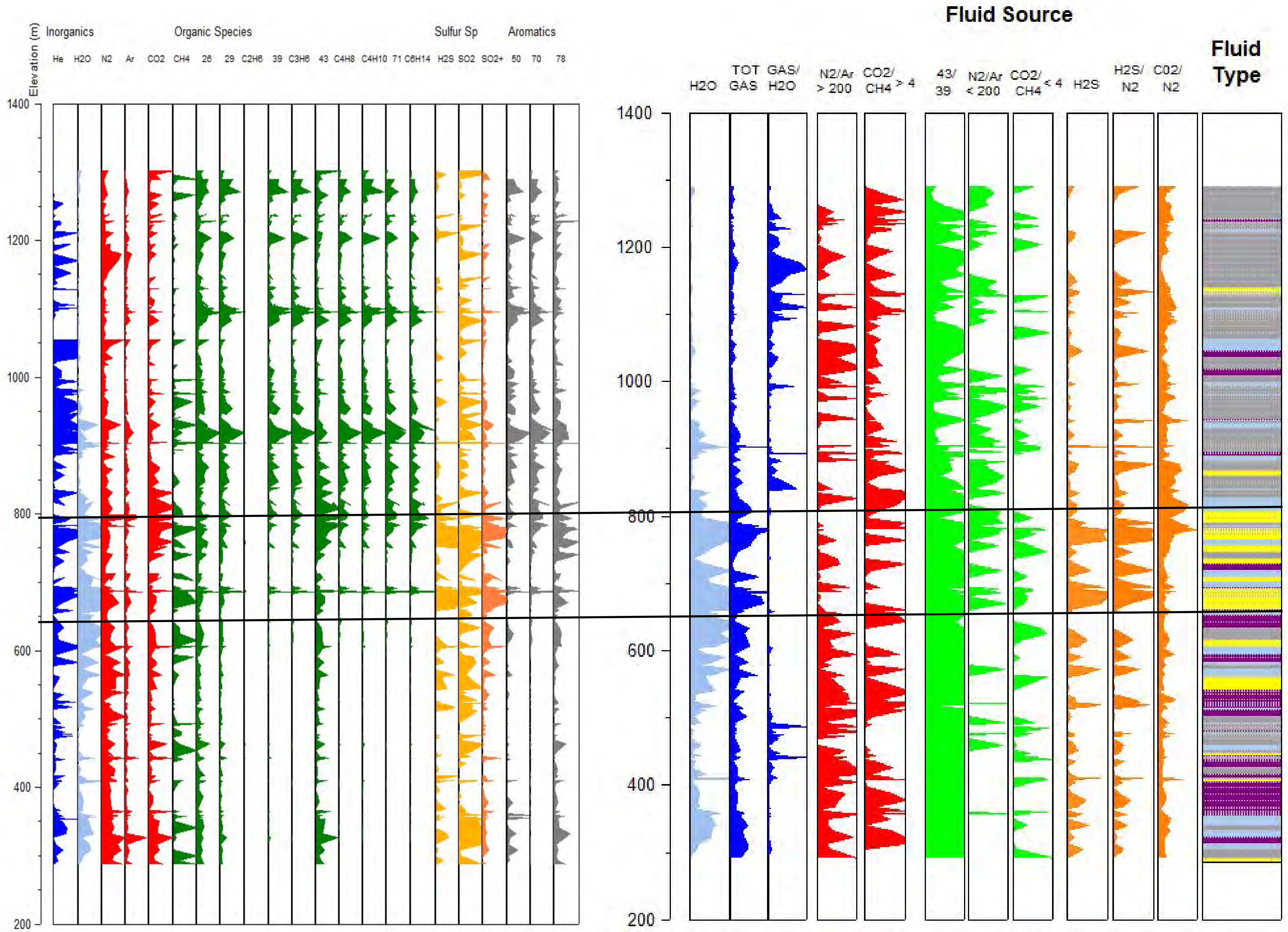


Figure 58. Fluid log for T2.

9.3 High-Temperature Basaltic Systems

The Puna system is a high-temperature basaltic system. Appendix J present the well logs and fluids types for each well as interpreted using the routine developed above. The routine indicates the fluids in each well are predominately meteoric with some minor condensate and background fluids. As discussed in Section 4.1.8 recharge to the system is from cold meteoric and saline waters and also from hydrothermally altered meteoric and saline waters. The fluid inclusion gas analysis only indicate meteoric fluids and would not be able to distinguish saline waters. In Well SOH#1 there is a band of organics from 3,800 feet to about 4,400 feet which is labeled as background fluids and may represent cold meteoric fluids There is also a band of organics from about 5,200 to 5,800 feet in Well SOH#4.

Thin condensate zones are noted to occur in Wells SOH#2 and SOH #4 which are both hotter than Well SOH #1. Well SOH#1 reaches temperatures of only about 300 to 330 F while SOH#2 and SOH #4 are above 450 to 500 F. Condensate could occur in these two wells and at the depths noted on the fluid logs.

Although the majority of species analyzed are low when compared to some of the felsic systems, the routine developed appears to produce fluids which can be explained in the context of the geothermal system. The fluid types are based on comparison of above average concentrations for each particular field as opposed to absolute numbers and therefore are applicable to fields where the species concentrations are low compared to other fields.

9.4 Sedimentary Systems

Fluid logs were developed for Salton Sea Wells Sinclair 24 and Elmore 12 and 16 and presented in Appendix J. Elmore 16 is a high temperature well. Much of the fluids in this well are classified as condensate due to the presences of hydrogen sulfide. However, condensate is not present in the Salton Sea. Hydrogen sulfide may be a byproduct of the organics and failed petroleum reserve and therefore may not be due to the geothermal system. Elmore 16 below about 5,000 feet encountered three zones of rhyolite and these can be seen on the fluid logs where water is present. Reservoir fluids are also indicated particularly from about 4,000 feet to 4,600 feet and then again from about 5,200 feet to about 5,800 feet.

Sinclair 24 fluid logs indicate a thick sulfide zone encountered from about 5,600 feet to the depth of the samples at 7,200 feet. Water, helium, CO_2, a number of organics, and H_2S all have peaks in the concentration in this zone. There is also a thin band of reservoir fluids at approximately 6,800 feet. This is indicated by the N_2/Ar ratio and CO_2/CH_4 ratios having small peaks along with presence of H_2O and high total gas.

Elmore 12 is comprised of mainly meteoric and background fluids with condensate fluids present at depth. This well does not have large peaks in the organics except for Mass 43 above 5,000 feet and large peaks in H_2O, H_2S, N_2, and CO_2 at depth below 6,000 feet.

9.5 Basin & Range Systems

Two wells, 57-13 and 77-13, were provided for analysis. Well 77-13 is a large producer at Beowawe. Temperatures range up to 200°C (392°F). Well 77-13 penetrates a fault at approximately 5500 feet and again at about 8000 feet. Well 57-13 was drilled in December 2005. The purpose of the well was to intersect the fault. The well was drilled to 10,600 feet, and it was unknown from the drilling logs if the fault was intersected. Bulk analysis of the drill cuttings fluid inclusions was conducted to determine if the fault could be recognized. At the time of the analysis, the drill rig was idling on-site costing the company thousands of dollars a day in downtime. The analysis took approximately four days and was used to determine if drilling should continue or if the well should be completed for production. Figures 57 and 58 present the results.

Well 77-13

Beowawe is in the Basin and Range province of Nevada and has a series of metasediments that infill the basin. The production temperatures are about 140°C (284°F) and production is from the highly fracture crystalline rocks. Well 77-13 indicates three main zones: a surface system zone, a major fracture with meteoric fluid signature, and a producing zone. The fault in this well, between about 5500 and 8000 feet, is approximately indicated by the major fracture zone with the meteoric fluid signature. Below this is the producing zone. The presence of water in the fluid inclusion data at about 7000 feet indicates a crystalline rock rather than metasediments.

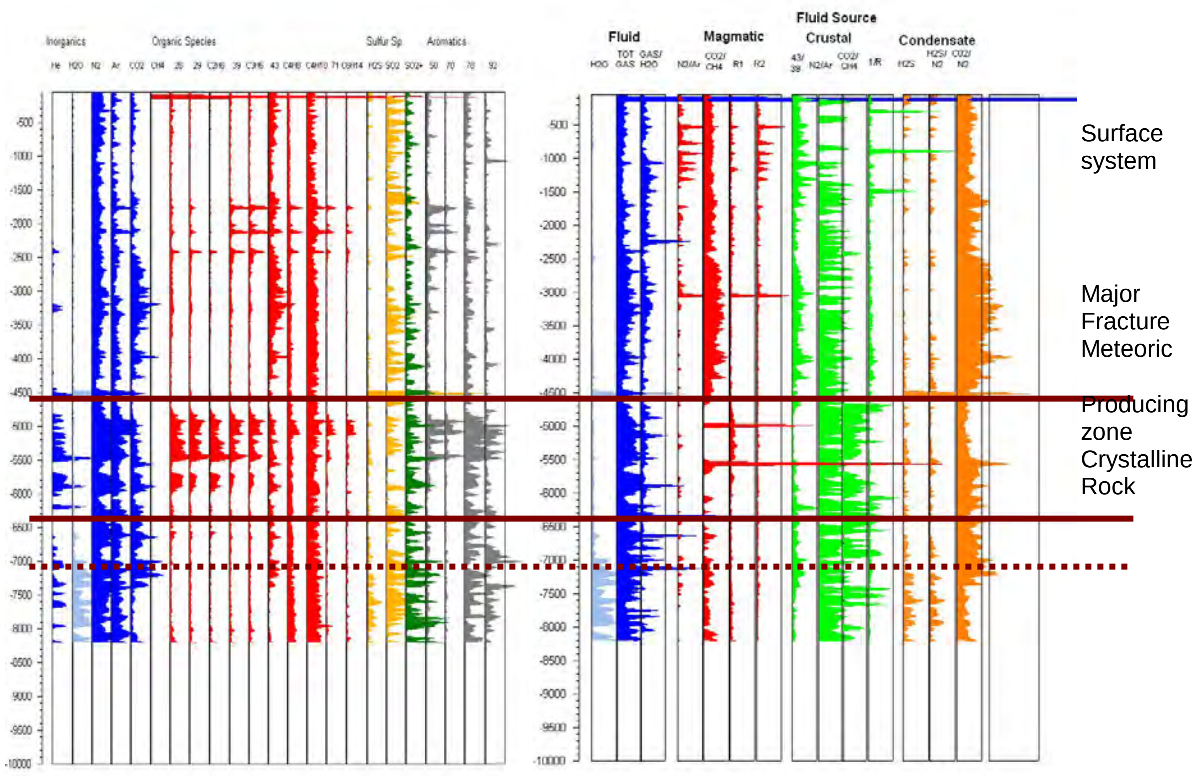


Figure 57: FIS logs for Beowawe 77-13.

Well 57-13

Comparing the logs for Well 57-13 with those developed for Well 77-13 there are similar zones including the major fracture zone with a meteoric signature and a producing zone that has a high water value. This would indicate that the fault was encountered in this well from about 5100 feet to about 6700 feet and that the producing zone is below this fracture zone.

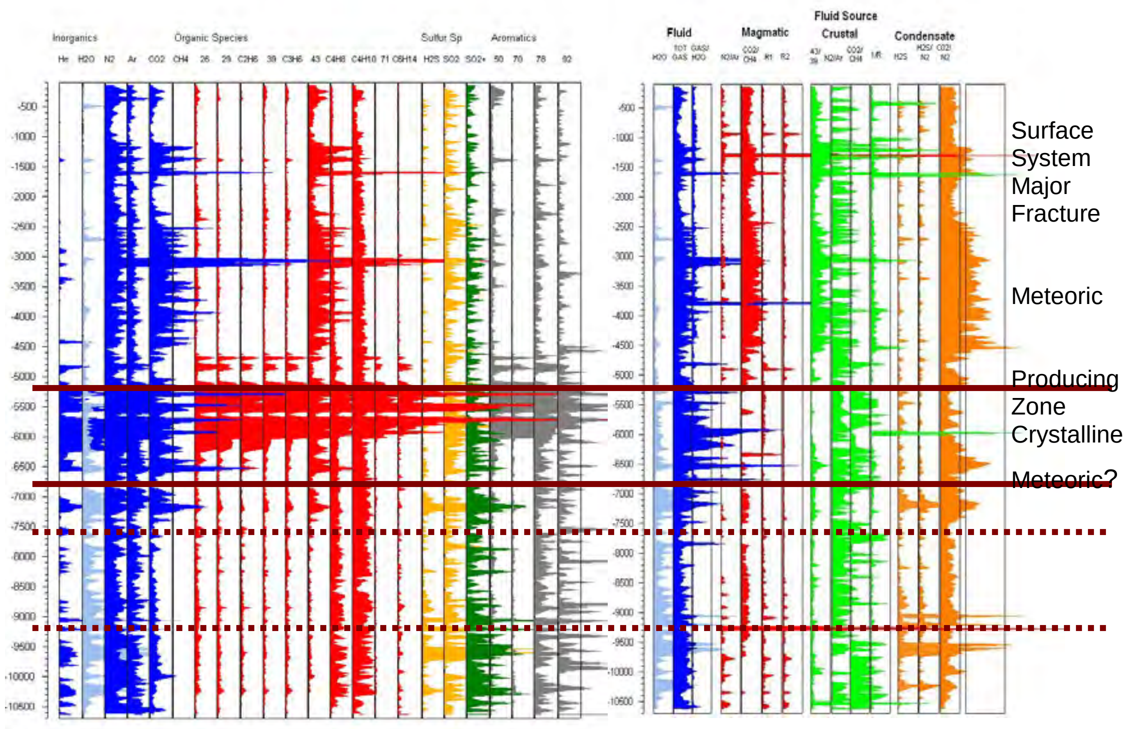


Figure 58: FIS log for Beowawe 57-13.

Although not much information was provided by the geologist at Beowawe regarding depth of the production zone, stratigraphy, or fluid types, the FIS logs presented for both wells analyzed indicate major zones and can be used to assist in well development. Based on the FIS analysis it was determined that Well 57-13 had penetrated the production zone and drilling was stopped. Production was expected, however the fluid flow necessary for production was not encountered

9.6 Low-Temperature Systems:

The low-temperature resources studied included Fallon, Hawthorne, El Centro. Select logs are presented in Appendix J. For Fallon Well CL82-36 the top of the well to about 5,400 feet in depth there is an upper zone characterized by a lack of water and only occasional peaks in the inorganic, organic and aromatic species. Below about 5,400 feet there are multiple peaks in many of the species indicating above average concentrations in those species. The FIS log for CL84-31 is mainly characterized by a similar upper zone to the same depth of 5,400 feet. The other two wells have the same upper zone occurring to depths of approximately 5,500 feet in CL82-36 and 6,950 feet in FOH3. This upper zone corresponds to the sediments and Tertiary andesites whereas the lower zone represents the siliceous volcaniclasitic rocks (tuffs) and andesites. Two of the wells, FLTH 88-24 and FDU-2D are different. There is water in the upper zone of FLTH 88-24 and throughout FDU-2D. FLTH 88-24 does not show high concentrations of many of the chemical species. Water occurs to a depth of about 1600 feet in FLTH 88-24. FDU-2D has concentrations of inorganic, organic, sulfur, and aromatic species throughout the well and is similar to the lower portions of FOH3 and 82-36. In FOH3 and CL82-36, metamorphic and intrusive rocks occur above the tuffs and andesites. This suggests that there may be a fault at these depths or dikes intruded into this material. The presence of a stronger FIS signature in the underlying andesites and tuffs as opposed to the upper andesites further suggest that a fault may be present allowing fluid flow in the bottom layers.

The FIS logs for the three wells at Hawthorne are dominated by meteoric fluid signatures. All four fluid types occur in the wells, however, reservoir fluids do not occur in HAD#2. They occur only as thin zones in the other two wells. The sulfide-rich fluids mostly occur in thin zones. HAD#1 is characterized by background and meteoric fluids. The thin layers of reservoir fluids in this well may indicate veins or areas of increased alteration. The majority of fluid types in HAD#2 is meteoric. Background and sulfide-rich fluid types also occur. There is a significant break in the gas chemistry at approximately 800 feet, which corresponds to the change in lithology from sediments to igneous bedrock. The inorganic species, CO_2, Ar, N_2, H_2O, and the sulfur species all decrease in concentration at this depth. Argon and N_2 still have high concentrations but show variability throughout the depth of the well. The majority of rock types encountered in HAD #3 consist of alluvium to a depth of about 3,500 feet. The fluid inclusion gas analyses reflect this in the high concentrations of organic species. At approximately 3,275 feet the concentrations of many of the species decrease dramatically, particularly H_2O, CO_2, and sulfur species.

The FIS logs for Superstition Mountain are dominated by meteoric fluid signatures. Sulfide-rich fluids occur in all of the wells. NAFEC 1 is characterized by background and meteoric fluids. Sulfide-rich fluids also occurs throughout. There is a portion of the well from 400 to 650 feet and from approximately 1,000 feet to 2,100 feet where there are fluid inclusions that contain no H_2O, minimal organic species, and generally have low concentrations of many of the species except for the sulfide species, CO_2, N_2, Ar and aromatics. This zone was interpreted as meteoric fluids. The lack of H_2O suggests that there may not be many inclusions. The other zones in the well are classified as sulfide-rich fluids and background fluids. The majority of fluid types in NAFEC 2 are meteoric with a thick zone of sulfide-rich fluids between 1,000 and 1,700 feet. Basalt was intersected in this well just below 1,700 feet. There are three zones in NAFEC 3 that have H_2O present: a sedimentary breccia zone from 600-1,000 feet, and two zones within the fractured granites from 1,400-1,650 feet and below 2,300 feet to the total depth of the well. There is a high concentration of CO_2 near the top of the well. The majority of fluid inclusions in this well are vapor-rich outside the zones that contain H_2O. The fluids are categorized as sulfide-rich and meteoric fluids. The break occurs at approximately 2,300 feet on the FIS log where H_2O is present. Petrography showed a change from siltstone to sandstone and evidence of shearing.

9.7 Refinement

When the methodology developed is applied to the various geothermal systems, the designation of condensate fluid is problematic. The methodology determines the meteoric and reservoir fluid types with regularity across the various fields. Condensate fluid is based on boiling and as discussed in Section 6 trying to determine boiling is difficult. Boiling is not evident in the low-temperature systems and in Salton Sea. Although temperatures are high enough in Salton Sea, the salinity of the fluids inhibit boiling. A refinement to the methodology presented would be to first determine if boiling is present and hence condensate fluids. The flow chart developed in Figure 59 presents this refinement.

In addition, tops of wells and margins determination are presented in the flow chart. Permeability evaluation is also presented.

Geothermal systems have a relatively narrow band of pressures and temperatures which control the chemistry of the fluids and gases observed. Within this band of pressures and temperatures and to a certain extent geology, select fluid-rock interactions can occur. A geothermal system is overprinted on the existing rocks. We see in the fluid gas chemistry that in the interior of systems, there is a defined chemistry and low variability, while on the outside of the system or periphery of the systems, the fluid inclusion gas chemistry is more variable and related to the rock types. In lower temperature systems, the fluid inclusions that occur do not have this overprinting of the active geothermal system and therefore, this approach indicates meteoric fluids and does not indicated lower temperature fluids that still may be economically viable for development.

For the top of the system, a routine was set up with IF/Then statements to determine if the two ratios were both above or below the average and then compared. If both ratios were trending the same way then a zero was placed at the depth. When not trending in the same direction, a 1 was placed at the depth in the spreadsheet. The depth when 3 consecutive 1's appeared was considered the top of the system. If additional depths had 0's below this depth, this was considered cold water entrances. The routine for permeability as explained in Section 7.4 was applied.

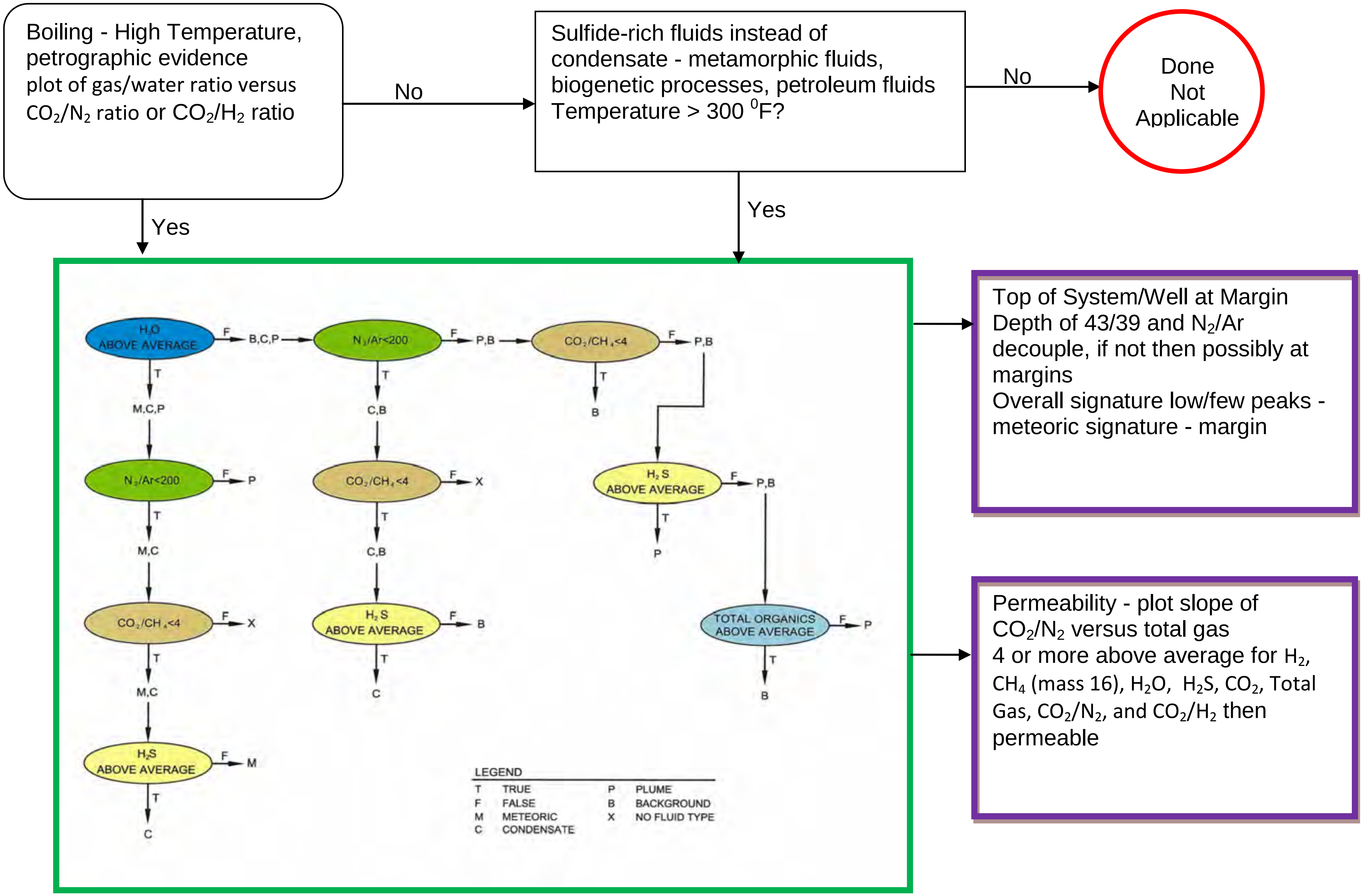


Figure 59: Refined flow chart for determining fluid type, permeability, and top of the system.

10.0 CONCLUSIONS

1. Bulk fluid inclusion data displayed systematic trends that reflect the effects of mixing, boiling, and condensation.
2. Bulk fluid inclusion analysis can be utilized to determine fluid types (e.g. meteoric, magmatic, evolved waters).
3. Alkane/Alkene ratios can be used to qualitatively characterize the degree of oxidation of the fluid.
4. The bulk data can be used to evaluate relative temperatures.
5. In high temperature (>300 F) geothermal systems there does not appear to be correlation between rock type and fluid inclusion gas chemistry.
6. In low temperature (<300 F) geothermal systems there does appear to be some correlation between rock type and fluid inclusion gas chemistry.
7. Vein mineralogy has some correlation with fluid inclusion gas chemistry across all systems.
8. High temperature systems in granitic/continental settings have higher average values for several species and ratios than systems in basaltic geological settings.
9. There is a narrow range of concentrations of species in fluid inclusions from geothermal systems that reflect the unique geological environment of geothermal systems.
10. Minor overall correlation between select gas ratios and temperature occurs field wide but not with individual wells. Hotter wells tend to have a more robust fluid inclusion gas signature whereas lower temperature wells have an overall suppressed fluid inclusion gas signature.
11. Select ratios correspond to permeability in a well. The slope of CO_2/N_2 versus total gas indicates boiling occurring in open systems which occurs in fractures.
12. Statistically select species have a higher average concentration in fractures than in non-fractures.
13. Fluids (meteoric, condensate, and reservoir) can be interpreted from the abundance of select fluid inclusion gas species and ratios.
14. Margins and caps of a geothermal system can be interpreted from the N_2/Ar and 43/39 relative percentages and if these two ratios parallel each other in abundance.
15. Methodology for identifying fluid types is based on above average concentrations per field of select fluid inclusion gases.
16. Lower overall temperature systems (<300 F) do not sufficiently overprint the existing fluid inclusions in the rock package to record the geothermal system.
17. A refinement to the methodology is necessary to determine if boiling has occurred in the system prior to applying the rules for identifying fluid types.
18. Fluid inclusions in hot, active systems with large fluid fluxes, can provide a record of recent conditions.

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APPENDIX A
DATA QUALITY TABLES

El Centro Well NAFEC 1

El Centro NAFEC-1					
Sample	min	max	avg	std dev	n
AMU2	0.25	52.02	18.56	16.66	9.00
AMU3	5.60	124.62	49.98	39.94	9.00
AMU4	7.66	200.00	95.84	78.52	9.00
AMU14	2.20	66.98	30.38	25.02	9.00
AMU15	4.91	96.53	34.81	30.97	9.00
AMU16	7.38	100.00	38.63	27.63	9.00
AMU18	4.89	193.79	55.93	62.09	9.00
AMU28	1.63	96.98	32.87	31.50	9.00
AMU30	0.82	68.97	34.54	21.30	9.00
AMU34	0.00	200.00	115.10	81.72	9.00
AMU39	0.76	57.78	24.28	21.03	9.00
AMU40	10.98	120.28	52.45	39.31	9.00
AMU43	2.79	84.06	25.87	24.34	9.00
AMU44	3.51	71.63	29.24	21.18	9.00
AMU48	0.00	200.00	121.70	86.02	9.00
AMU50	3.95	200.00	106.31	77.04	9.00
AMU56	12.67	106.76	33.50	34.18	9.00
AMU58	5.16	125.28	43.00	43.83	9.00
AMU64	0.00	200.00	70.52	84.22	9.00
AMU70	5.59	99.29	30.62	29.76	9.00
AMU86	0.50	73.83	30.12	27.15	9.00
AMU92	63.90	200.00	153.45	61.11	9.00

El Centro Well NAFEC 3

El Centro NAFEC-3					
Sample	min	max	avg	std dev	n
AMU2	0.25	52.02	19.30	19.67	5.00
AMU3	5.60	124.62	45.83	48.05	5.00
AMU4	7.66	200.00	78.21	78.92	5.00
AMU14	2.20	66.98	26.72	25.26	5.00
AMU15	4.91	96.53	35.24	36.68	5.00
AMU16	7.38	100.00	36.53	37.81	5.00
AMU18	4.89	193.79	65.14	76.53	5.00
AMU28	1.63	96.98	34.40	37.57	5.00
AMU30	0.82	68.97	26.93	26.74	5.00
AMU34	0.00	200.00	81.17	82.26	5.00
AMU39	0.76	57.78	22.57	21.82	5.00
AMU40	9.00	120.28	46.40	45.27	5.00
AMU43	2.79	84.06	29.21	32.21	5.00
AMU44	3.51	71.63	26.91	26.96	5.00
AMU48	0.00	200.00	83.35	83.01	5.00
AMU50	3.95	200.00	79.26	80.50	5.00
AMU56	9.00	106.76	39.22	39.49	5.00
AMU58	5.16	125.28	45.25	48.30	5.00
AMU64	0.00	200.00	72.75	80.13	5.00
AMU70	5.59	99.29	34.85	37.81	5.00
AMU86	0.50	73.83	28.12	28.39	5.00
AMU92	9.00	200.00	97.49	77.33	5.00

El Centro Well NAFEC 11

El Centro NAFEC-11					
Sample	min	max	avg	std dev	n
AMU2	0.25	52.02	19.27	18.81	10.00
AMU3	5.00	124.62	45.82	45.62	10.00
AMU4	5.00	200.00	76.08	74.56	10.00
AMU14	2.20	66.98	25.97	24.14	10.00
AMU15	4.91	96.53	35.46	34.92	10.00
AMU16	5.00	100.00	36.94	35.89	10.00
AMU18	4.89	193.79	67.10	72.51	10.00
AMU28	1.63	96.98	34.75	35.76	10.00
AMU30	0.82	68.97	26.31	25.36	10.00
AMU34	0.00	200.00	77.43	77.06	10.00
AMU39	0.76	57.78	22.08	20.89	10.00
AMU40	5.00	120.28	45.80	43.16	10.00
AMU43	2.79	84.06	29.93	30.63	10.00
AMU44	3.51	71.63	26.86	25.68	10.00
AMU48	0.00	200.00	78.81	77.49	10.00
AMU50	3.95	200.00	76.50	75.73	10.00
AMU56	5.00	106.76	39.56	37.83	10.00
AMU58	5.00	125.28	45.53	45.92	10.00
AMU64	0.00	200.00	72.16	75.87	10.00
AMU70	5.00	99.29	35.68	35.93	10.00
AMU86	0.50	73.83	27.64	27.10	10.00
AMU92	5.00	200.00	87.63	74.72	10.00

Fallon Well FOH3

	min	max	avg	std dev	n
AMU2	0.57	79.63	15.03	15.68	39.00
AMU4	0.00	200.00	84.01	96.94	39.00
AMU14	1.02	85.09	22.35	20.77	39.00
AMU15	0.45	90.70	25.16	19.91	39.00
AMU16	0.07	200.00	27.28	42.97	39.00
AMU18	1.04	147.51	55.91	40.78	39.00
AMU28	0.77	98.25	22.11	21.80	39.00
AMU30	0.00	200.00	58.12	59.62	39.00
AMU34	0.00	200.00	115.63	85.79	39.00
AMU39	0.68	96.35	17.13	18.98	39.00
AMU40	0.49	200.00	60.04	54.21	39.00
AMU43	2.42	80.82	21.10	16.82	39.00
AMU44	0.94	61.91	15.78	12.97	39.00
AMU48	0.00	200.00	127.55	90.56	39.00
AMU50	0.12	199.45	62.31	60.94	39.00
AMU56	0.27	158.34	46.57	37.48	39.00
AMU58	0.24	177.55	52.41	47.76	39.00
AMU64	0.00	200.00	118.75	80.75	39.00
AMU70	0.37	72.06	20.10	19.22	39.00
AMU78	0.17	121.75	34.41	29.72	39.00
AMU86	4.97	200.00	78.19	68.23	39.00
AMU92	0.00	200.00	119.63	85.83	39.00

Fallon Well Carson Lake 82-36

	min	max	avg	std dev	n
AMU2	0.07	59.82	9.47	12.54	25.00
AMU4	0.00	200.00	80.77	94.32	25.00
AMU14	0.21	79.45	23.18	20.99	25.00
AMU15	0.09	87.61	20.09	22.37	25.00
AMU16	0.34	183.34	24.69	36.71	25.00
AMU18	0.40	200.00	52.27	51.40	25.00
AMU28	0.58	118.72	26.41	32.87	25.00
AMU30	0.42	200.00	51.84	58.92	25.00
AMU34	0.00	200.00	113.08	87.09	25.00
AMU39	0.01	158.25	29.58	38.25	25.00
AMU40	0.00	200.00	61.71	56.70	25.00
AMU43	2.83	57.53	19.22	13.10	25.00
AMU44	0.12	50.48	18.03	13.79	25.00
AMU48	0.00	200.00	105.66	87.49	25.00
AMU50	0.00	200.00	62.96	71.50	25.00
AMU56	0.00	200.00	54.38	52.55	25.00
AMU58	0.12	146.49	48.83	42.20	25.00
AMU64	0.00	200.00	79.42	73.27	25.00
AMU70	0.28	89.10	22.24	20.99	25.00
AMU78	3.86	200.00	58.80	62.18	25.00
AMU86	0.00	200.00	74.28	68.60	25.00
AMU92	0.00	200.00	124.66	88.55	25.00

Fallon Well Carson Lake 84-31

	min	max	avg	std dev	n
AMU2	1.80	31.25	11.85	8.97	10.00
AMU4	0.00	200.00	40.02	84.32	10.00
AMU14	0.40	84.08	28.25	24.75	10.00
AMU15	3.42	99.40	27.74	28.35	10.00
AMU16	2.08	39.17	21.87	14.40	10.00
AMU18	8.37	152.26	82.17	47.20	10.00
AMU28	0.16	80.25	25.08	25.10	10.00
AMU30	0.00	200.00	63.97	67.73	10.00
AMU34	0.00	200.00	97.27	82.00	10.00
AMU39	1.03	97.93	20.79	28.90	10.00
AMU40	2.94	166.84	64.91	50.27	10.00
AMU43	1.98	40.91	17.81	12.20	10.00
AMU44	2.21	25.87	12.71	8.95	10.00
AMU48	0.00	200.00	93.63	85.07	10.00
AMU50	0.12	200.00	56.08	68.07	10.00
AMU56	2.55	130.11	42.76	38.78	10.00
AMU58	3.96	139.56	48.42	45.44	10.00
AMU64	37.67	200.00	139.90	67.35	10.00
AMU70	3.47	68.06	26.44	20.52	10.00
AMU78	4.22	141.01	49.89	39.42	10.00
AMU86	7.87	200.00	109.59	82.44	10.00
AMU92	4.82	200.00	143.83	76.58	10.00

Hawthorne Well HAD#1

Well HAD #1					
Sample	min	max	avg	std dev	n
AMU2	2.92	23.96	9.30	6.57	15.00
AMU4	9.54	200.00	77.46	67.69	15.00
AMU14	1.83	47.63	13.65	15.76	15.00
AMU15	2.42	62.07	15.20	14.40	15.00
AMU16	3.29	46.37	18.76	12.52	15.00
AMU18	0.39	87.59	24.56	25.58	15.00
AMU28	1.27	70.17	19.42	21.01	15.00
AMU30	0.14	104.84	19.74	25.31	15.00
AMU34	4.68	200.00	88.54	76.66	15.00
AMU39	1.50	52.00	18.88	15.86	15.00
AMU40	0.57	128.03	27.45	36.72	15.00
AMU43	3.38	49.93	19.94	14.68	15.00
AMU44	3.02	50.93	19.38	14.93	15.00
AMU48	0.00	200.00	66.07	68.40	15.00
AMU50	1.47	200.00	70.23	54.91	15.00
AMU56	0.22	45.11	21.97	15.02	15.00
AMU58	2.72	72.87	29.78	20.01	15.00
AMU64	4.23	200.00	46.95	53.97	15.00
AMU70	3.87	33.74	19.00	8.89	15.00
AMU78	5.98	76.60	32.28	23.72	15.00
AMU86	0.49	64.33	24.46	17.92	15.00
AMU92	4.25	200.00	73.98	58.36	15.00

Hawthorne Well HWAAD#2

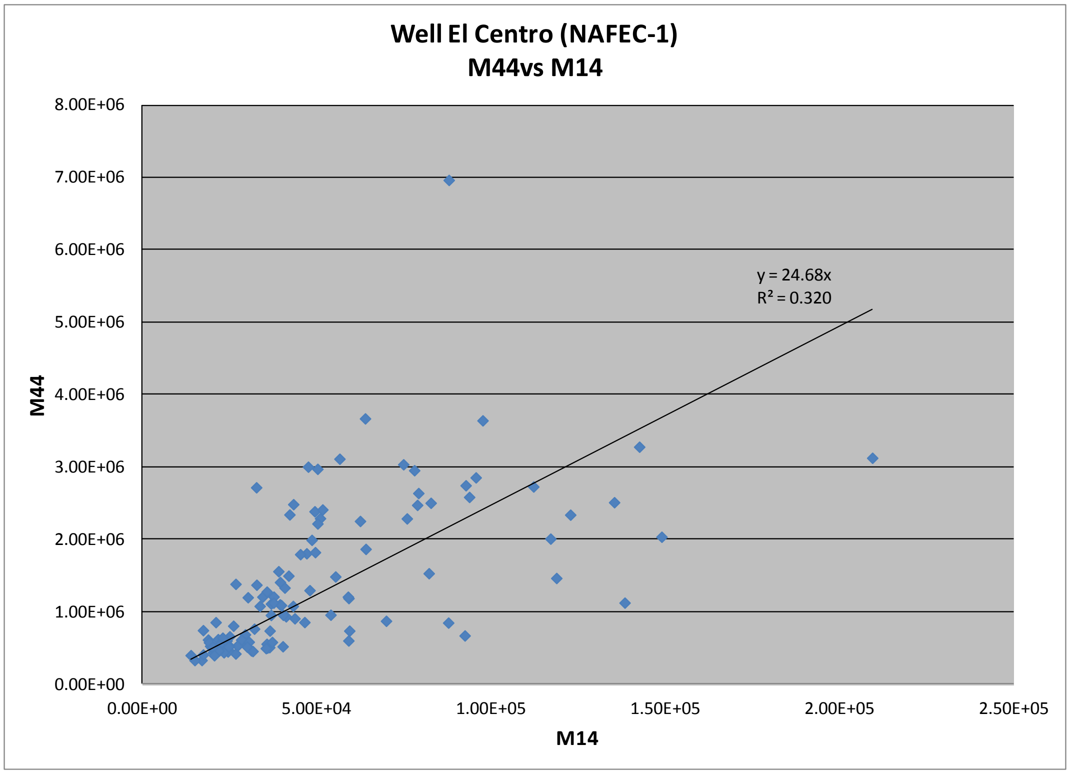
Well HWAAD #2					
Sample	min	Max	avg	std dev	n
AMU2	2.50	34.89	14.30	9.09	22.00
AMU4	0.00	200.00	119.85	81.97	22.00
AMU14	0.61	39.14	16.58	11.40	22.00
AMU15	0.35	82.79	23.88	19.78	22.00
AMU16	3.41	96.23	21.53	21.20	22.00
AMU18	2.78	102.52	42.06	33.60	22.00
AMU28	1.76	55.53	21.24	16.10	22.00
AMU30	2.89	70.32	28.81	17.67	22.00
AMU34	0.00	200.00	107.33	84.81	22.00
AMU39	1.11	114.53	35.01	34.12	22.00
AMU40	2.49	163.61	28.93	37.93	22.00
AMU43	1.16	125.65	34.06	30.53	22.00
AMU44	2.78	86.51	30.77	22.68	22.00
AMU48	0.00	200.00	125.88	83.33	22.00
AMU50	0.07	200.00	103.38	88.78	22.00
AMU56	0.15	200.00	57.54	50.54	22.00
AMU58	0.05	121.30	57.91	40.62	22.00
AMU64	0.00	200.00	97.22	74.78	22.00
AMU70	0.05	88.47	38.20	26.97	22.00
AMU78	3.16	200.00	62.29	48.89	22.00
AMU86	4.74	105.21	43.89	27.90	22.00
AMU92	0.00	200.00	123.79	80.11	22.00

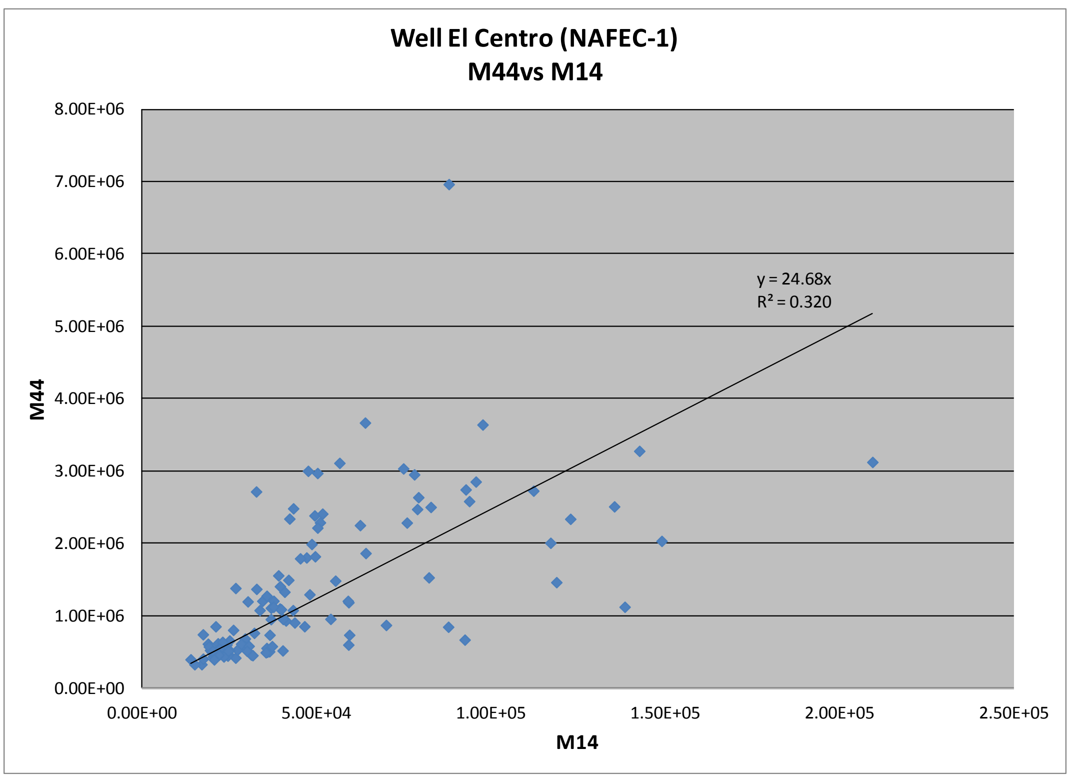
Hawthorne Well HWAAD#3

Well HWAAD #3					
Sample	min	max	avg	std dev	n
AMU2	0.32	24.32	8.23	6.70	20.00
AMU4	4.82	200.00	88.75	67.24	20.00
AMU14	0.48	48.65	14.11	12.34	20.00
AMU15	1.32	58.96	15.42	13.53	20.00
AMU16	0.05	61.10	19.01	17.73	20.00
AMU18	0.07	116.26	30.59	28.60	20.00
AMU28	0.30	134.75	22.23	29.62	20.00
AMU30	0.58	33.02	16.16	11.46	20.00
AMU34	0.00	200.00	101.73	71.21	20.00
AMU39	1.73	122.43	23.37	26.19	20.00
AMU40	2.87	200.00	46.77	60.44	20.00
AMU43	0.74	73.97	26.64	18.99	20.00
AMU44	0.44	79.58	32.02	22.24	20.00
AMU48	0.00	200.00	103.47	76.52	20.00
AMU50	0.17	146.56	48.58	47.61	20.00
AMU56	1.26	50.92	18.82	13.77	20.00
AMU58	0.16	92.19	36.52	26.94	20.00
AMU64	2.47	200.00	54.08	53.20	20.00
AMU70	2.94	38.44	18.64	11.86	20.00
AMU78	0.92	153.90	49.16	39.97	20.00
AMU86	2.57	51.23	19.79	15.67	20.00
AMU92	0.00	200.00	105.47	86.05	20.00

APPENDIX B
FRACTIONATION PLOTS

El Centro Well NAFEC-1





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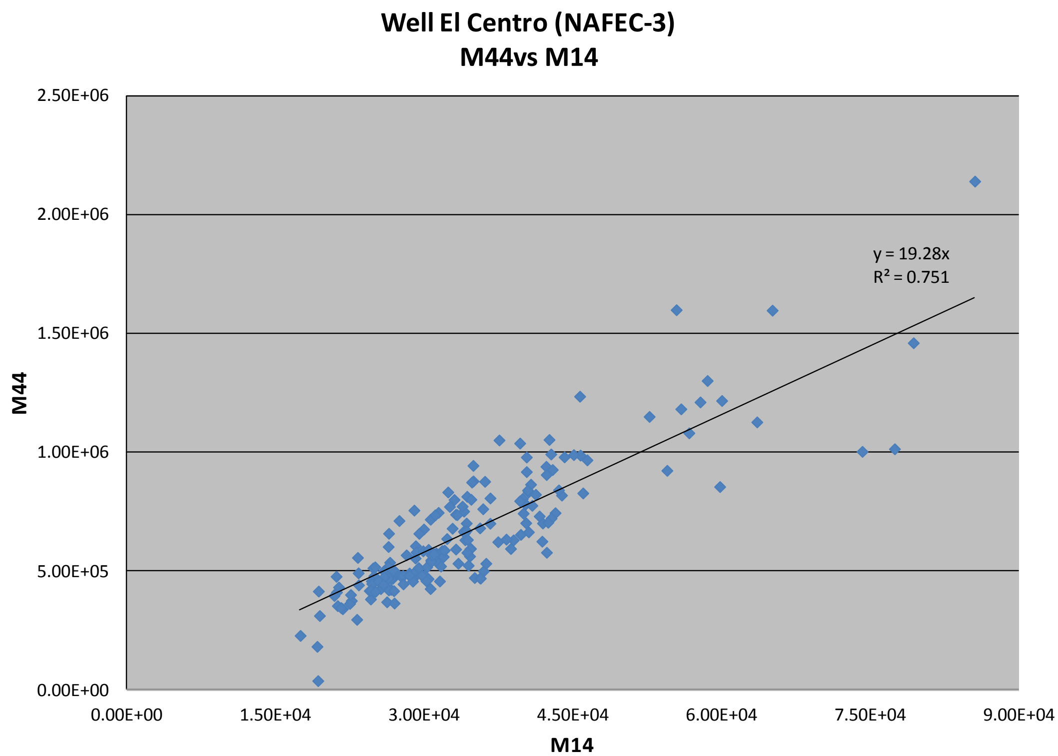
Methodologies for Reservoir Characterizations Using Fluid Inclusion Gas Chemistry

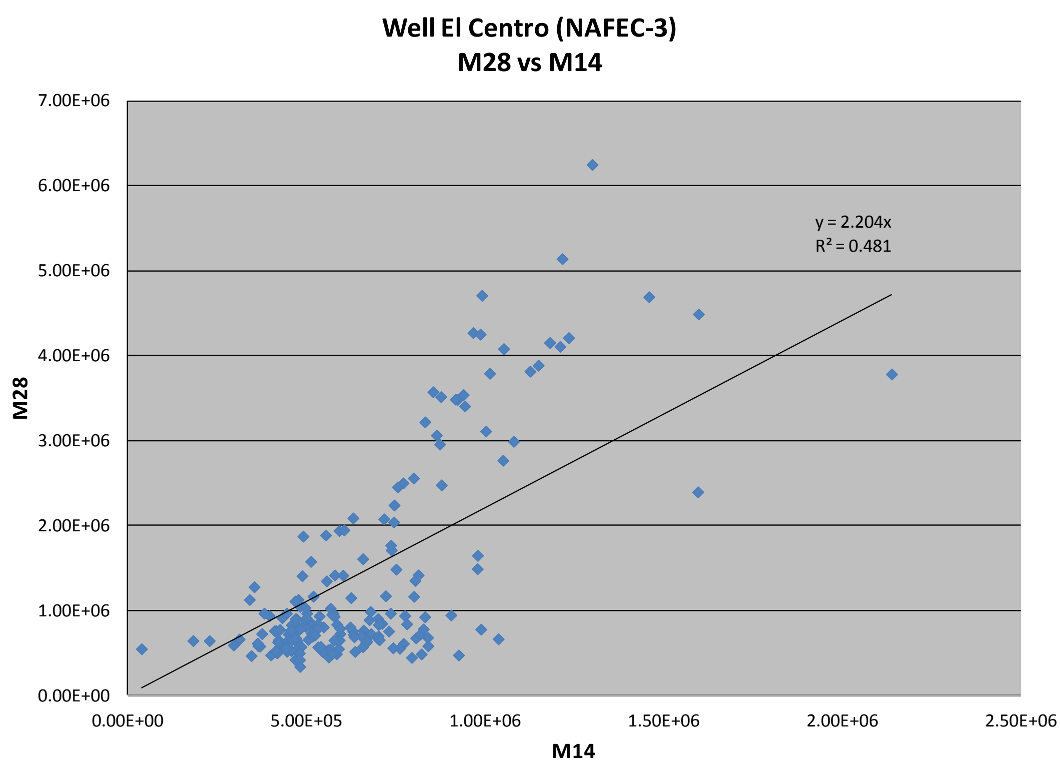
El Centro Well NAFEC-1
US Department of Energy

November 2013

Figure 1

El Centro Well NAFEC-3





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El Centro Well NAFEC-3

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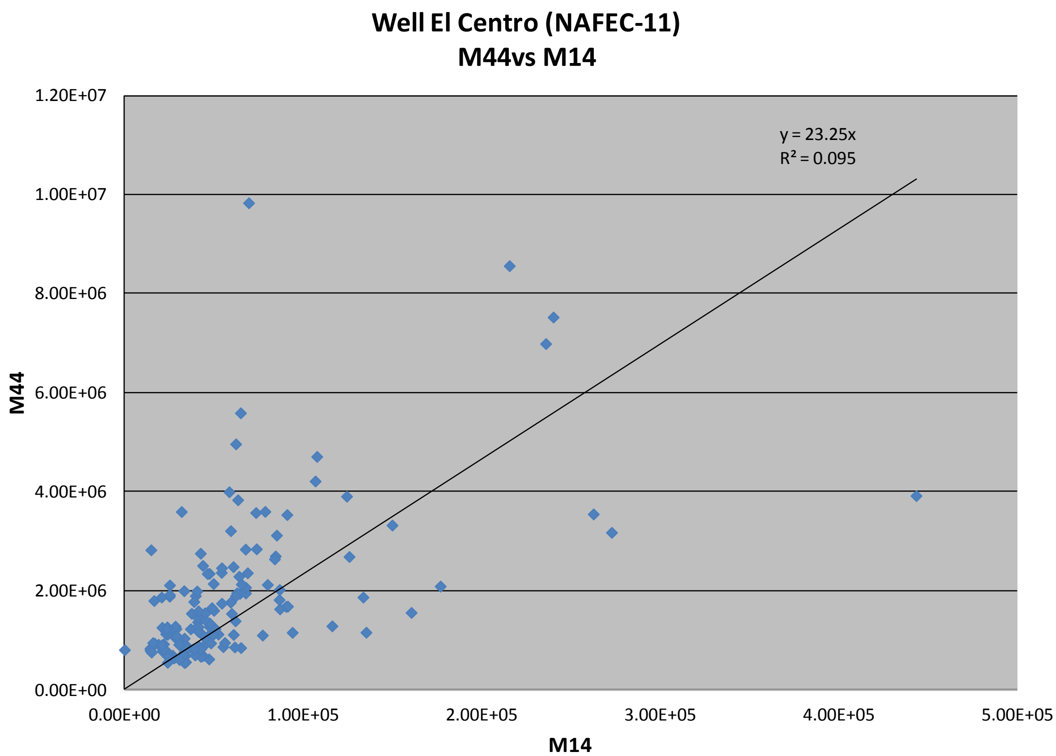
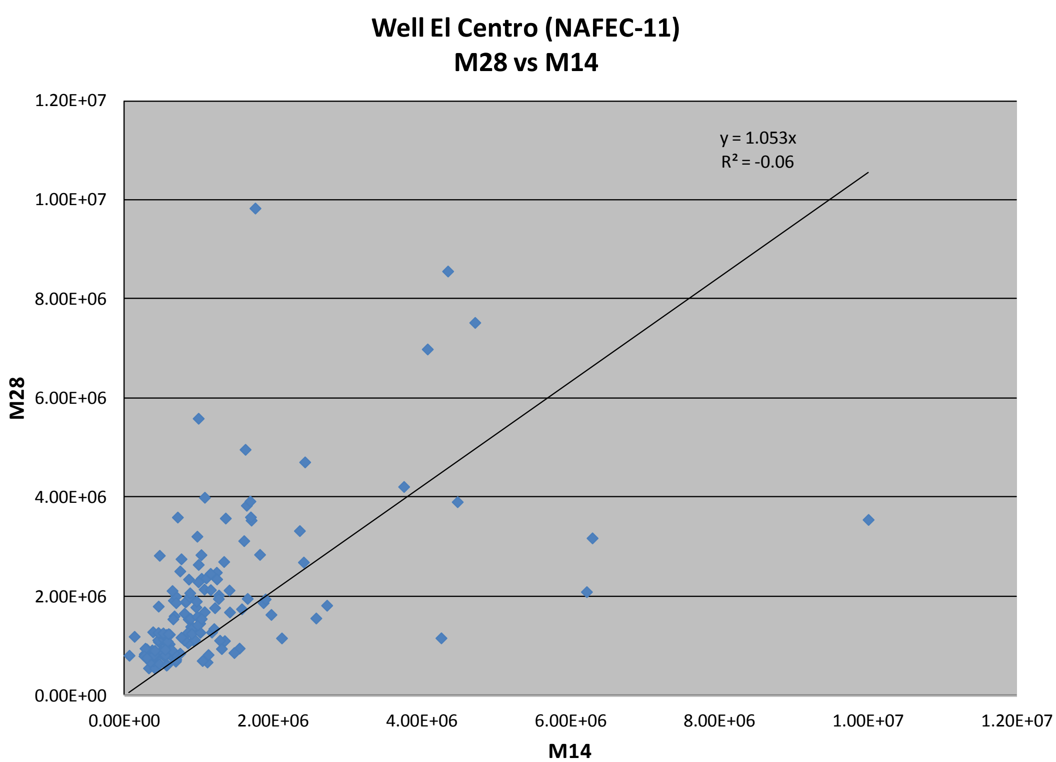
Figure 2

El Centro Well NAFEC-11





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El Centro Well NAFEC-11
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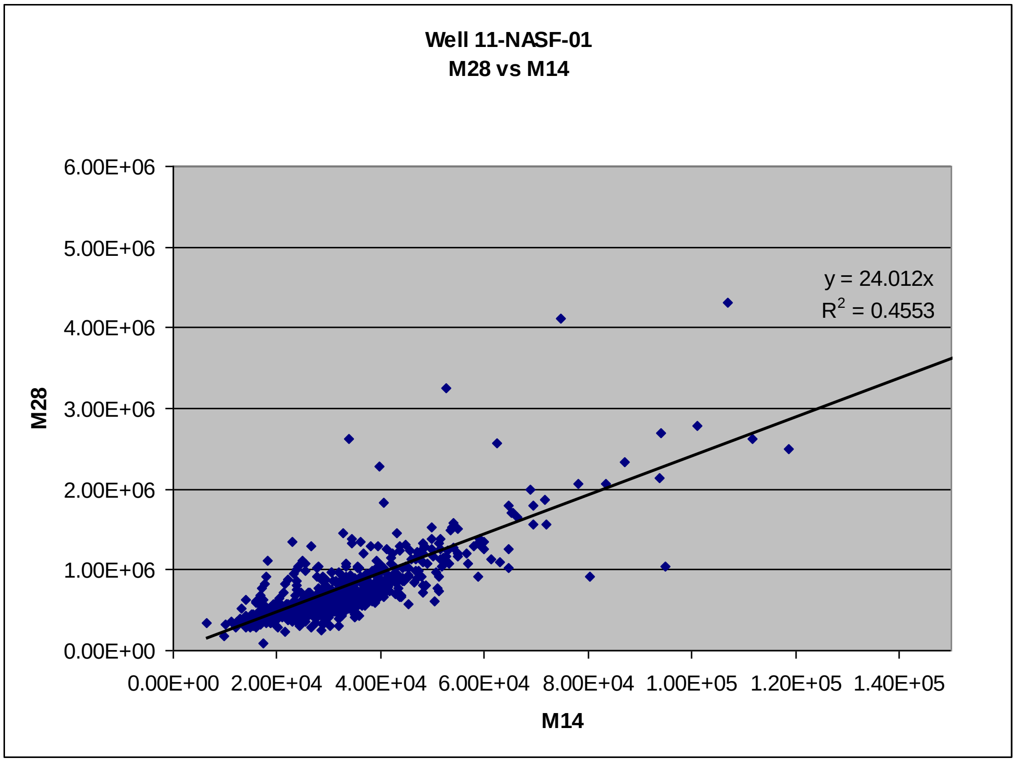
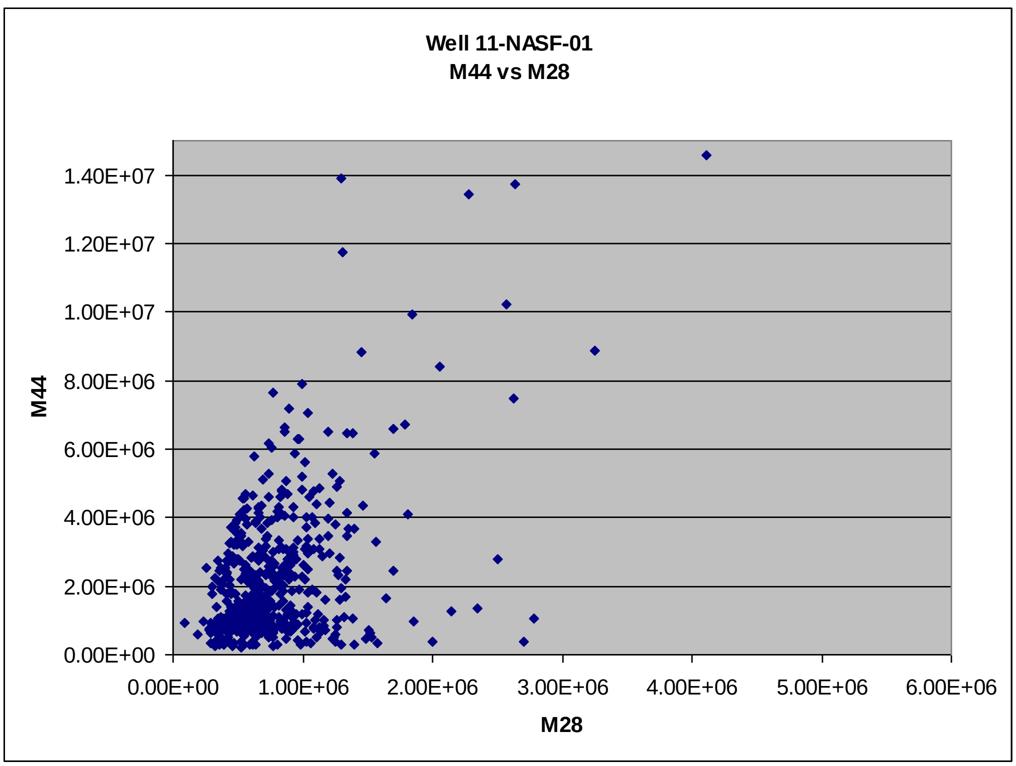
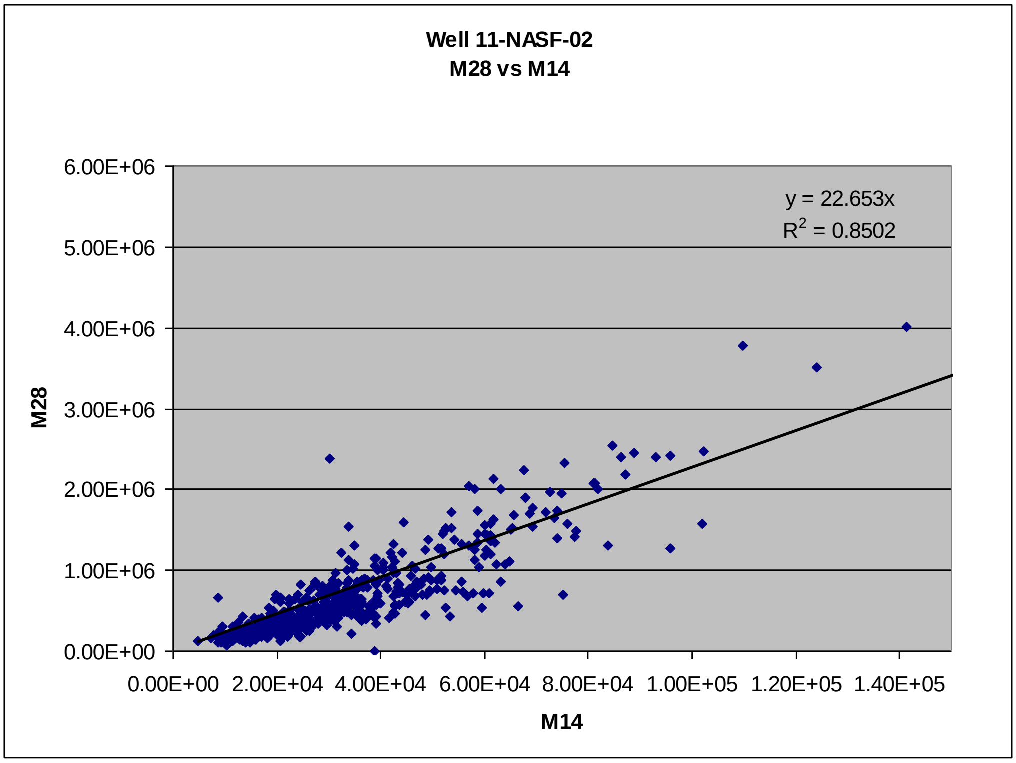
Figure 3

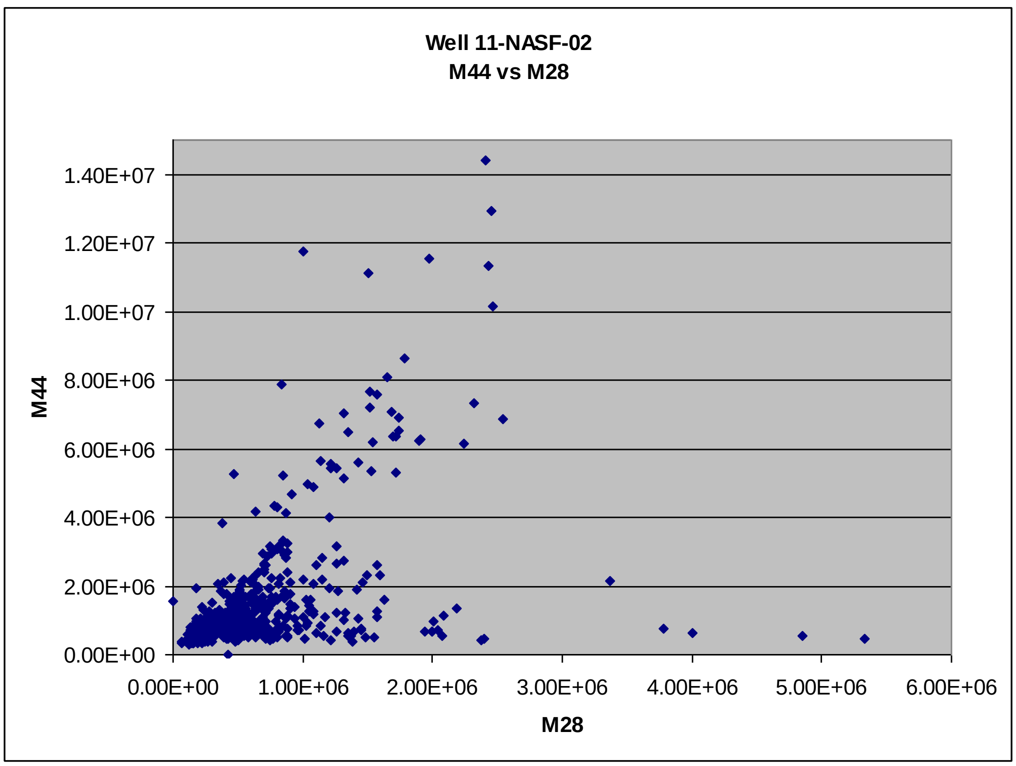
Fallon Well 11-NASF-01





Fallon Well 11-NASF-02





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Fallon Well 11-NASF-01
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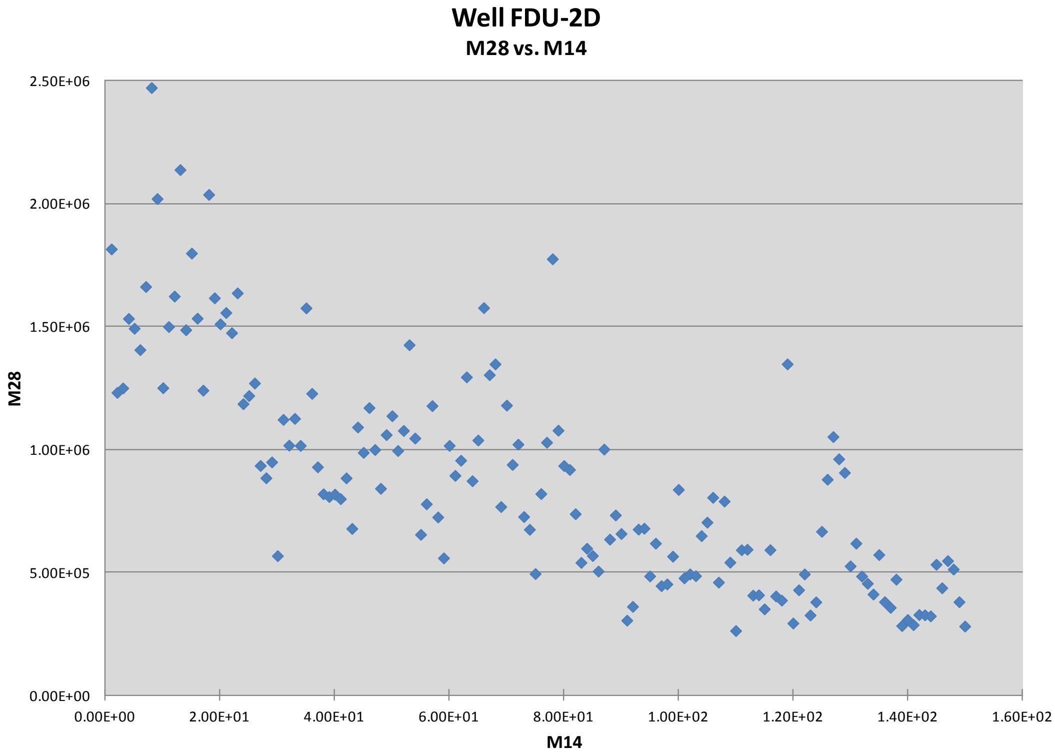
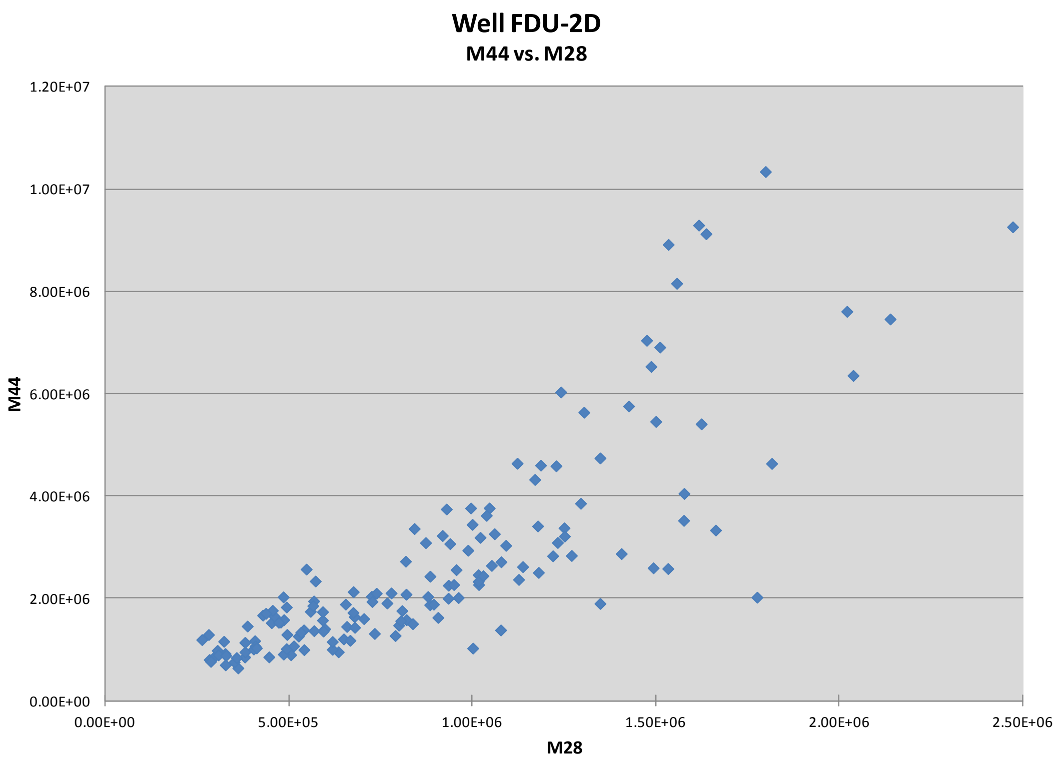
Figure 5

Fallon Well FDU-2D





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Fallon Well FDU-2D
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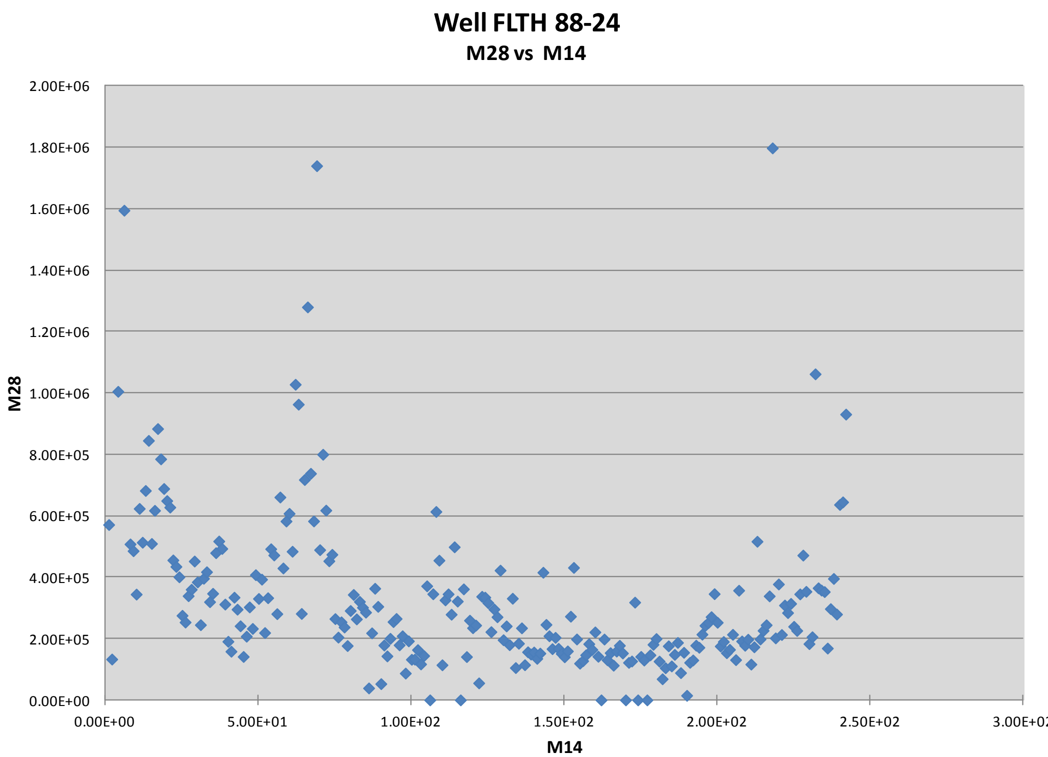
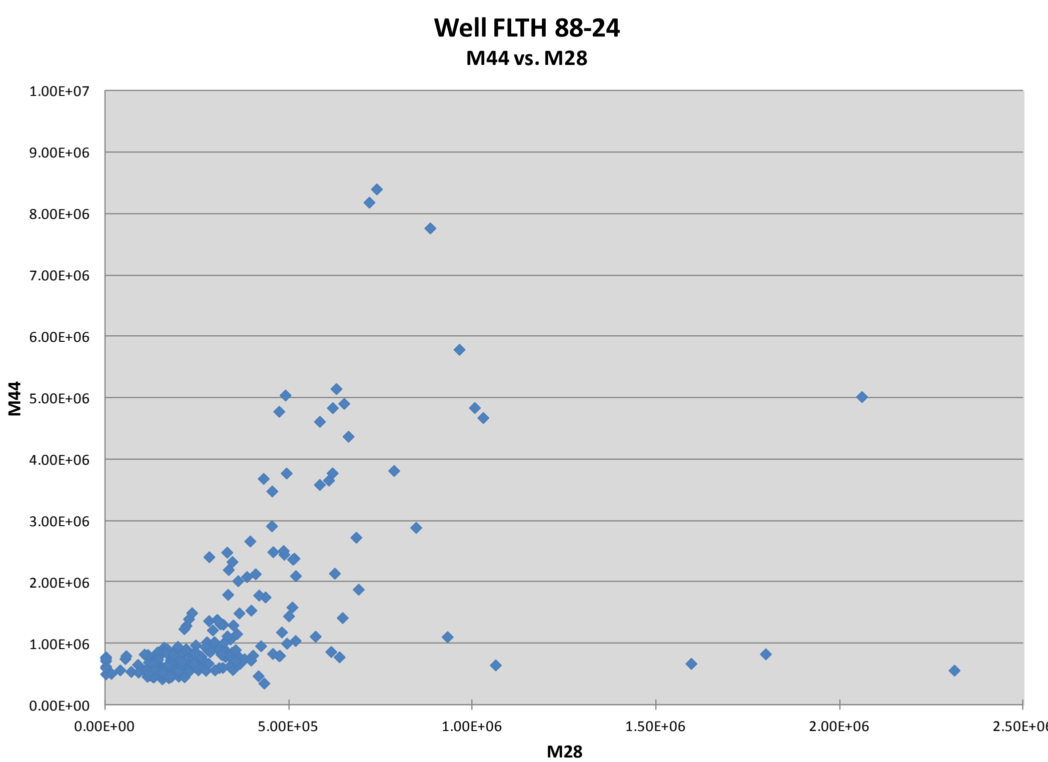
Figure 6

Fallon Well FLTH 88-24





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Fallon Well FLTH 88-24
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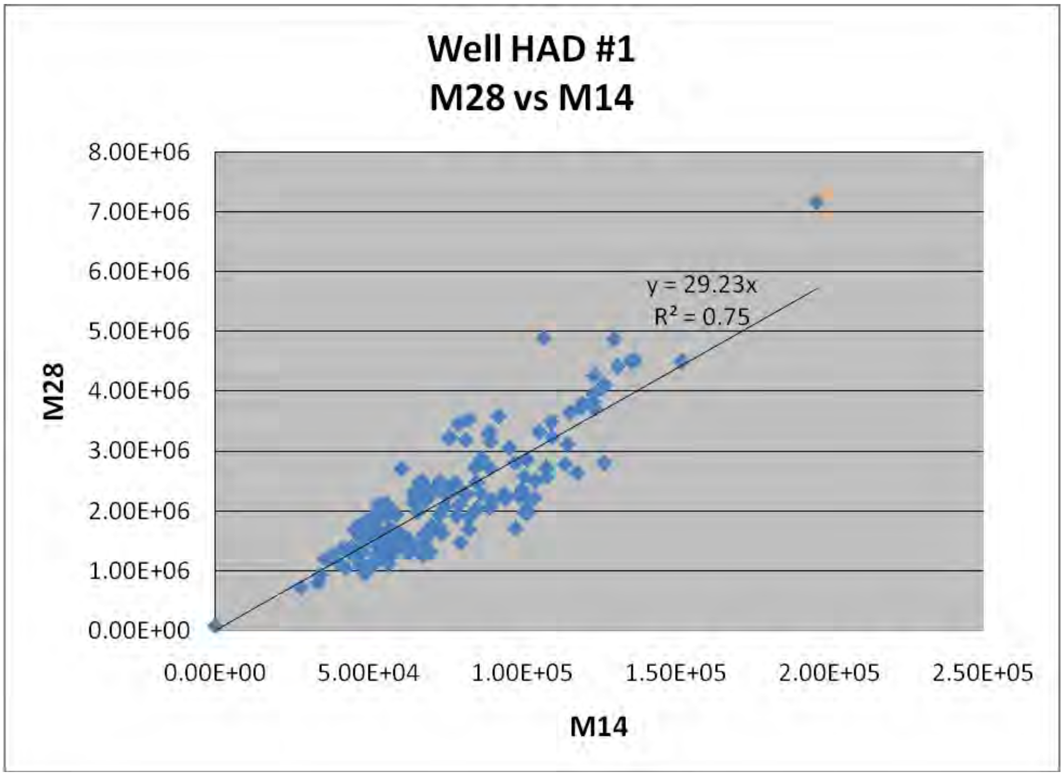
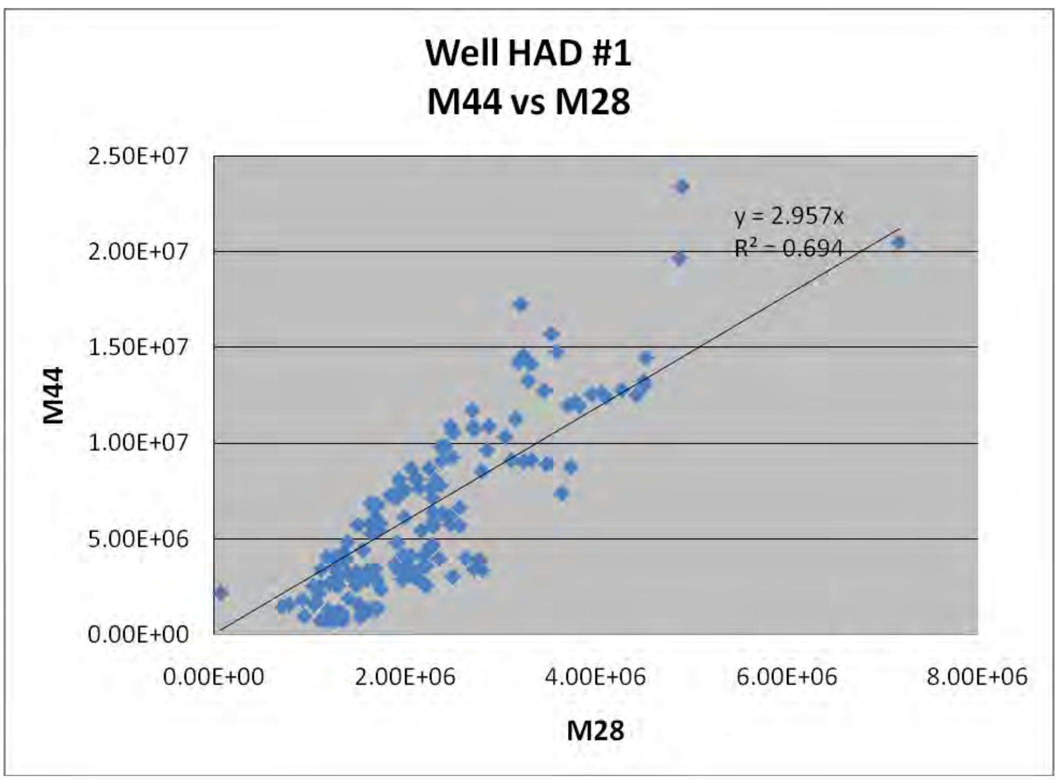
Figure 7

Hawthorne Well HAD#1





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Hawthorne HAD #1
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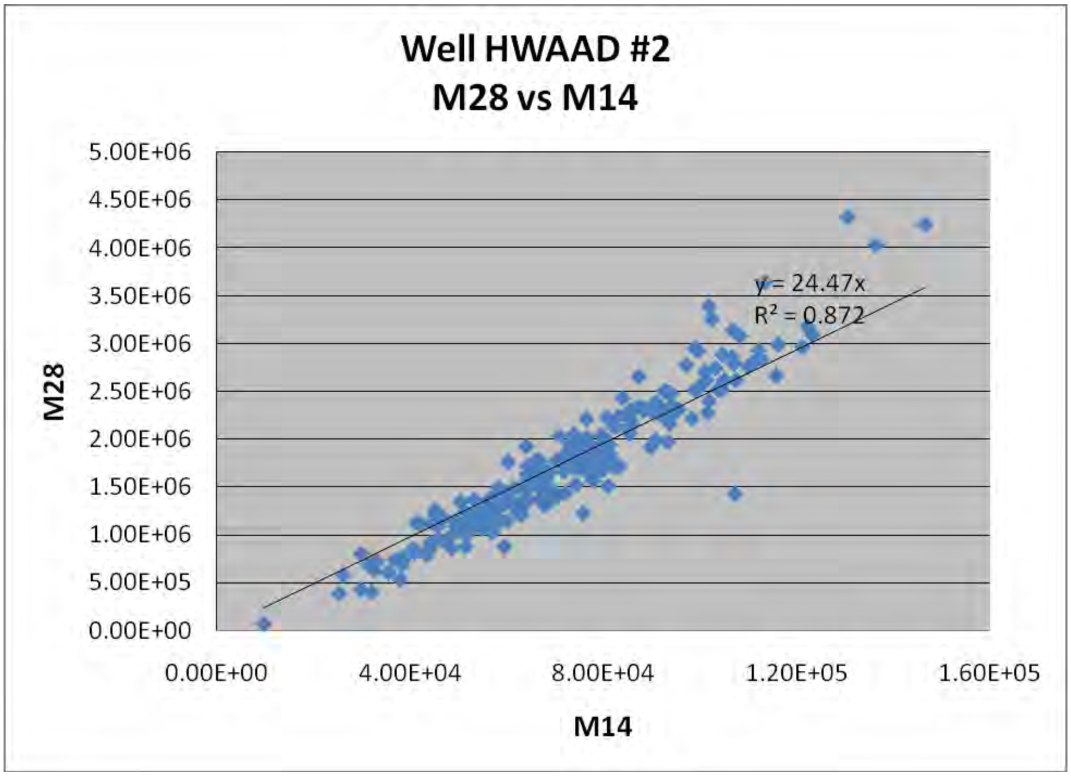
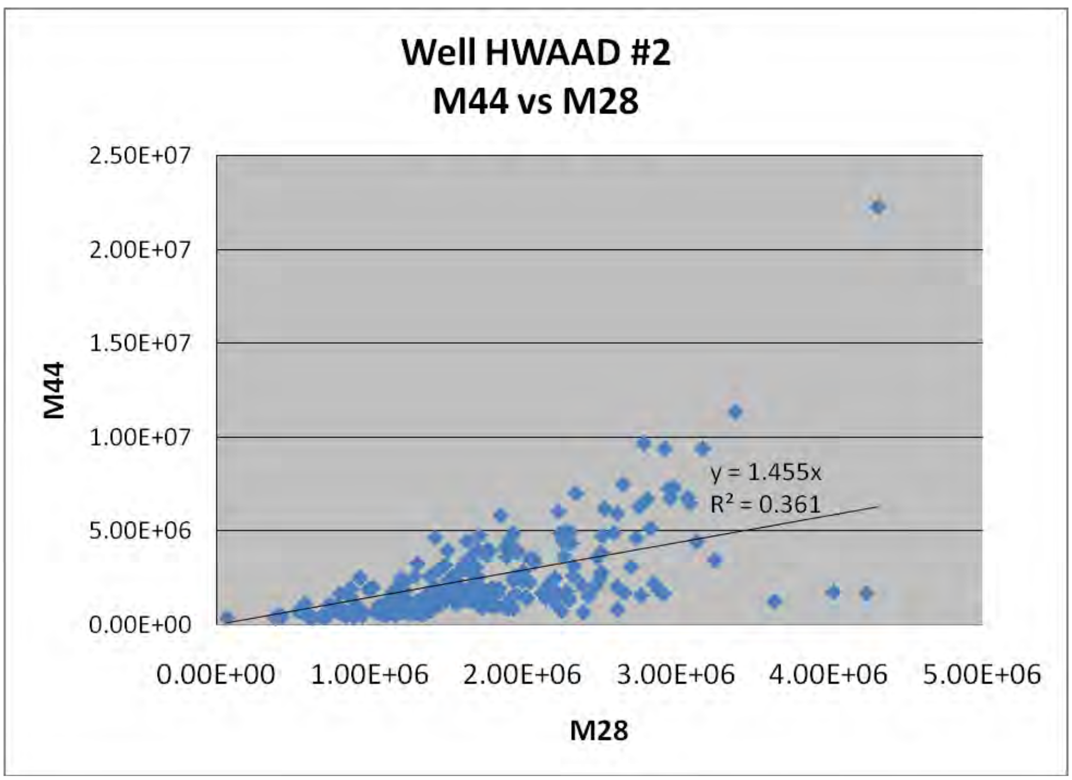
Figure 8

Hawthorne Well HWAAD#2





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Hawthorne HWAAD #2
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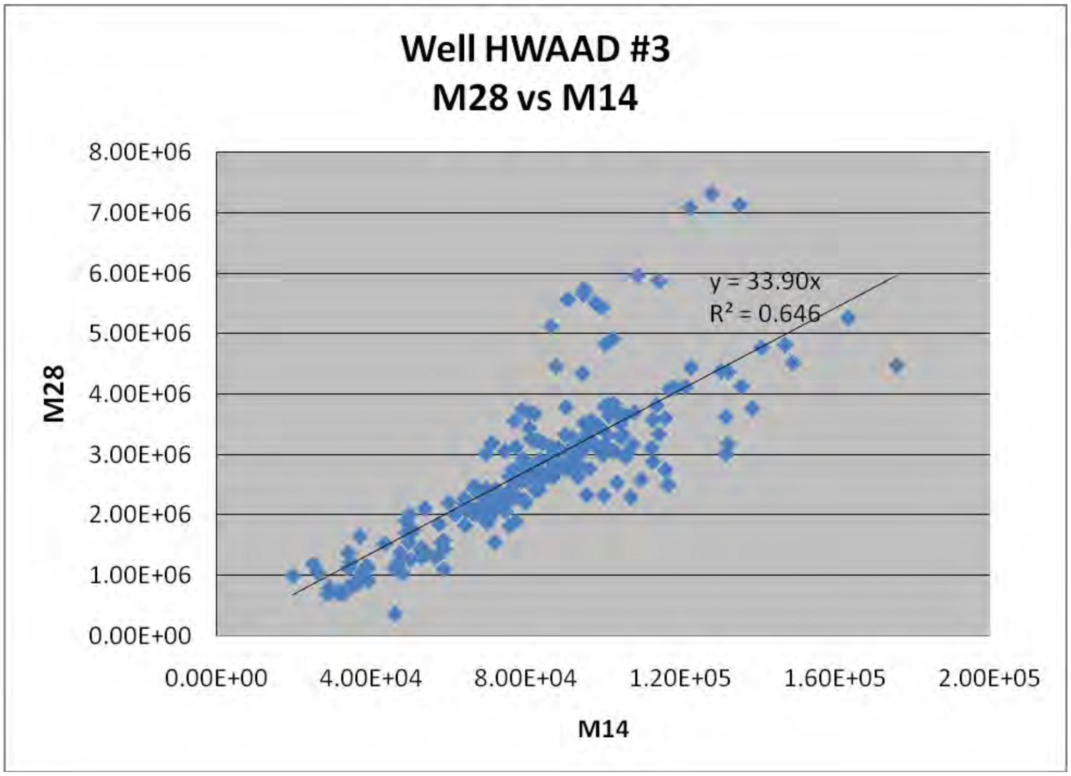
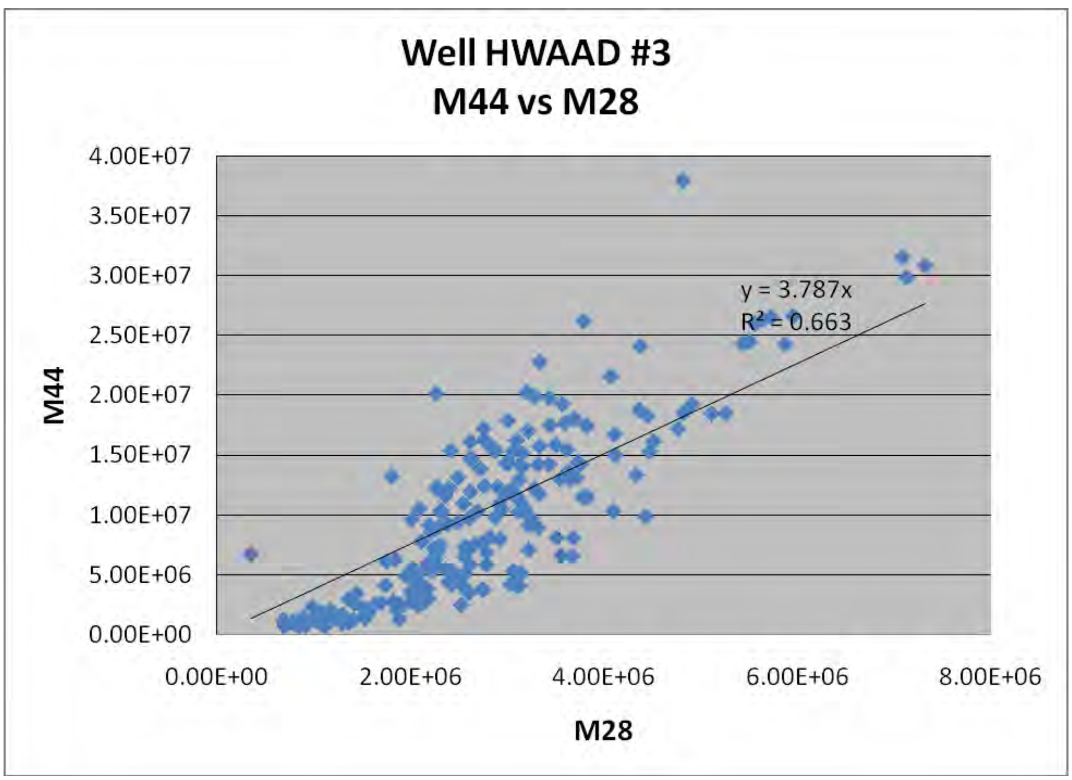
Figure 9

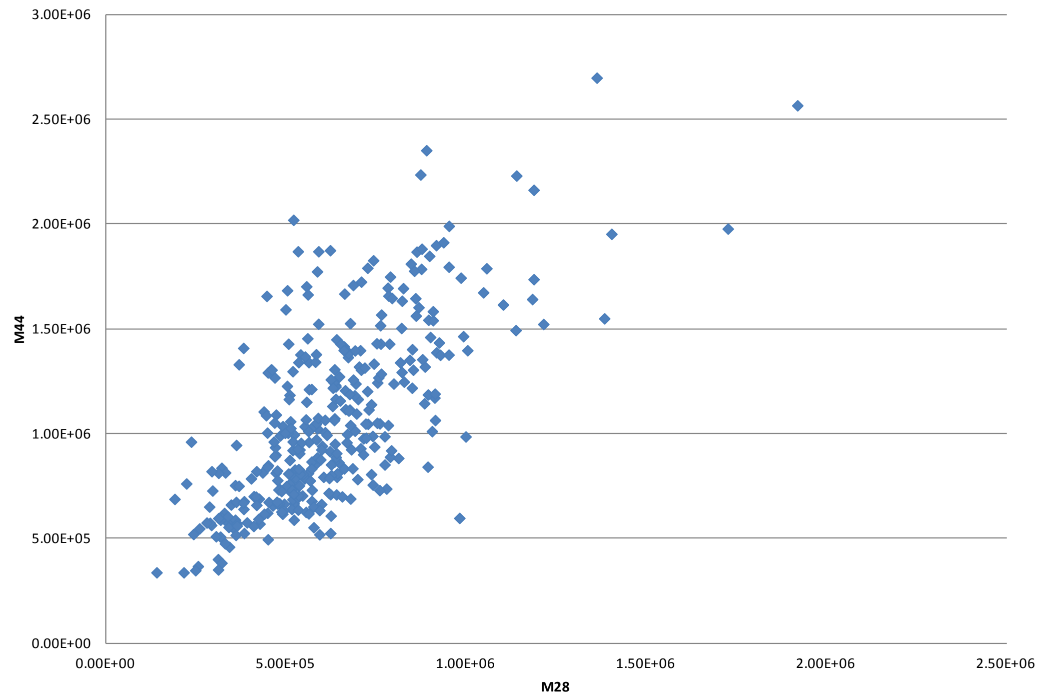
Hawthorne Well HWAAD#3



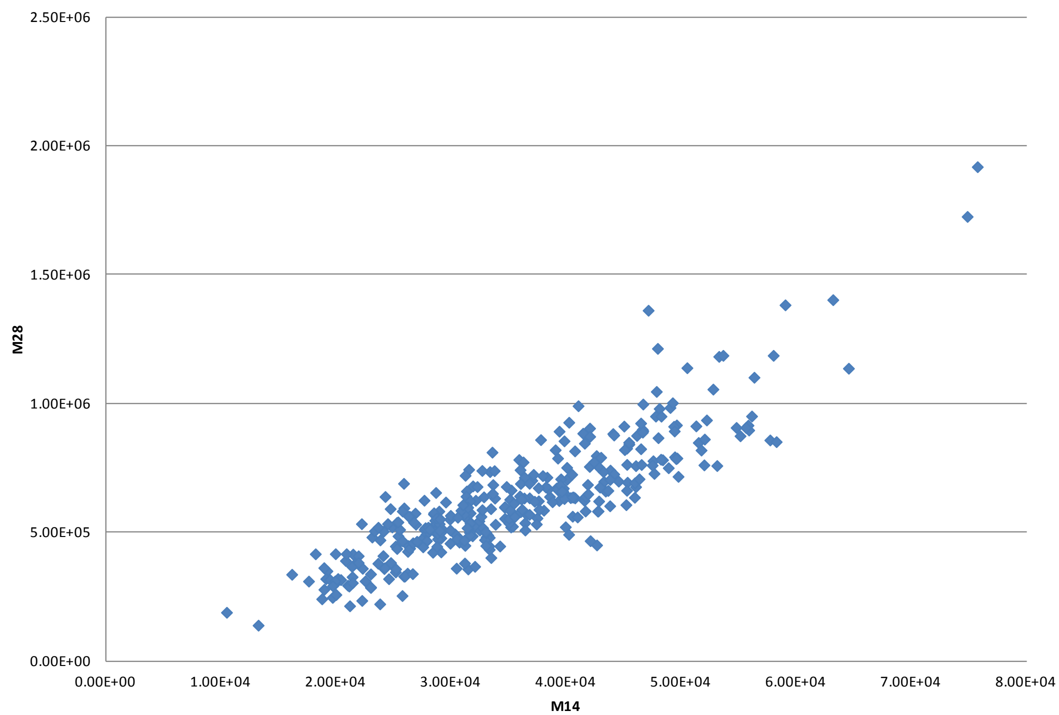


Salton Sea Well Del Ranch

M44 vs. M28



M28 vs. M14



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Salton Sea Well Del Ranch
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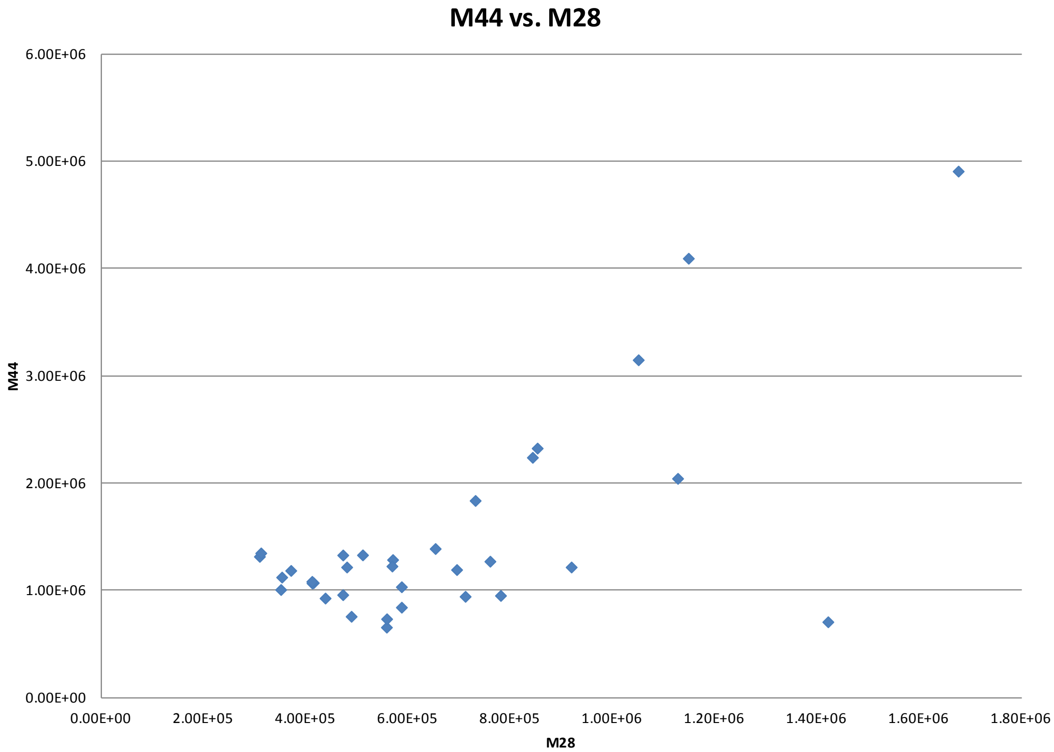
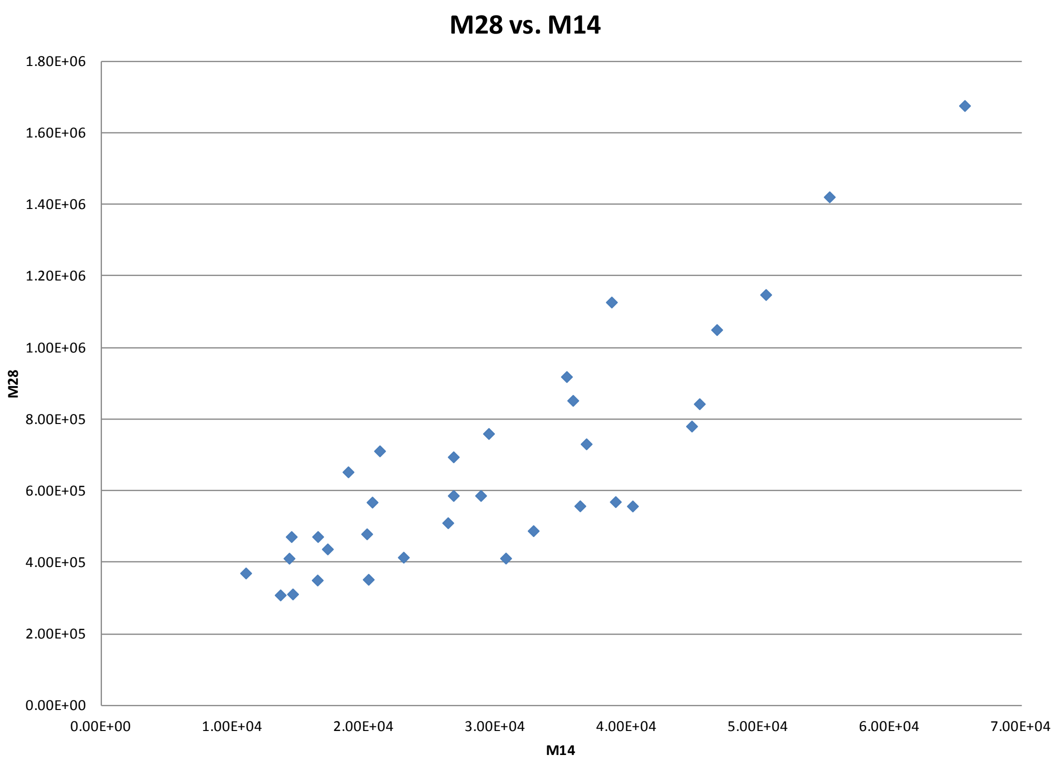
Figure 11

Salton Sea Well ELIW 6





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Salton Sea Well ELIW 6
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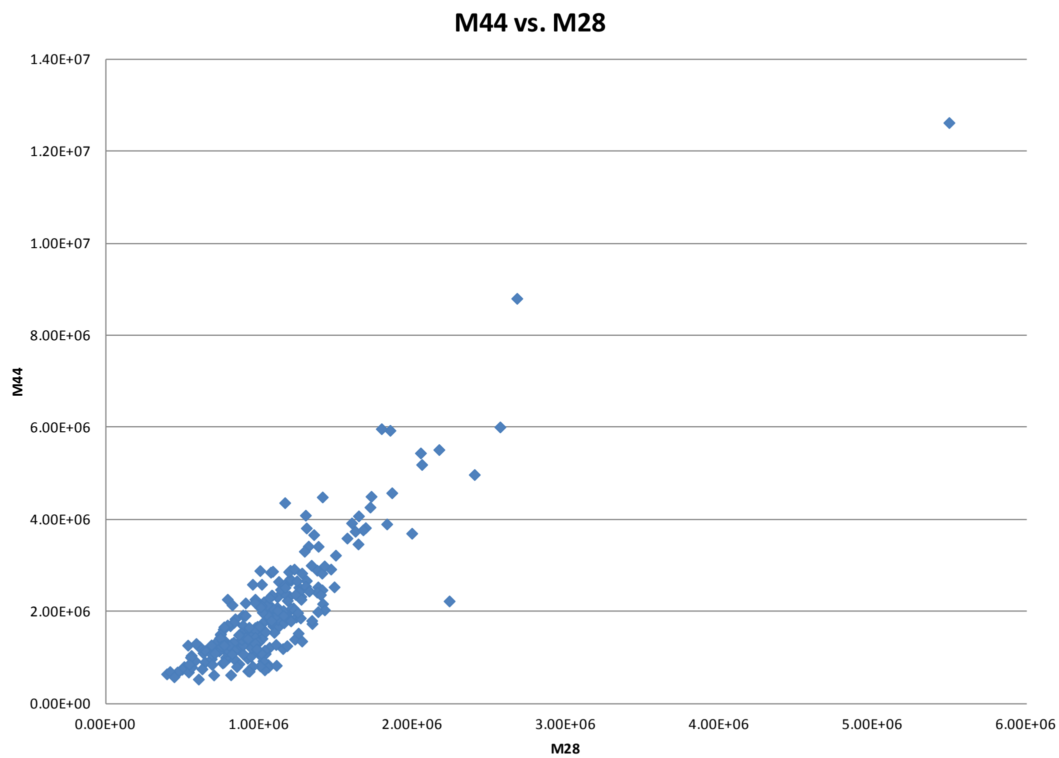
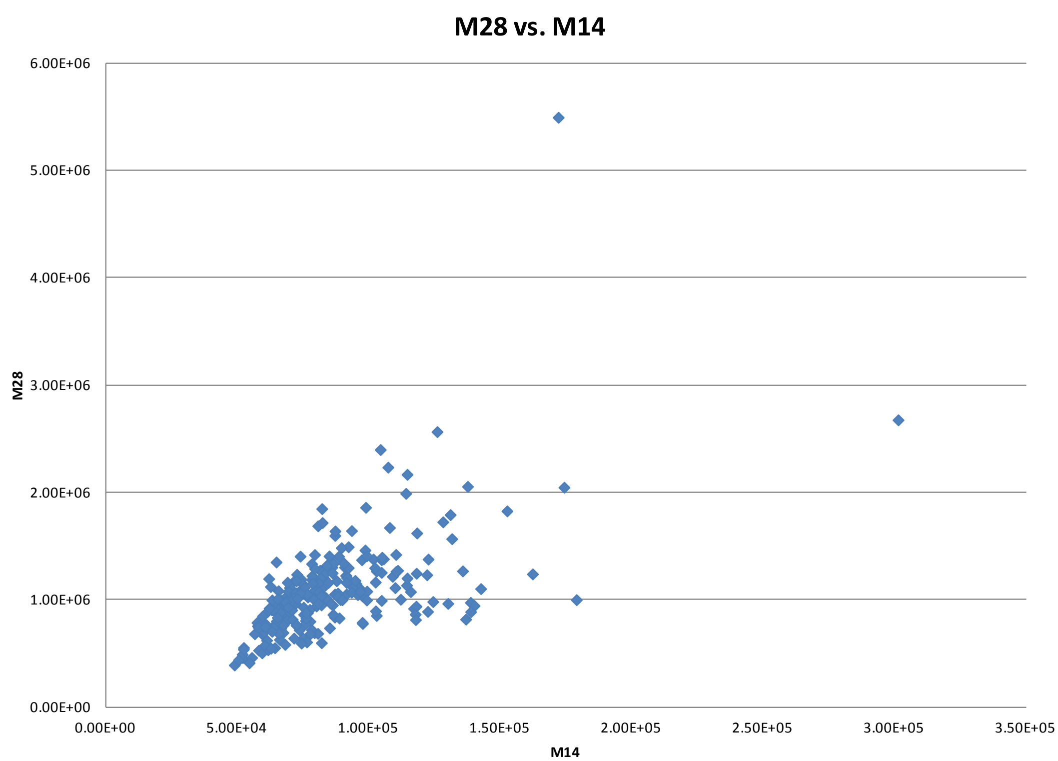
Figure 12

Salton Sea Well Elmore 12





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Salton Sea Well Elmore 12
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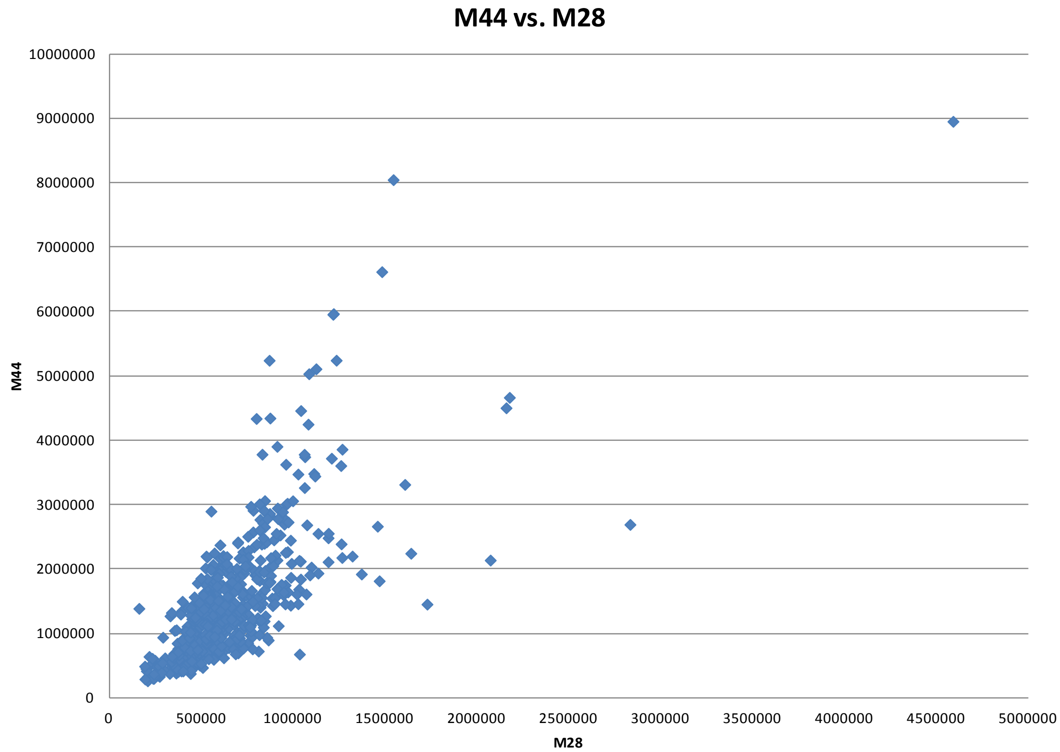
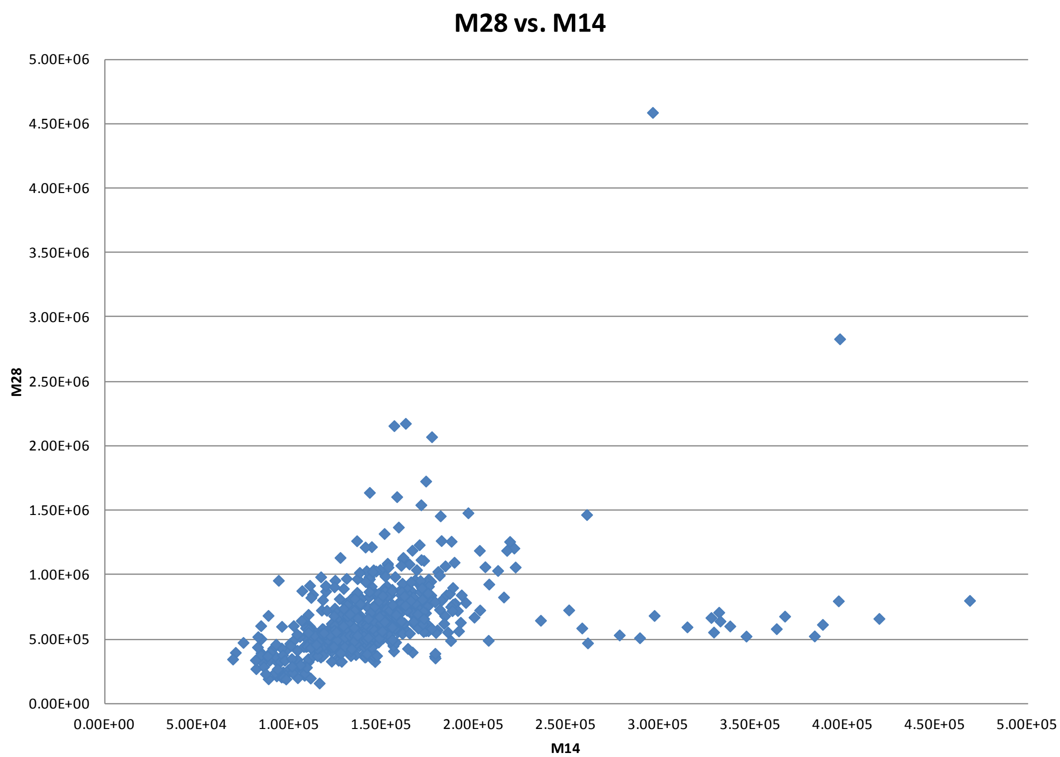
Figure 13

Salton Sea Well Elmore 16





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Salton Sea Well Elmore 16
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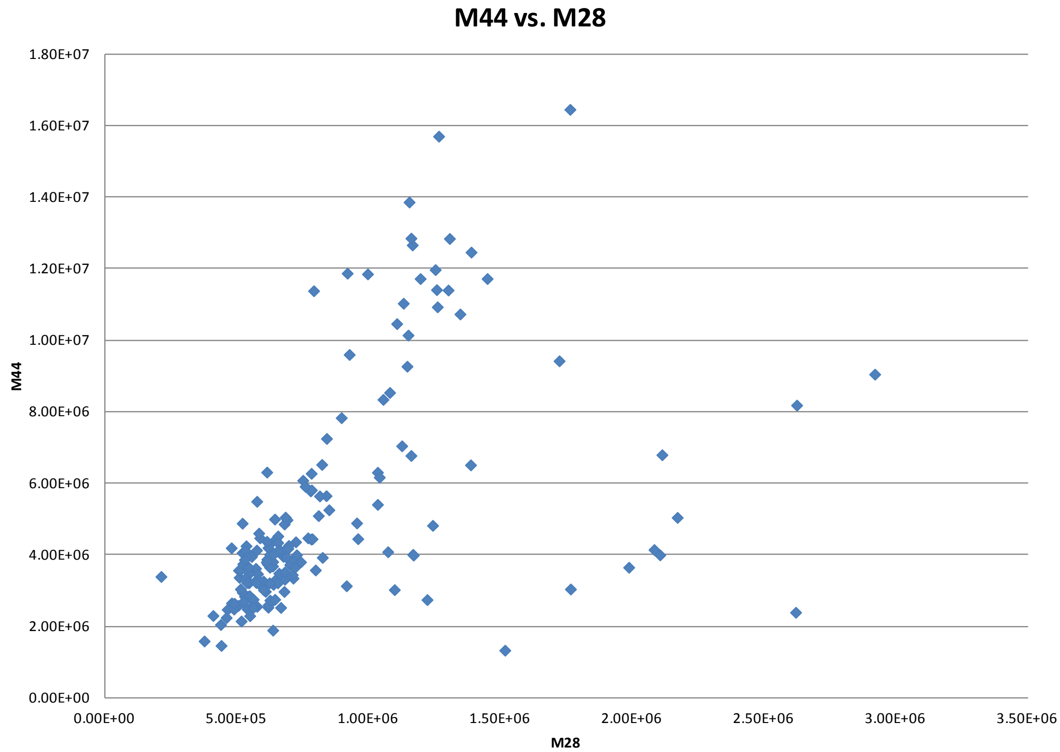
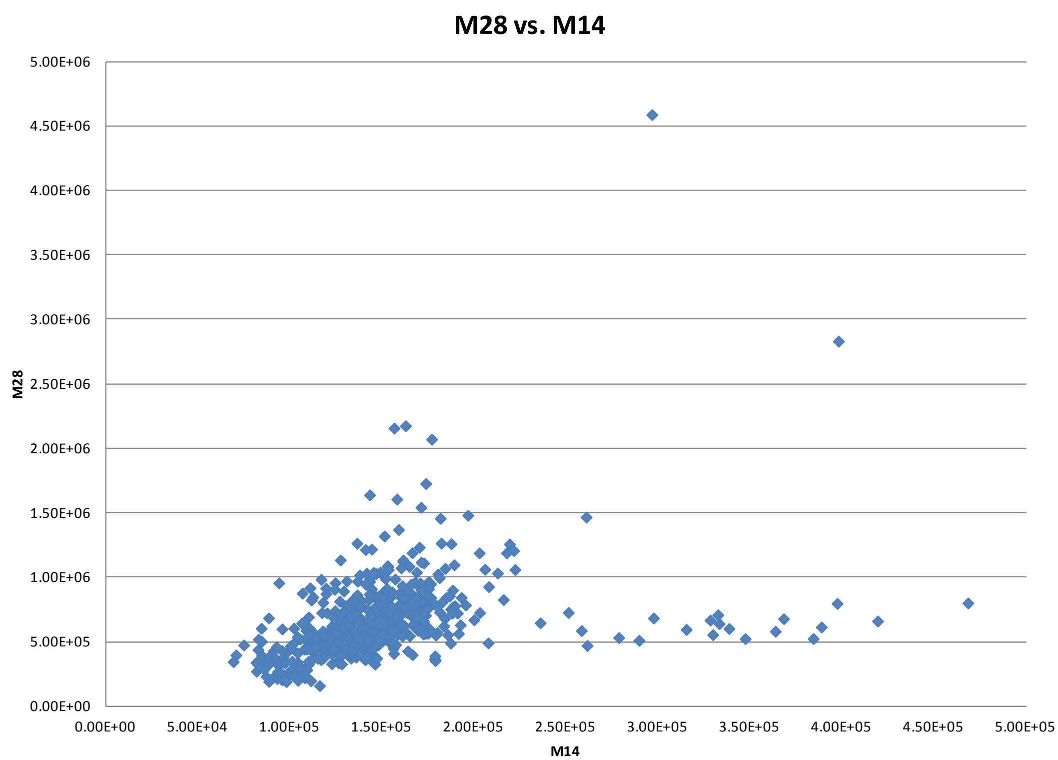
Figure 14

Salton Sea Well River Ranch 4





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Salton Sea Well River Ranch 4

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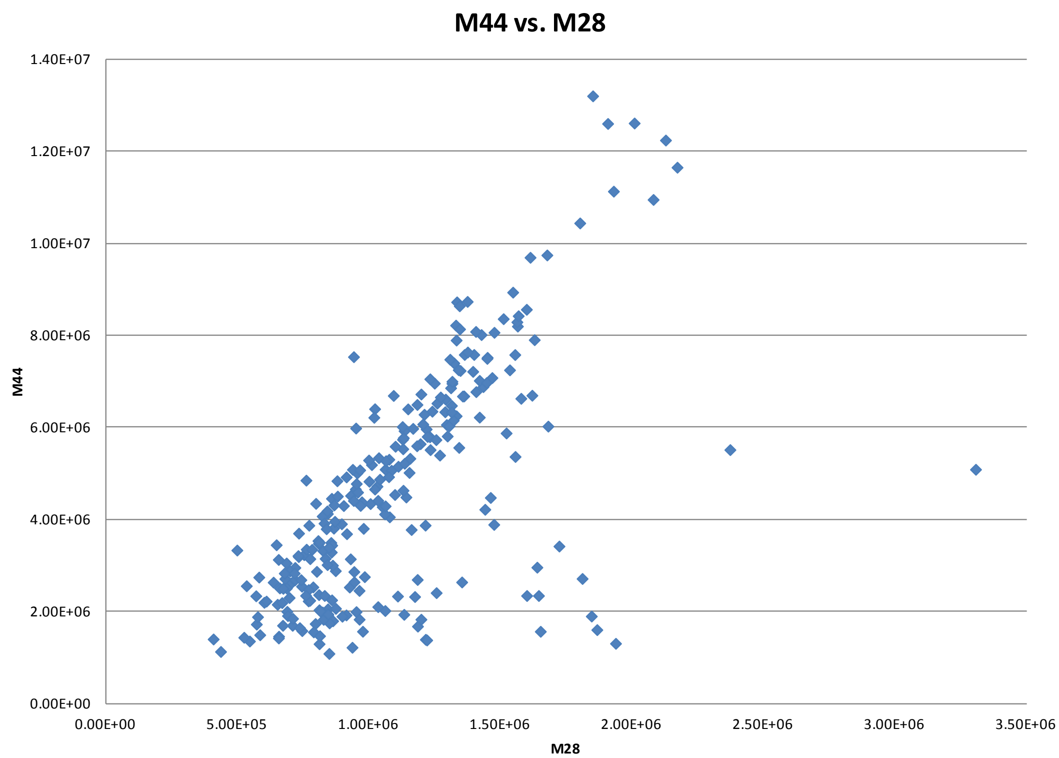
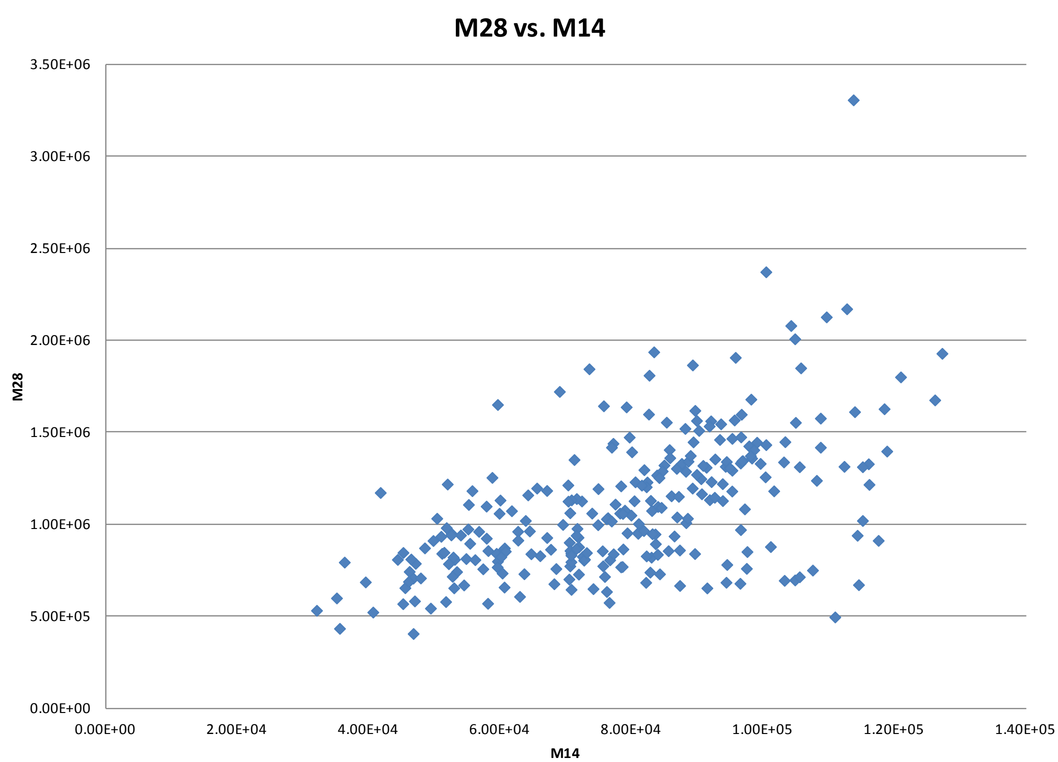
Figure 15

Salton Sea Well Sinclair 24





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Salton Sea Well Sinclair 24
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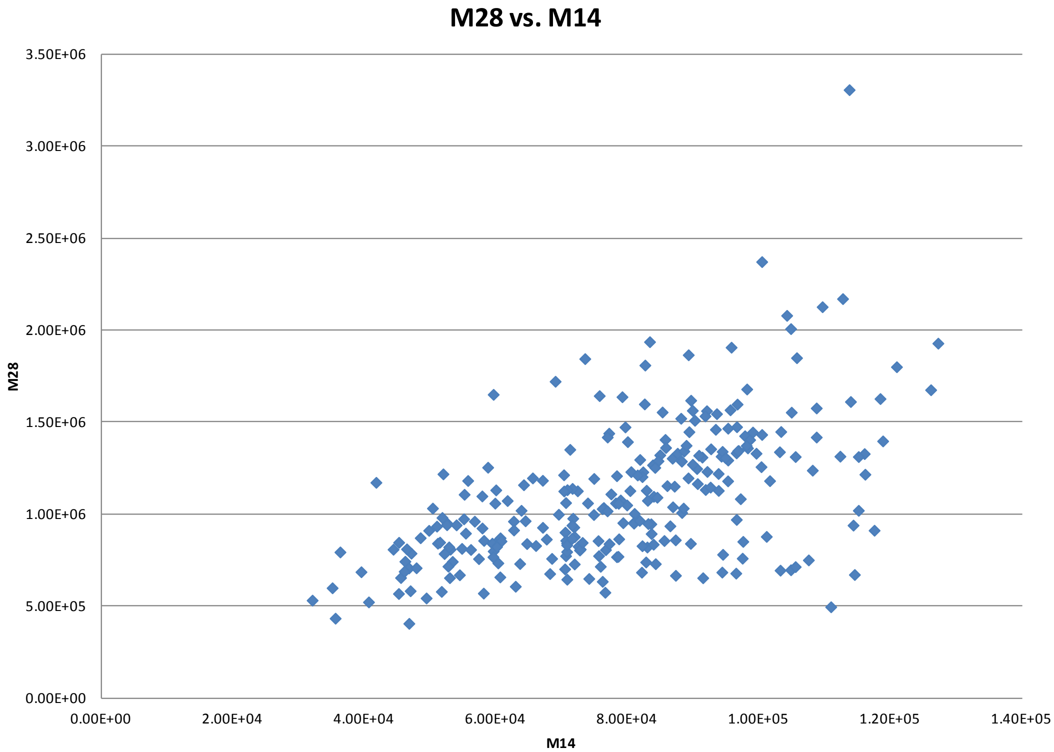
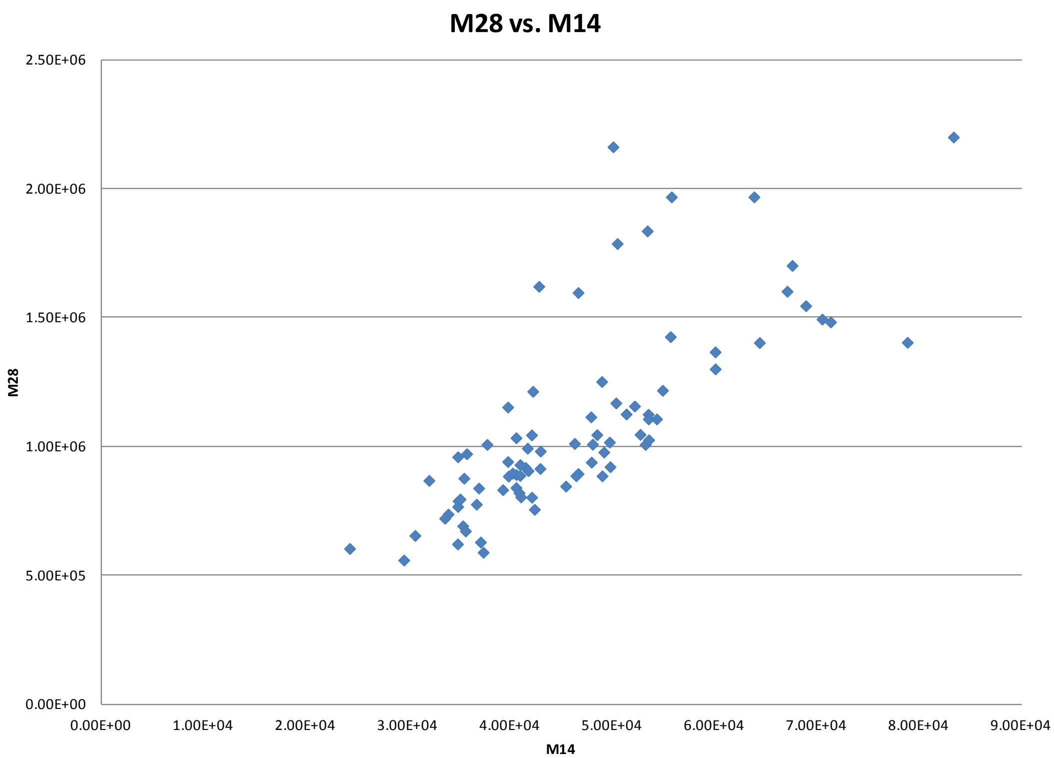
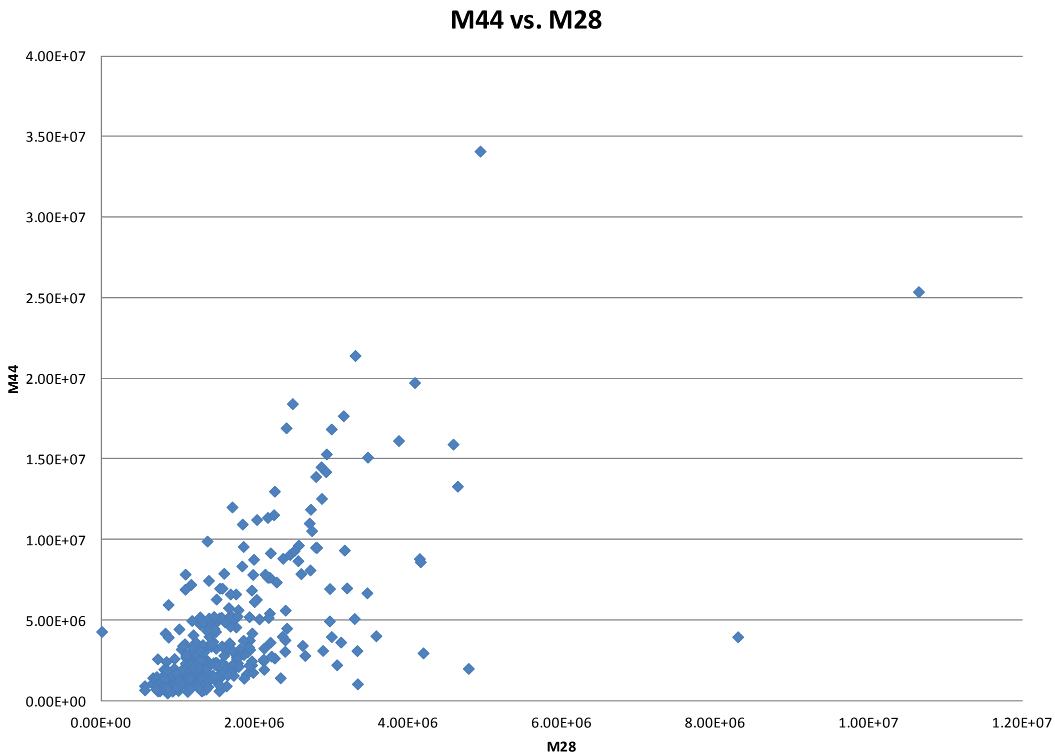
Figure 16

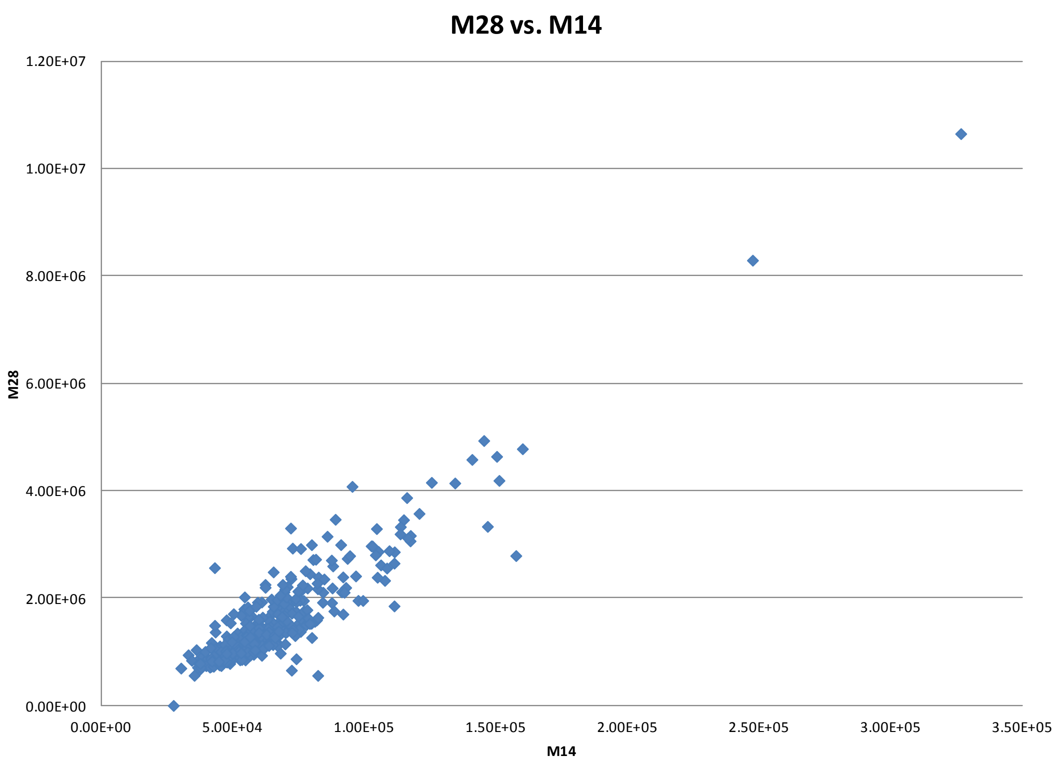
Salton Sea Well Vulcan





Coso Well 15A-17





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Coso Well 15A-7

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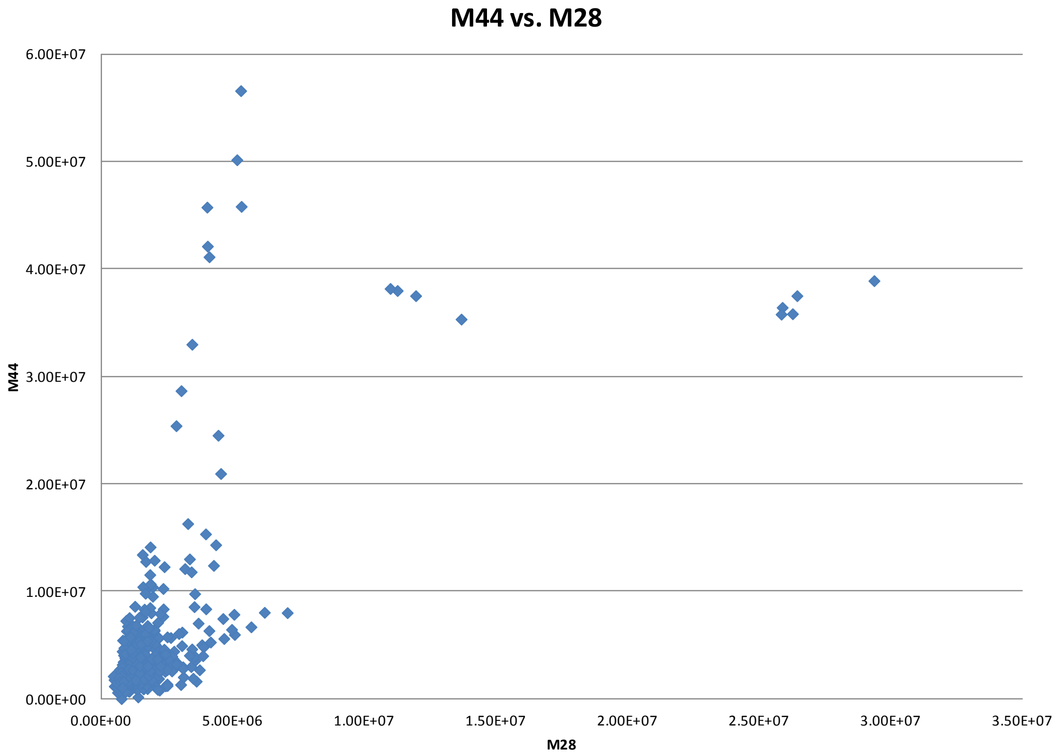
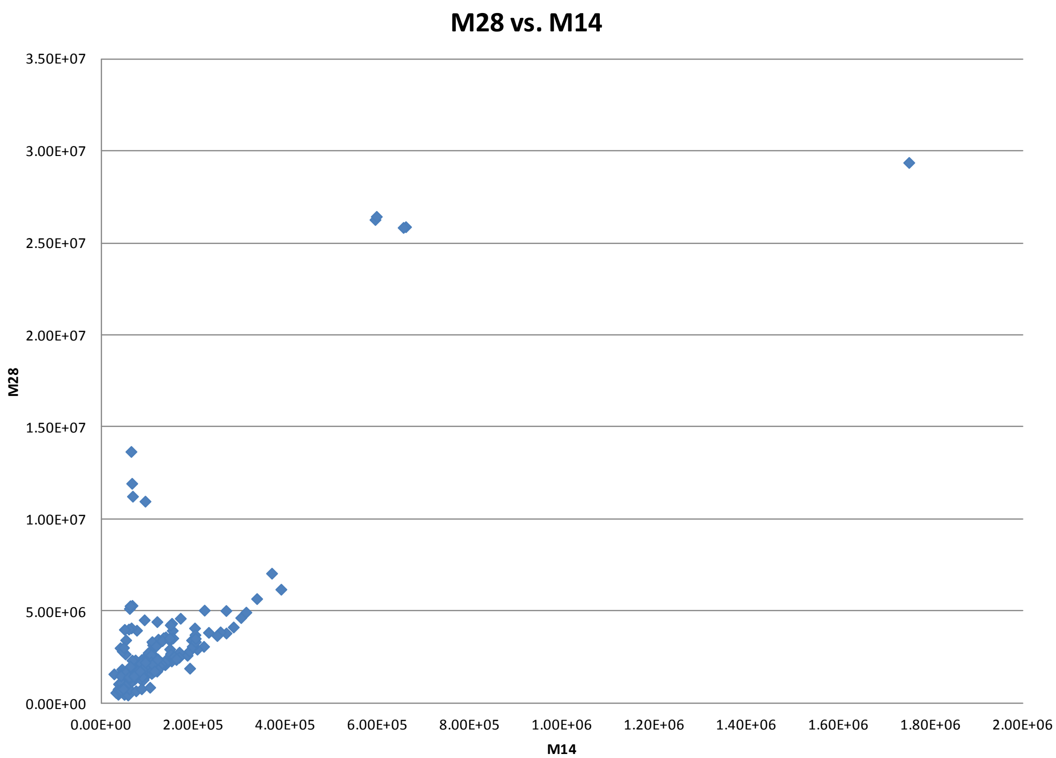
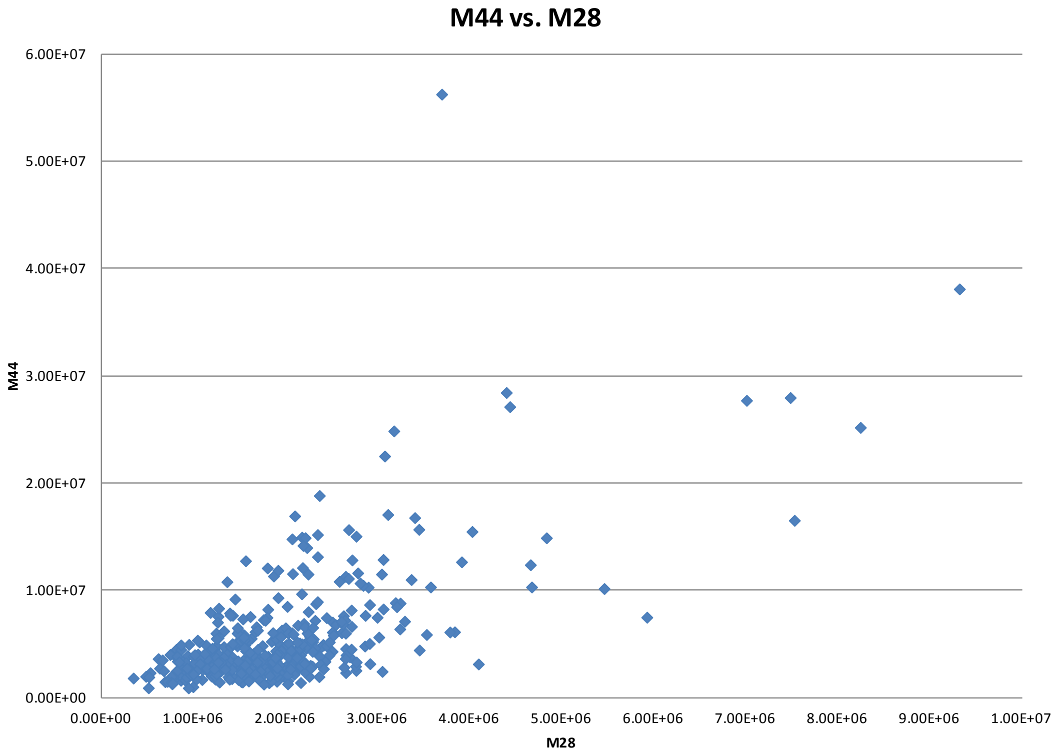
Figure 18

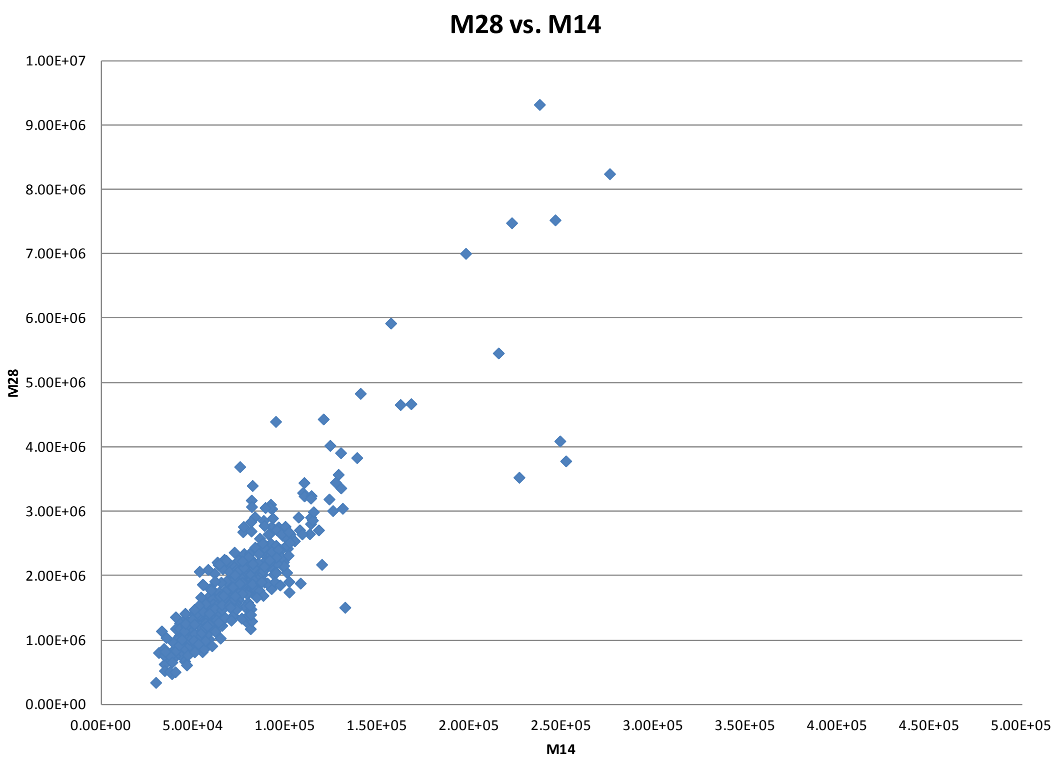
Coso Well 23A-17





Coso Well 23A-19





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Coso Well 23A-19
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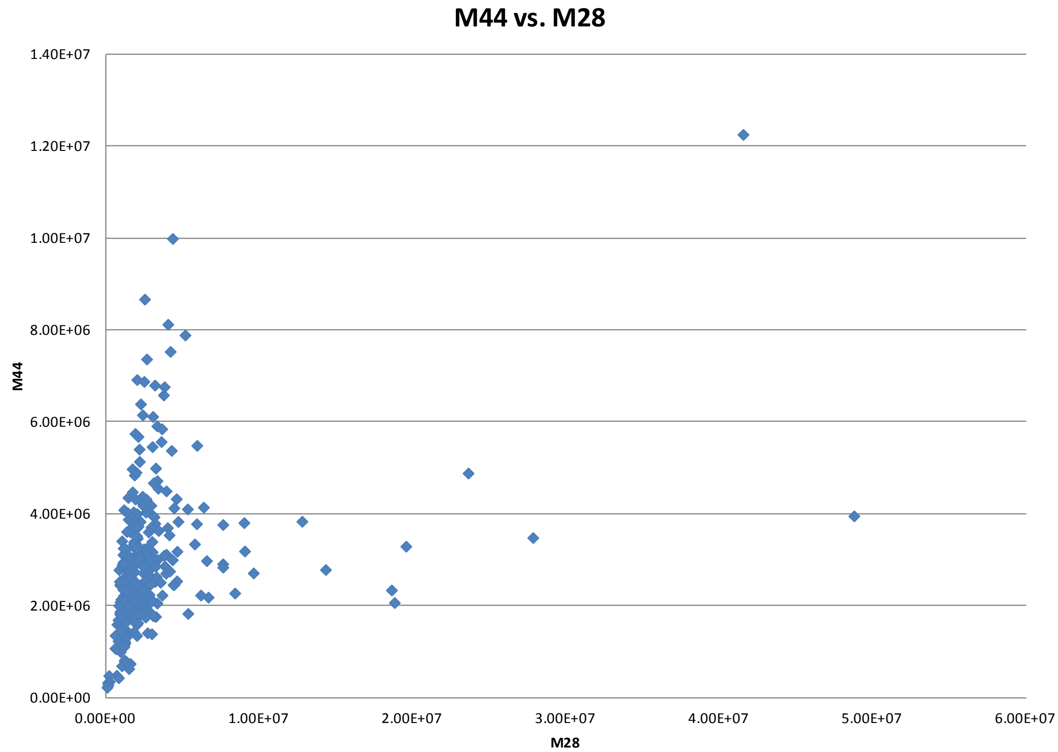
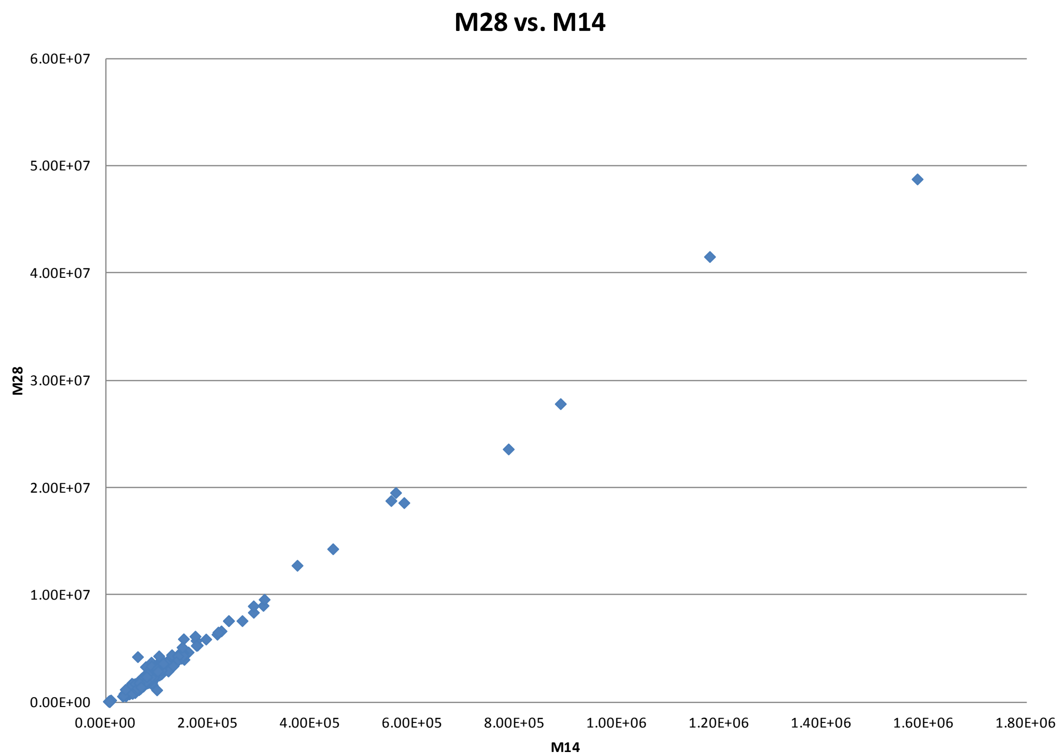
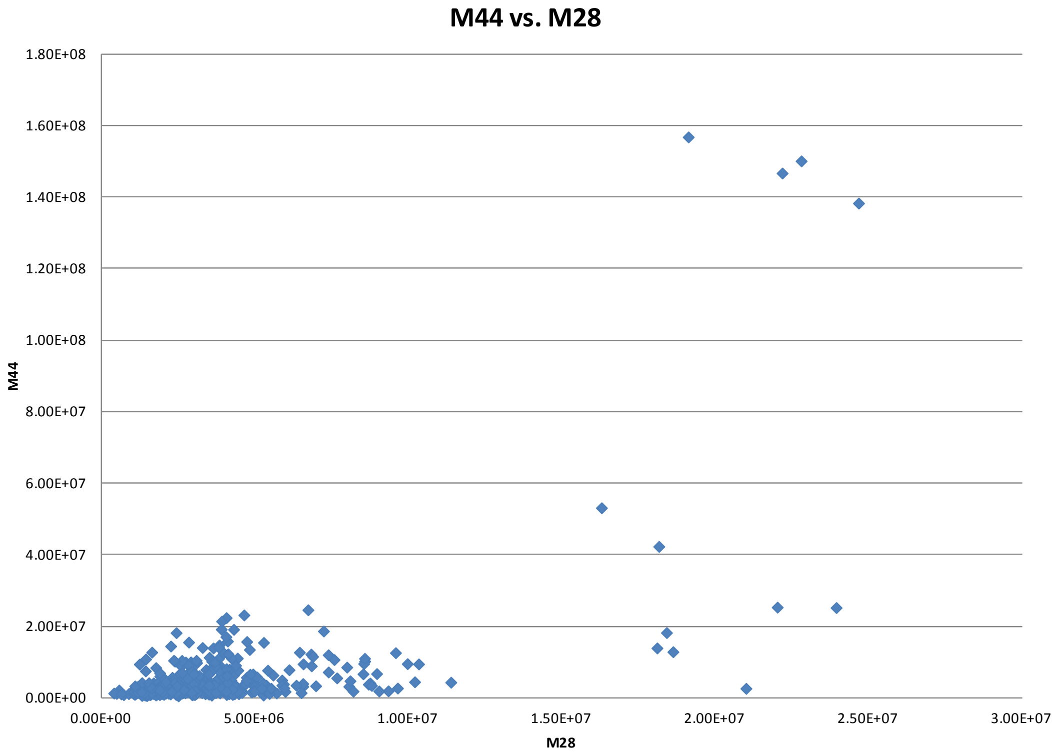
Figure 20

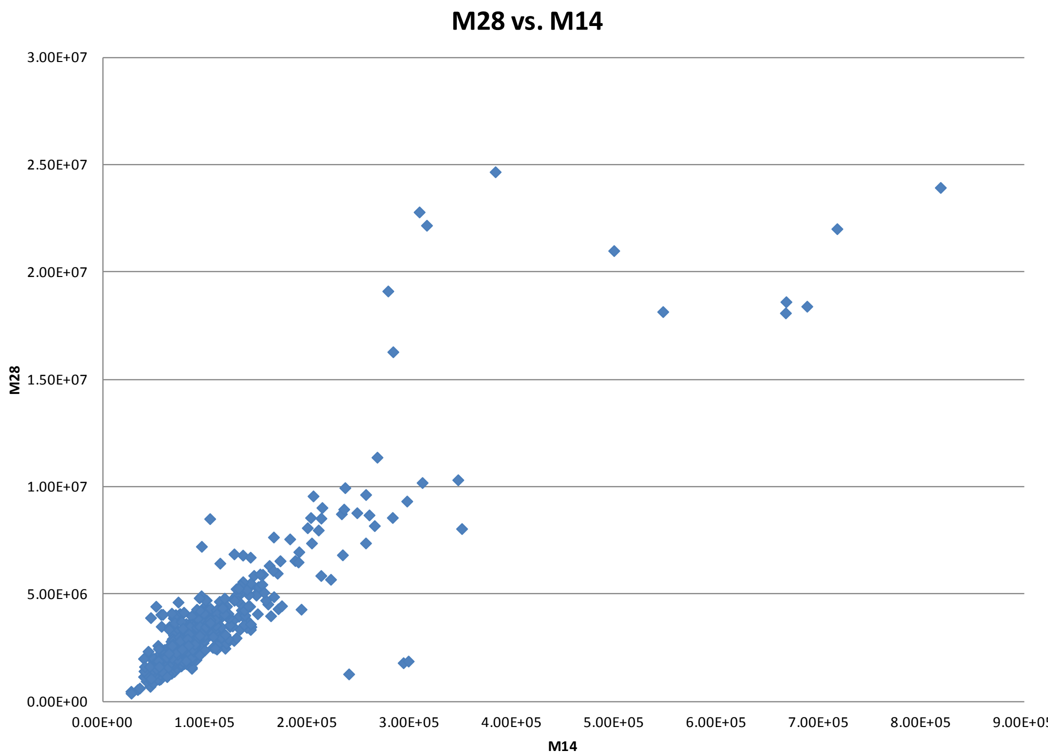
Coso Well 24A-8



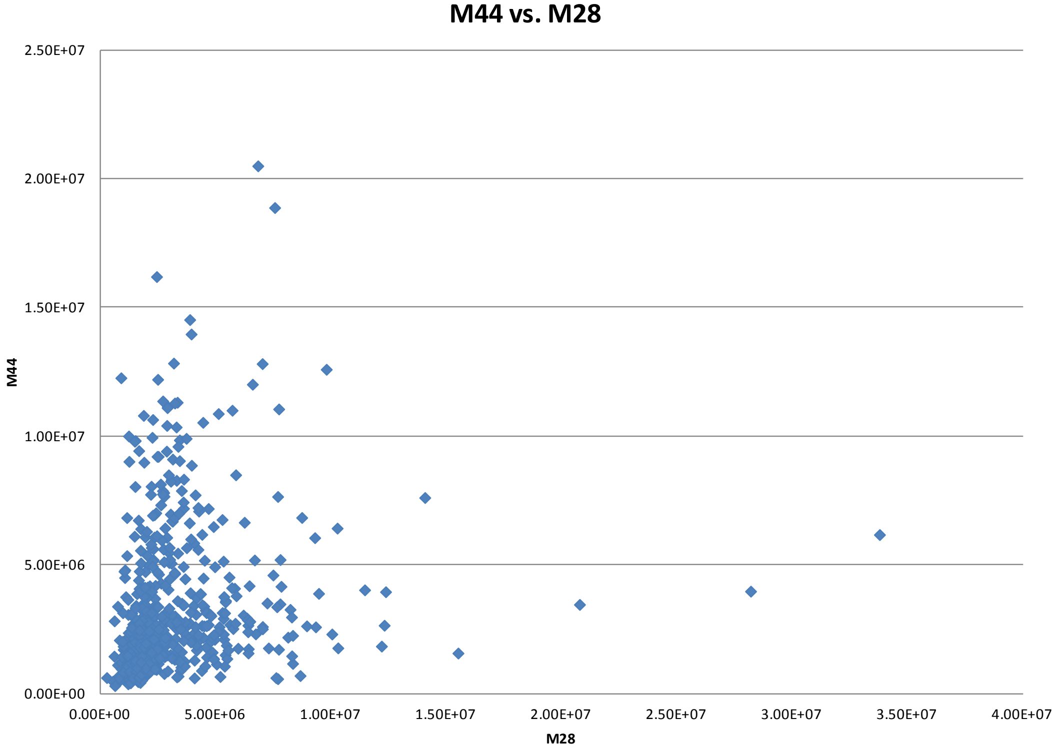


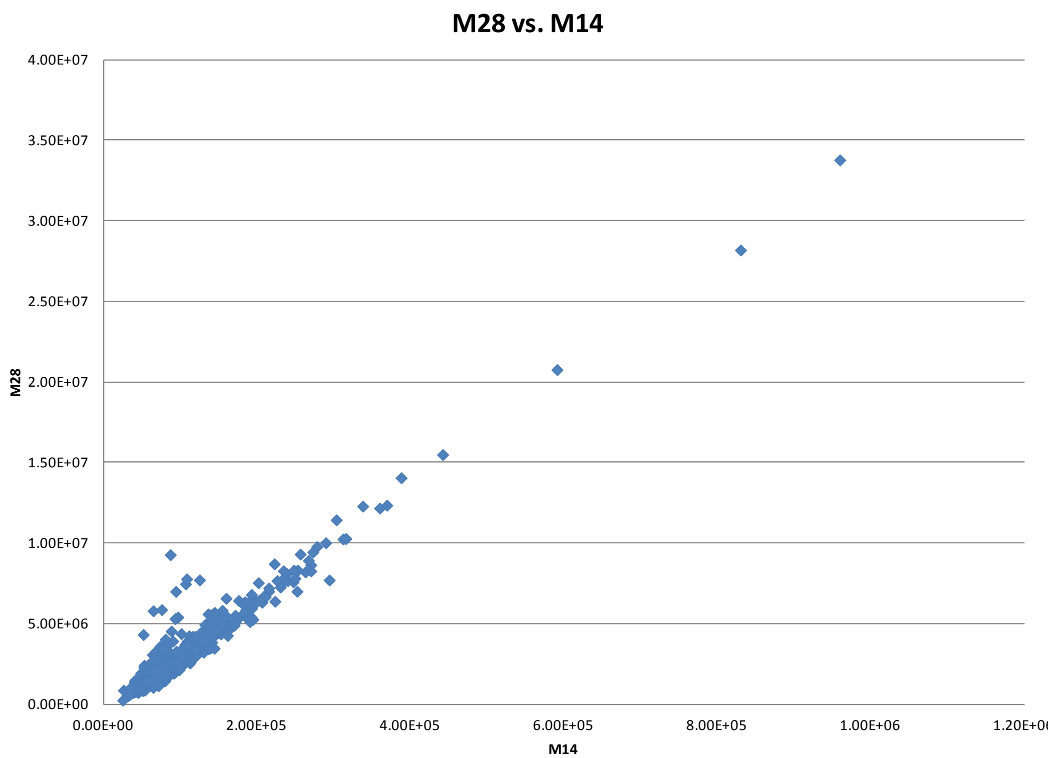
Coso Well 33-7





Coso Well 38C-9





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Coso Well 38C-9

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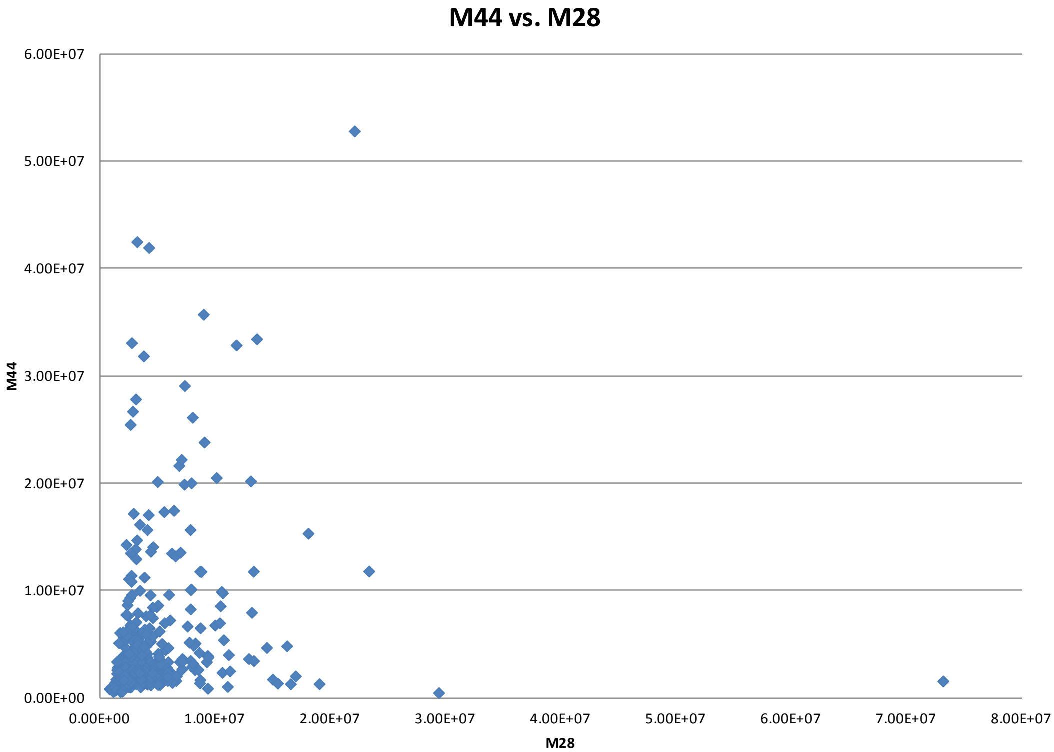
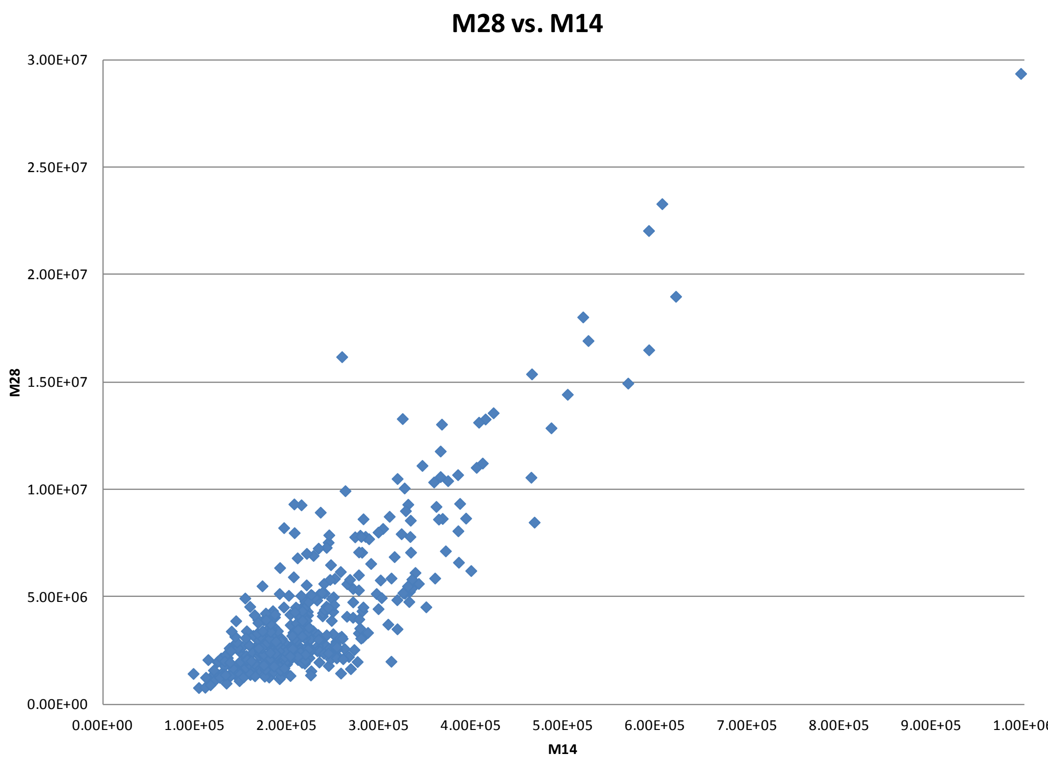
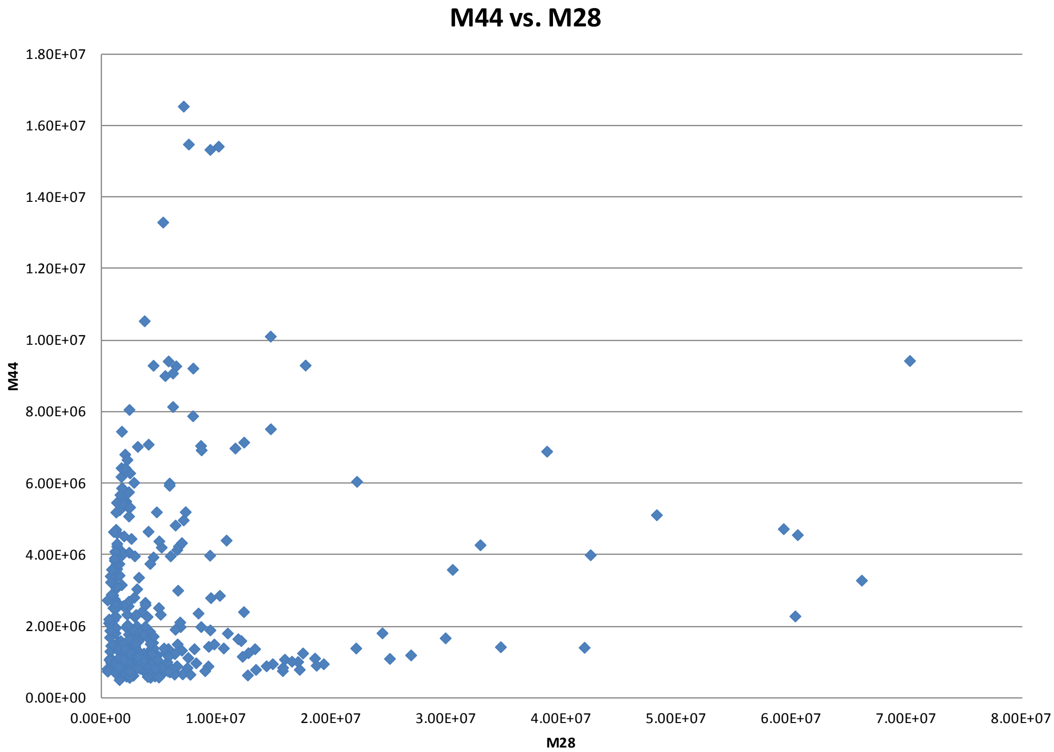
Figure 23

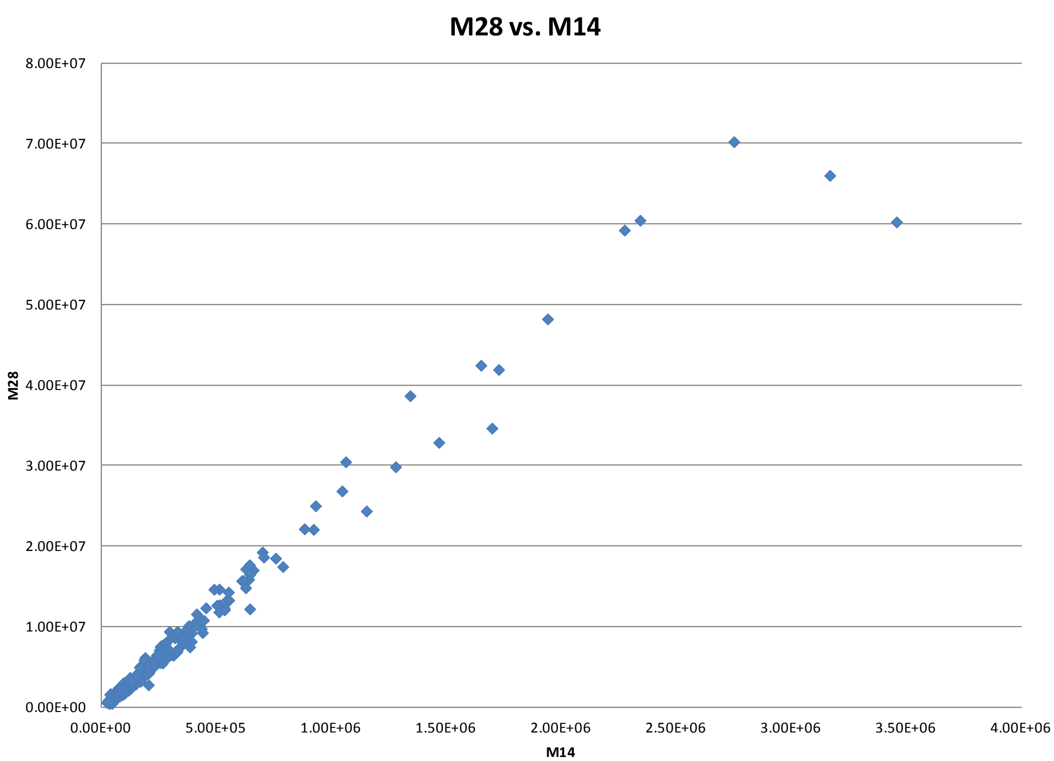
Coso Well 38D-9



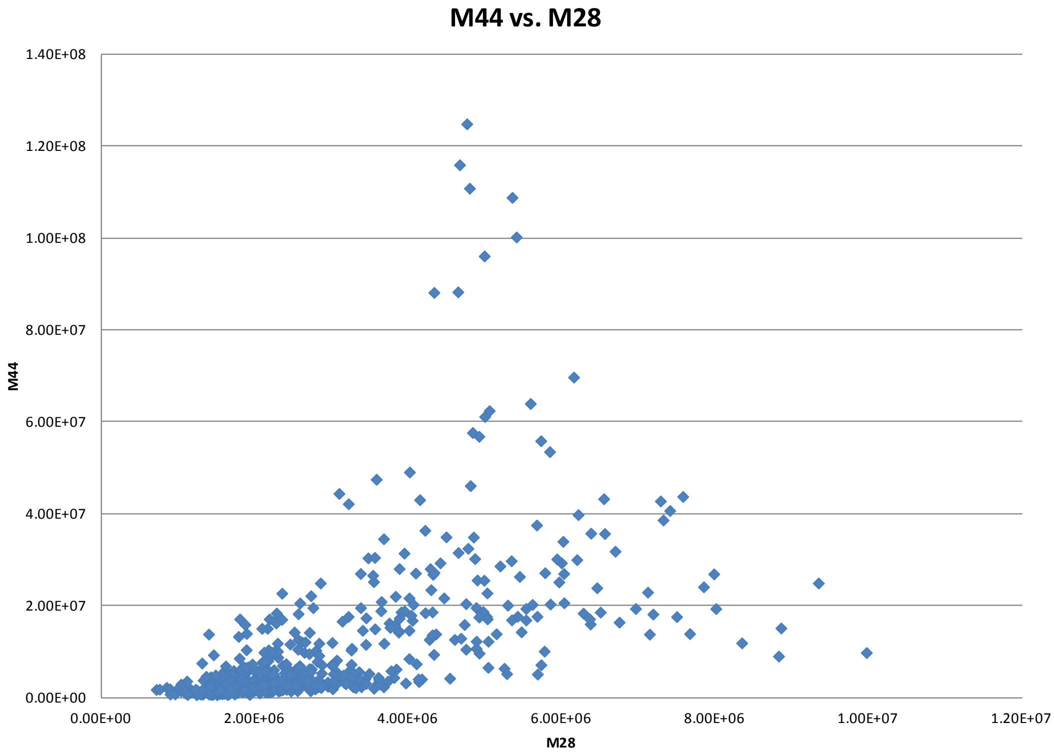


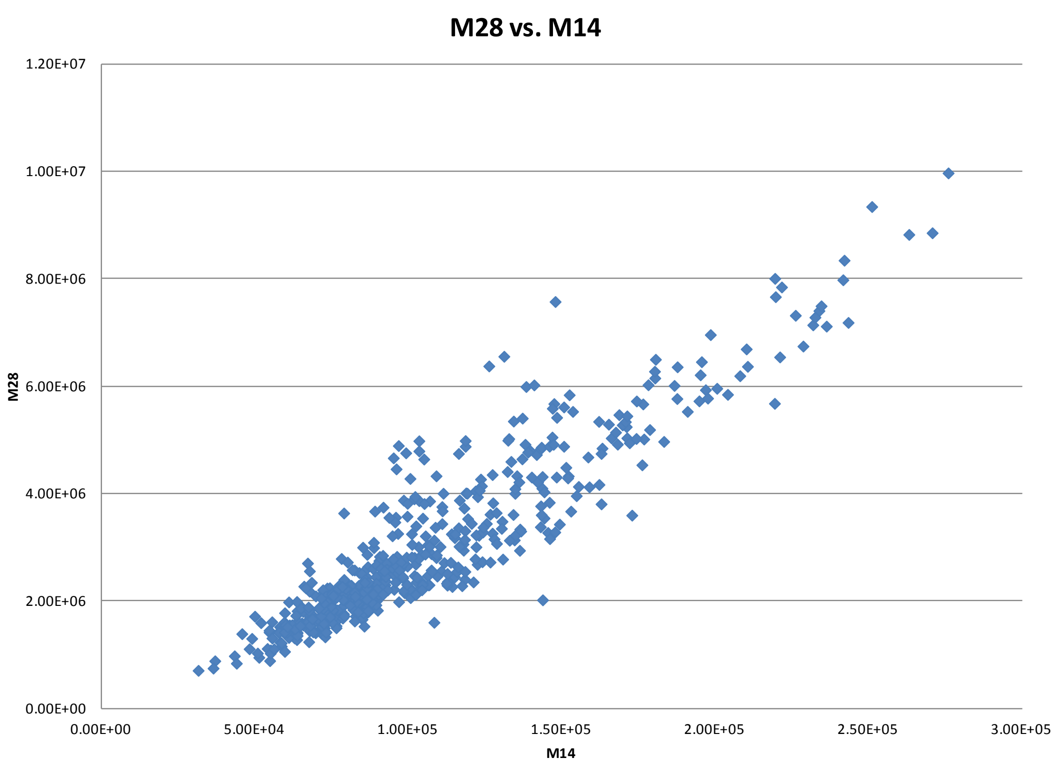
Coso Well 41B-8





Coso Well 46A-19RD





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Coso Well 46A-19RD
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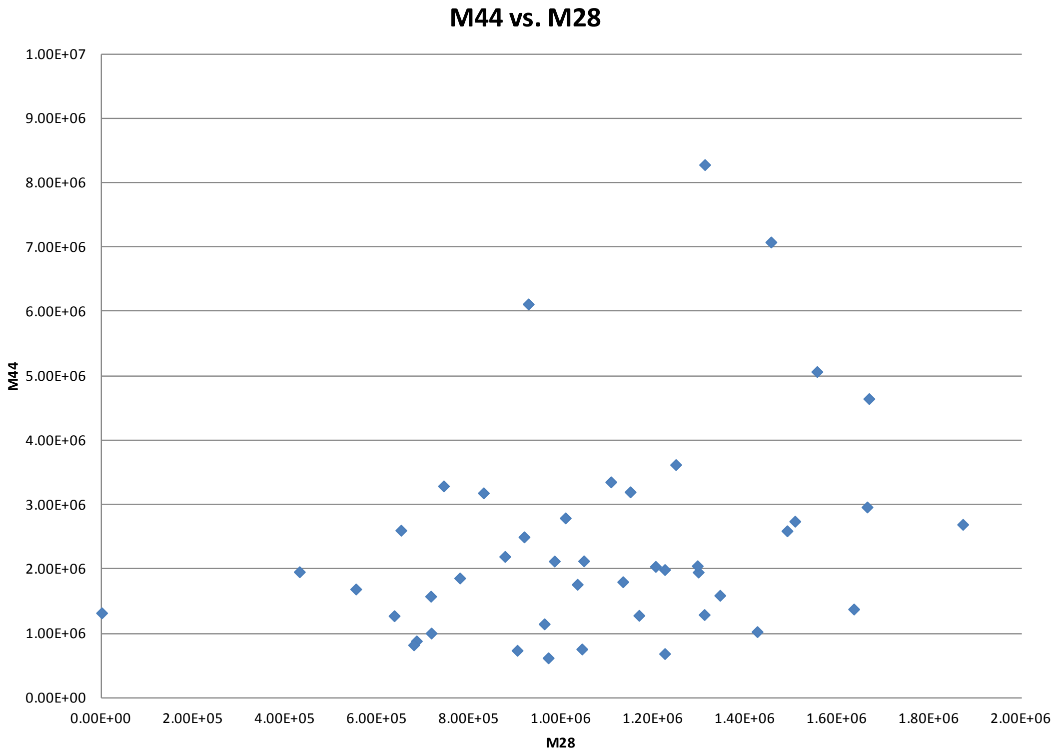
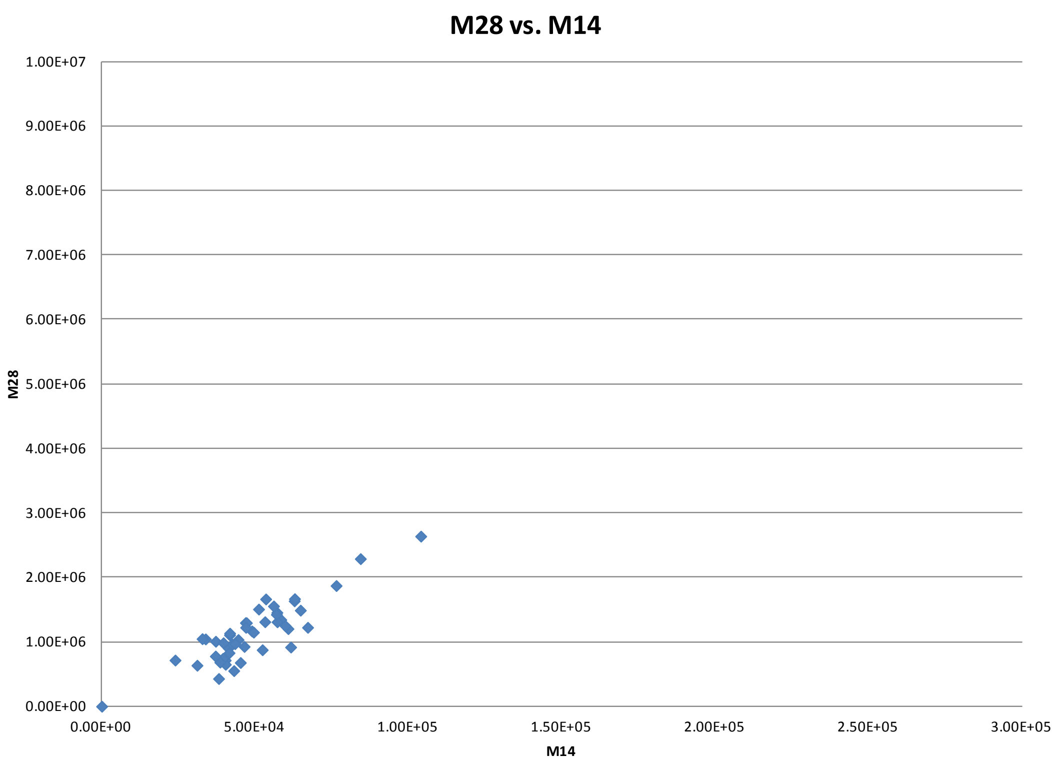
Figure 26

Coso Well 47A-8





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Coso Well 47A-8

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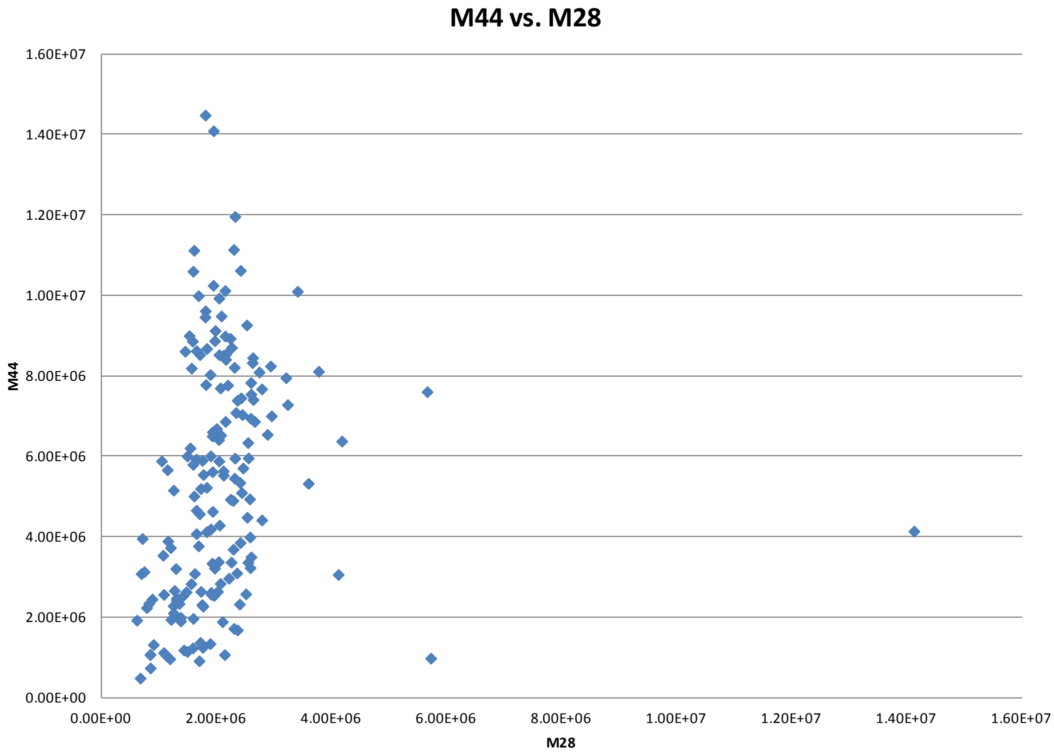
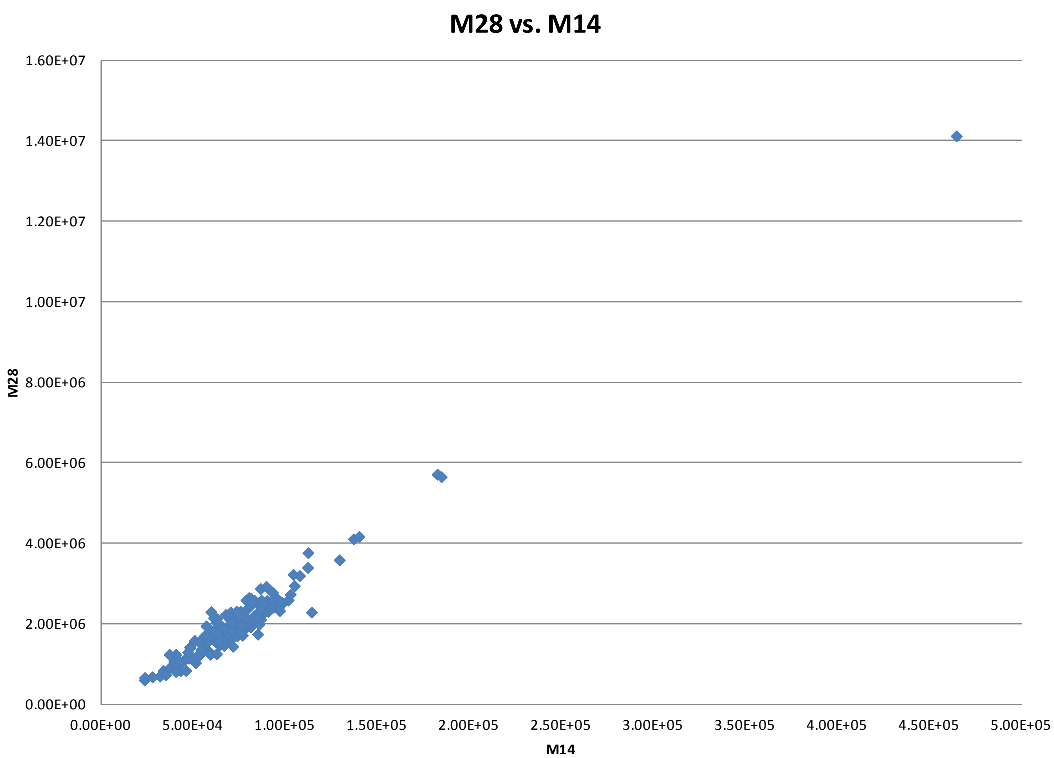
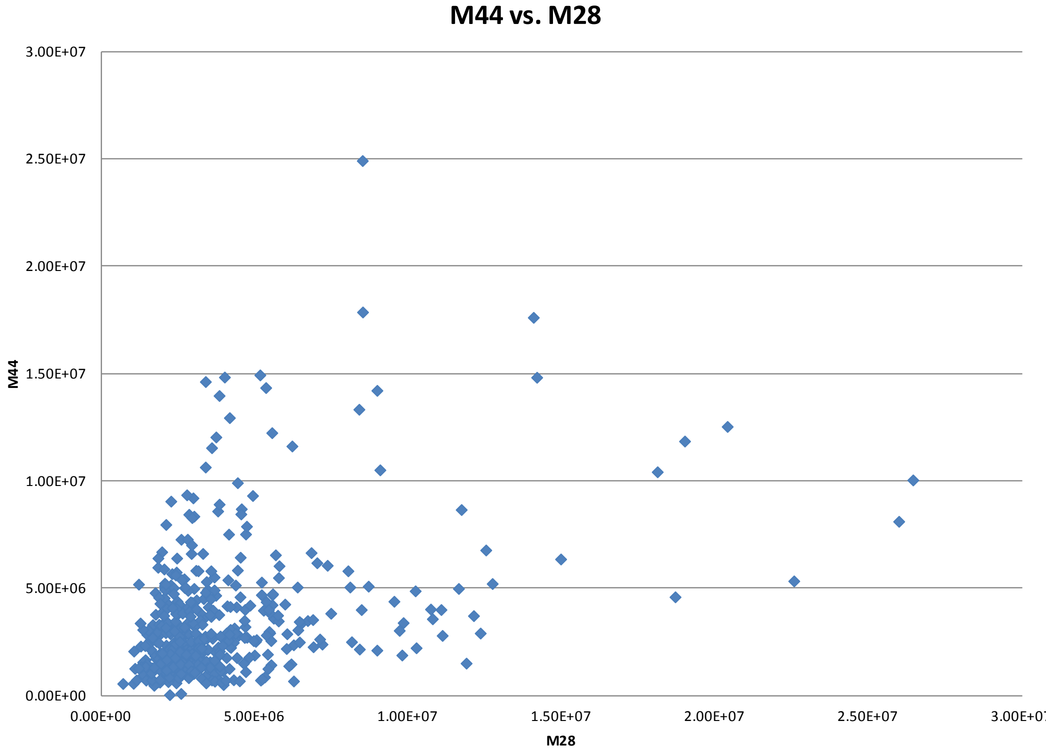
Figure 27

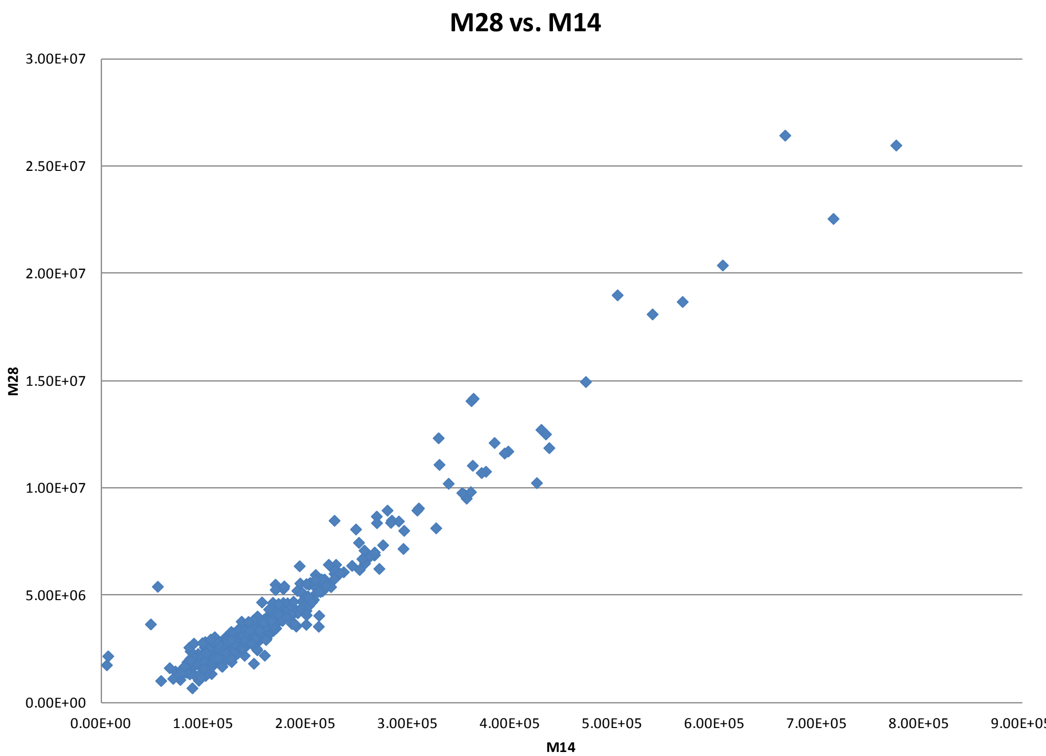
Coso Well 47A-8RD





Coso Well 51B-16





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Coso Well 51B-16
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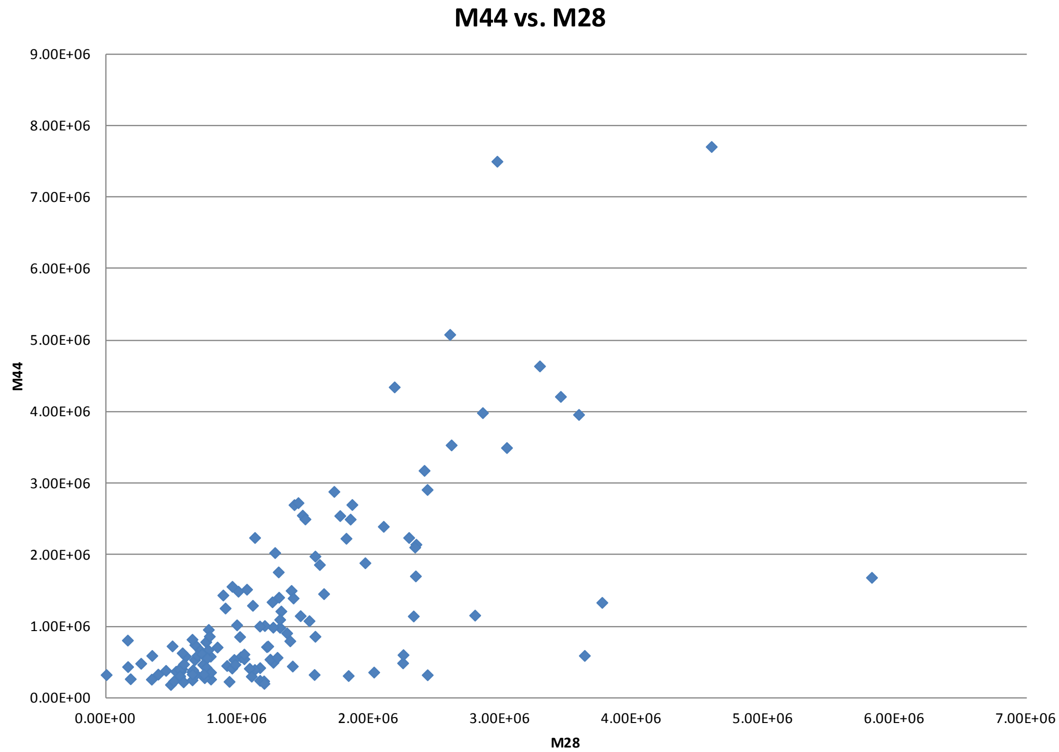
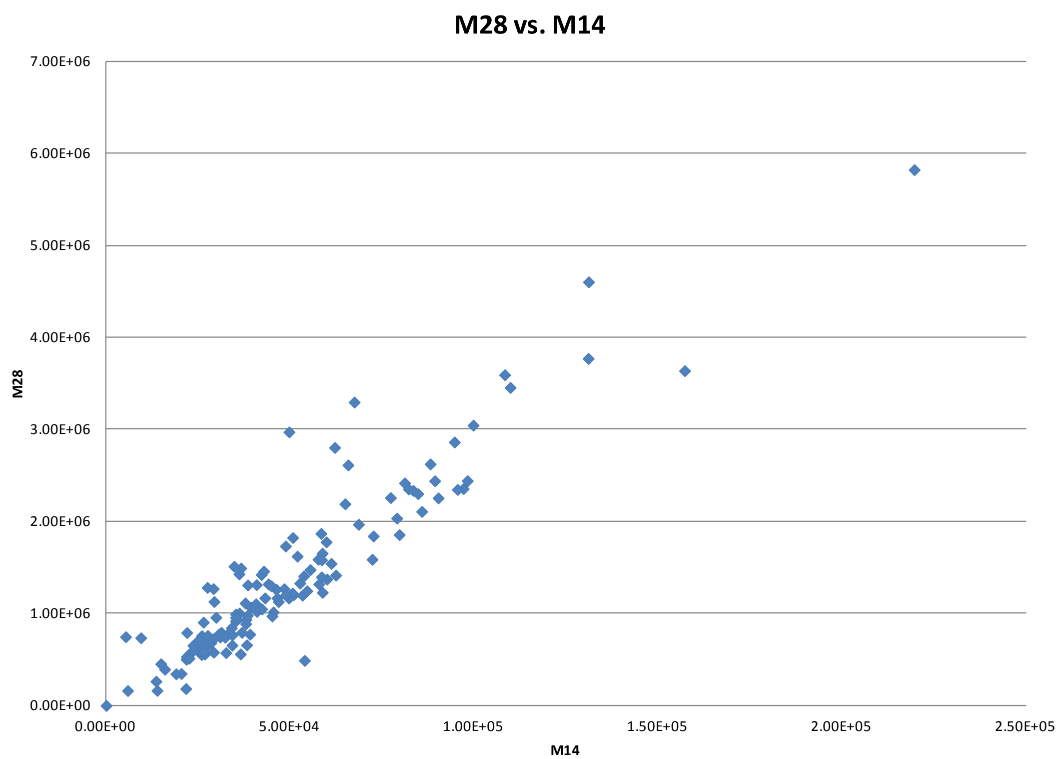
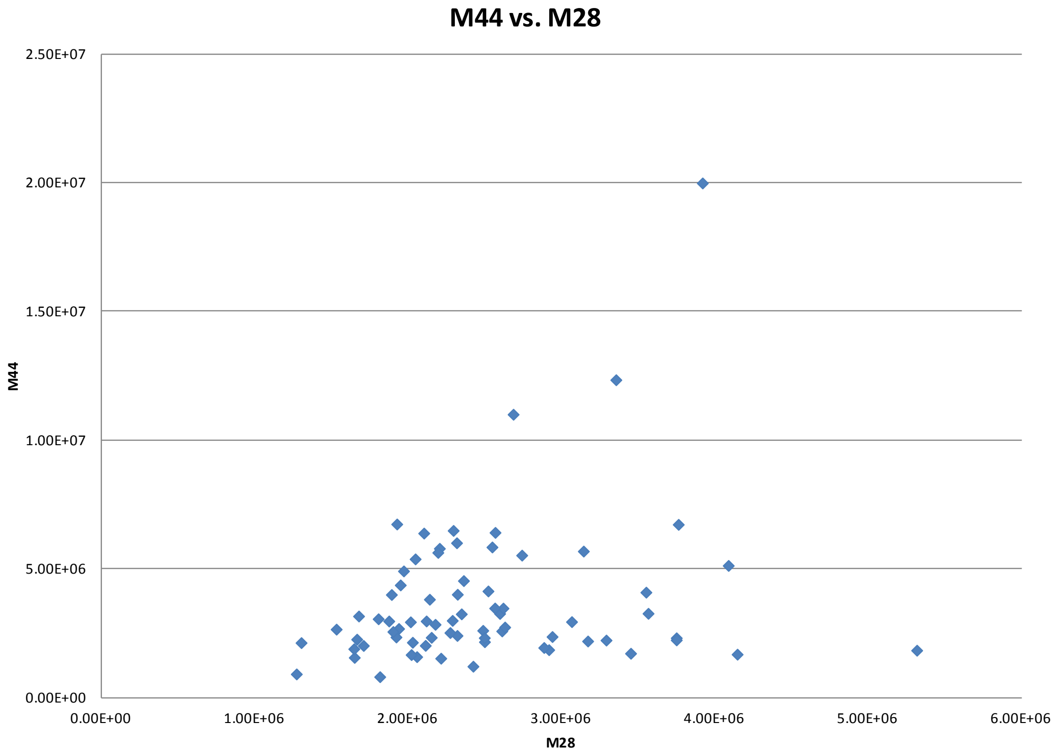
Figure 29

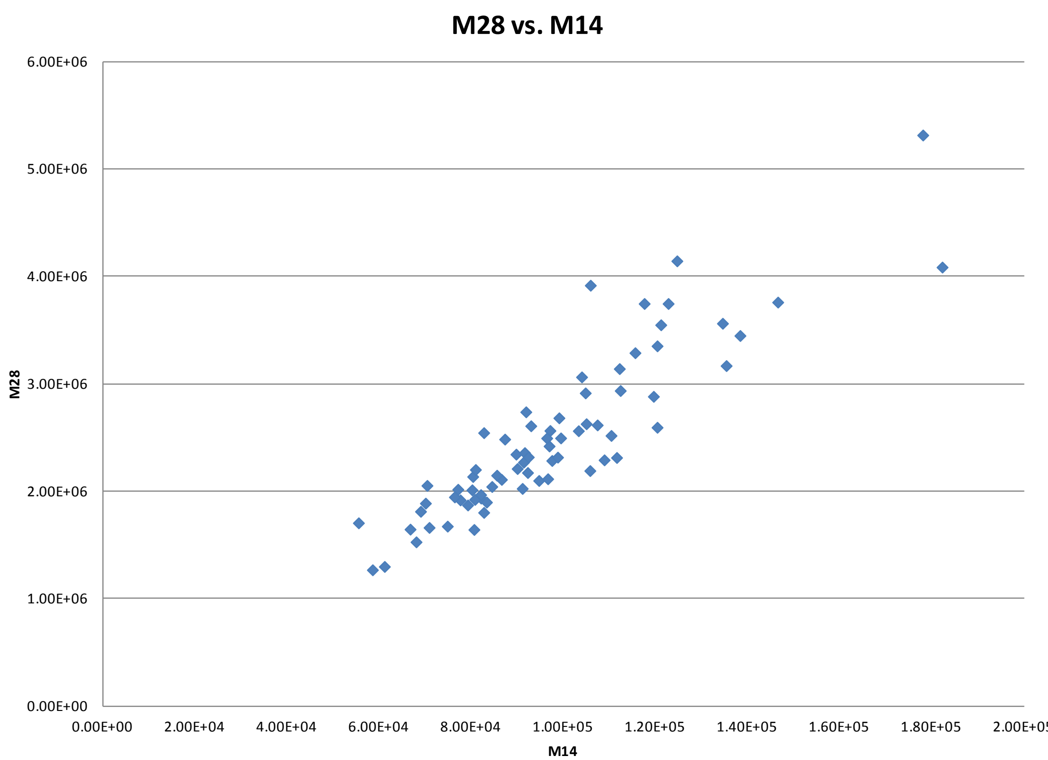
Coso Well 52-20



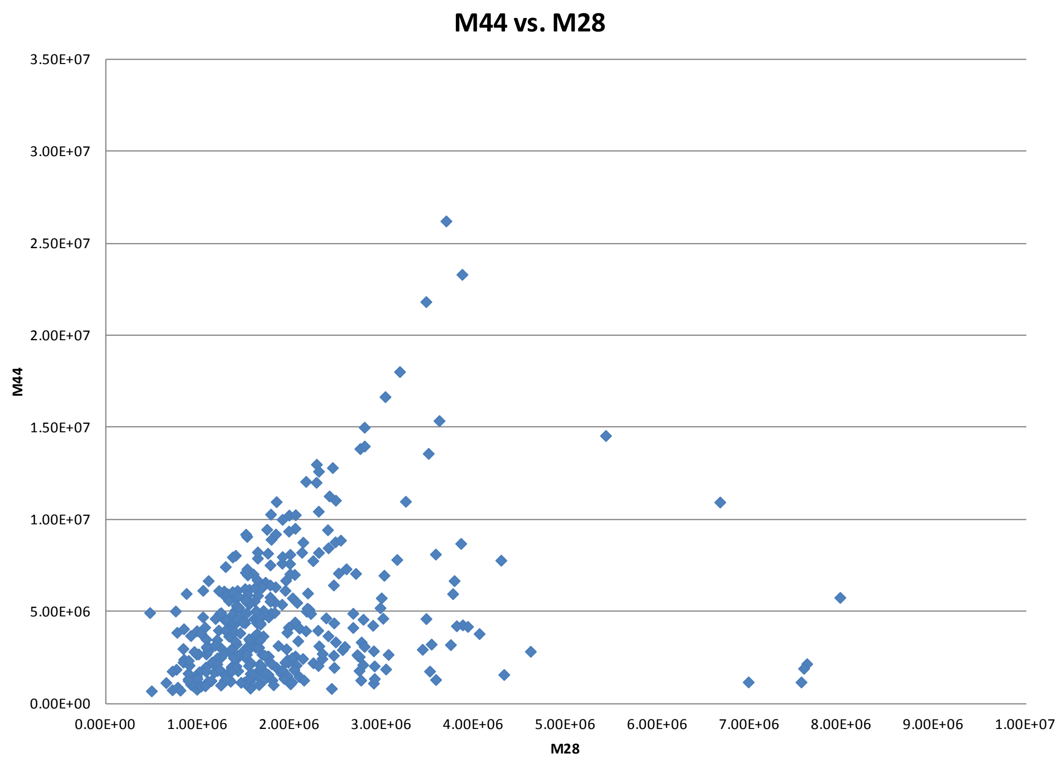


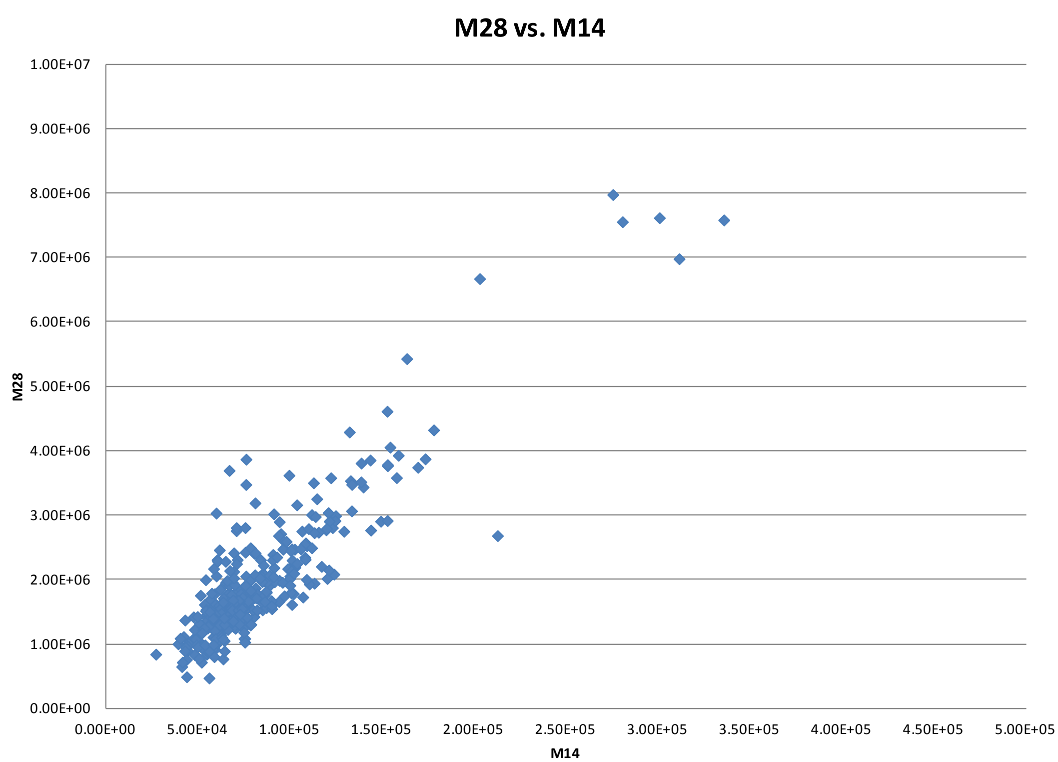
Coso Well 54-7



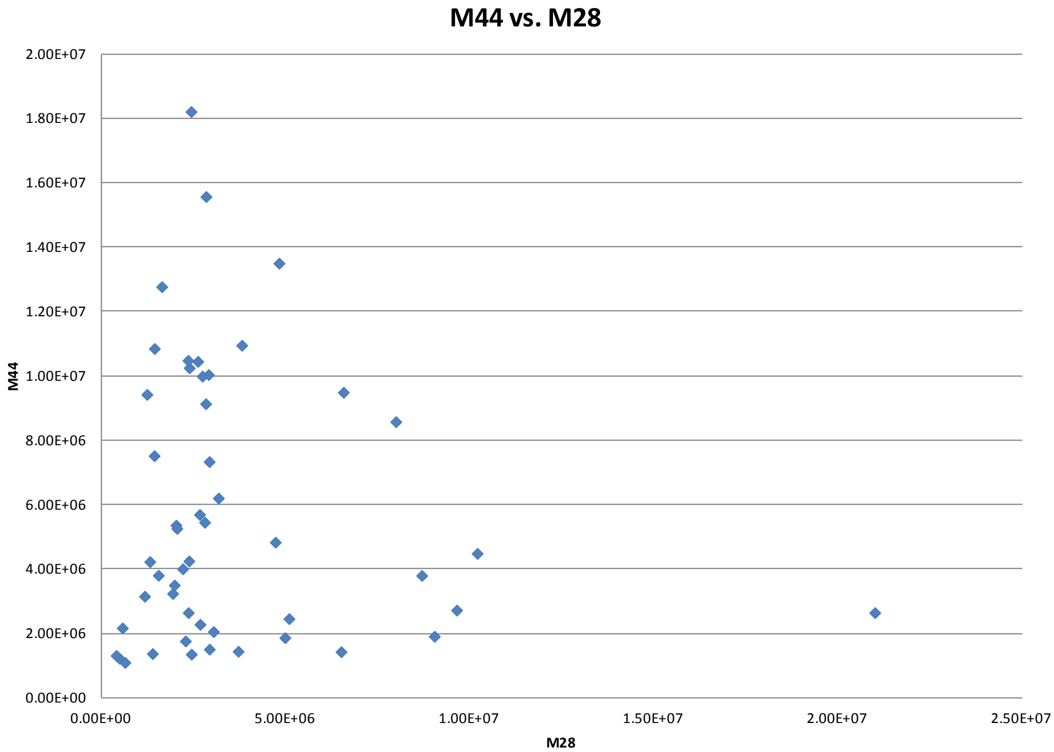


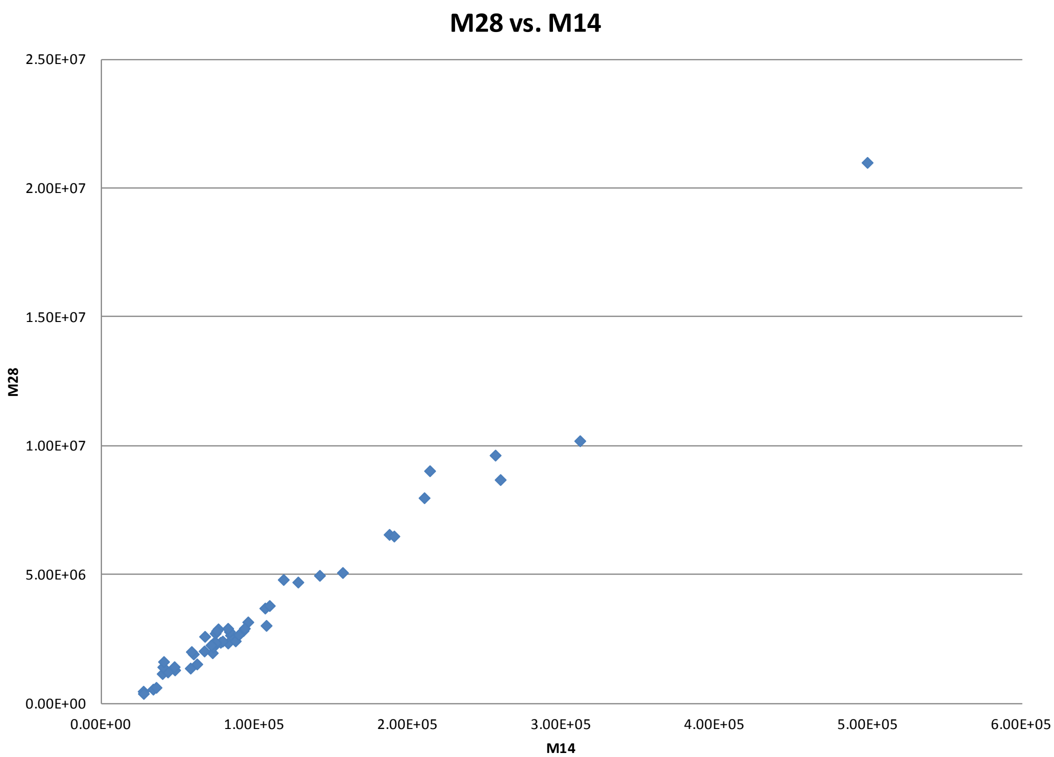
Coso Well 54-7RD





Coso Well 58A10





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Coso Well 58A10
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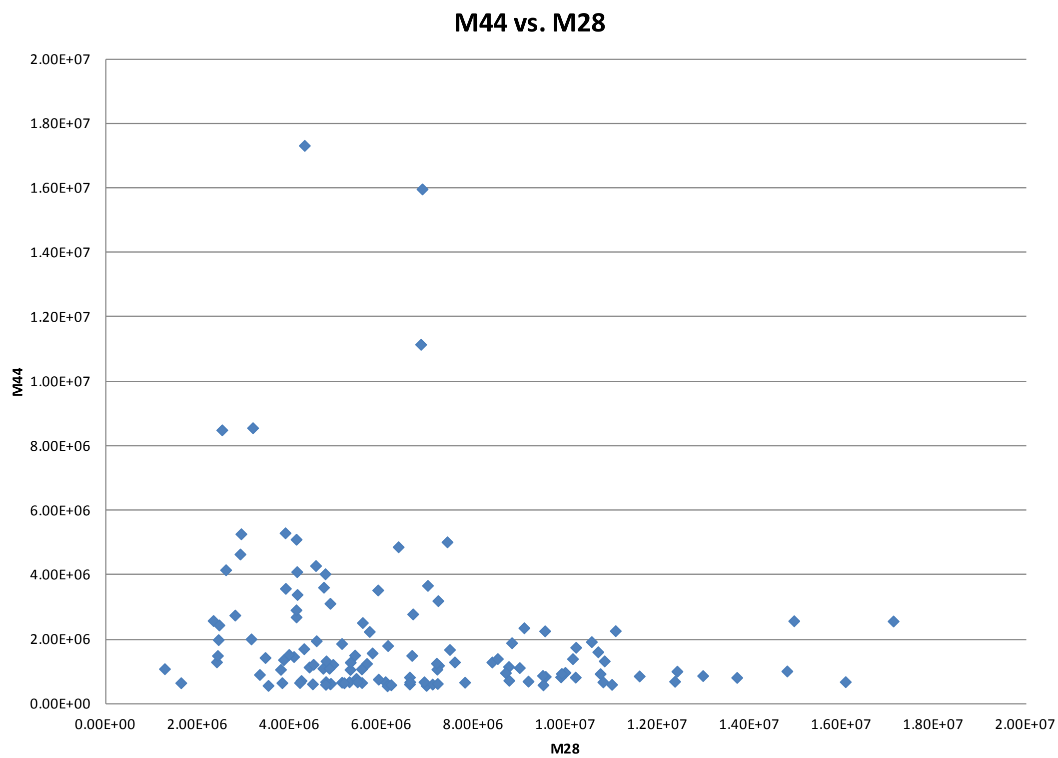
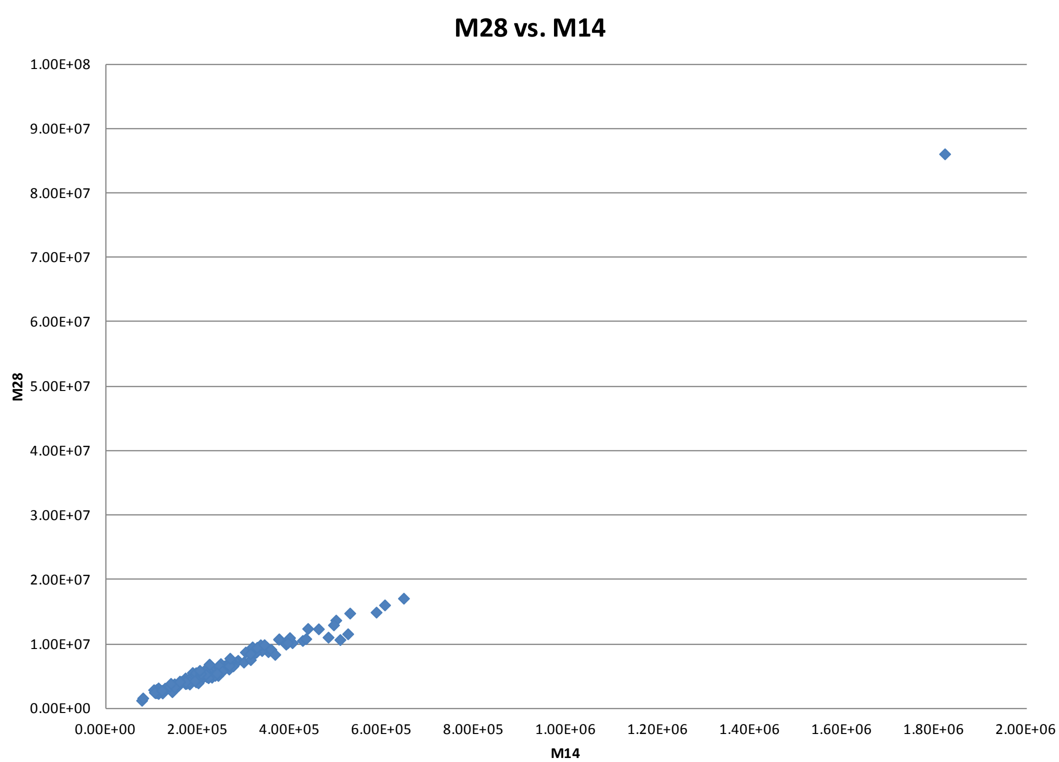
Figure 33

Coso Well 58A-10





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Coso Well 58A-10
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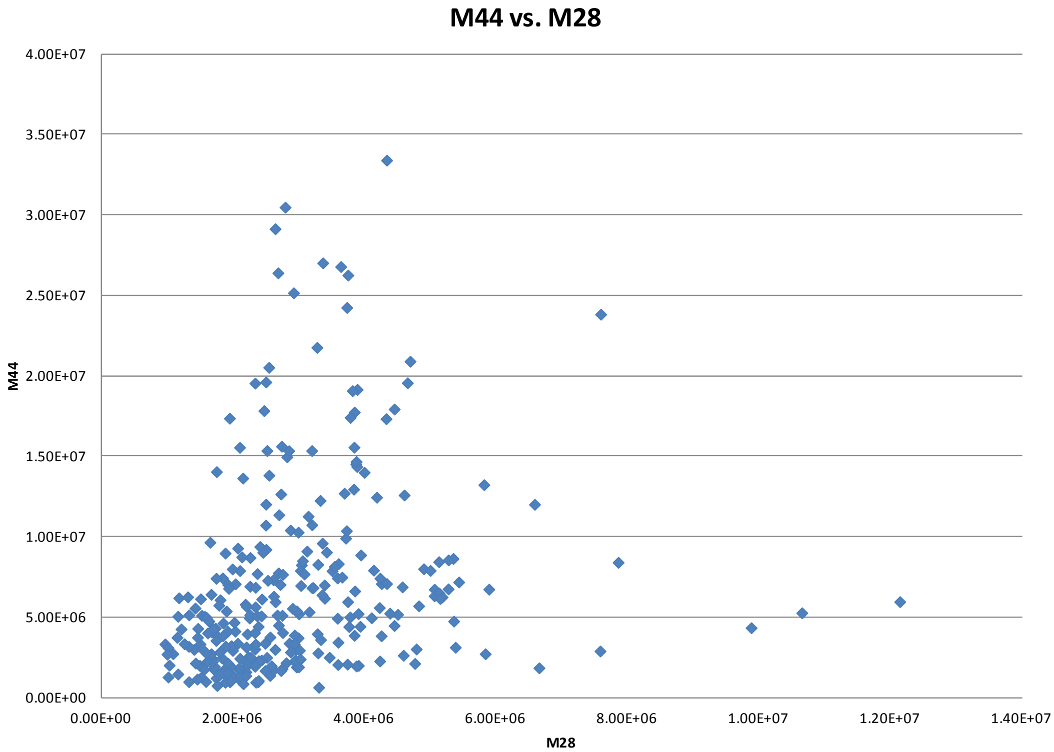
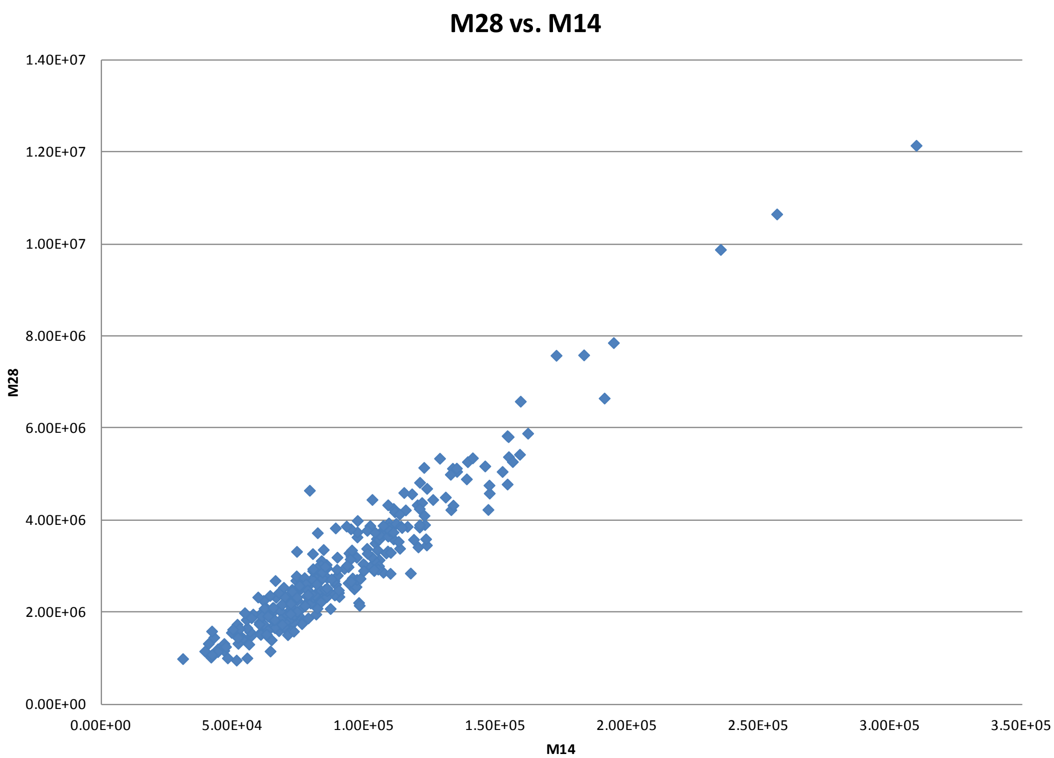
Figure 34

Coso Well 58A-18





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Coso Well 58A-18
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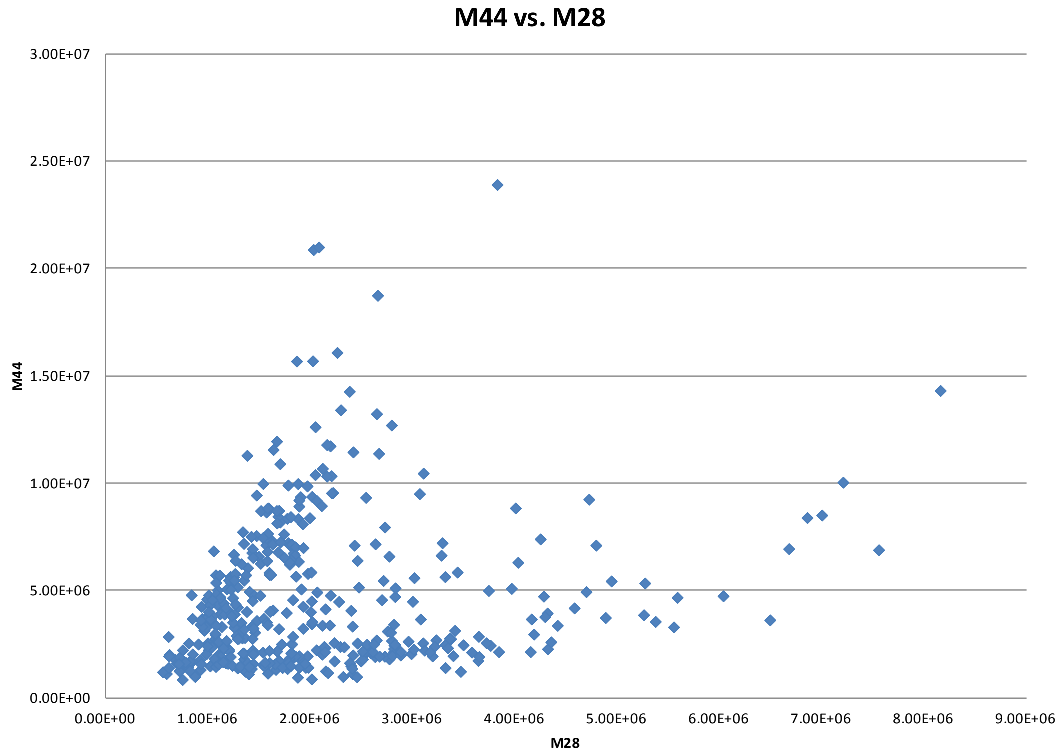
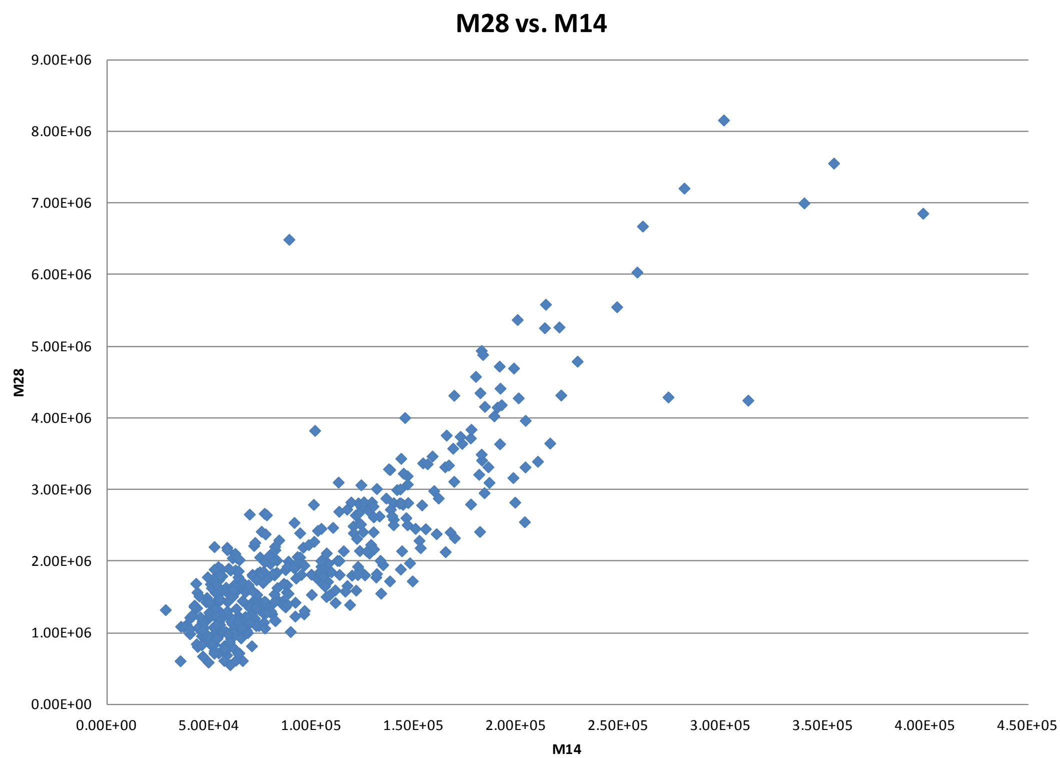
Figure 35

Coso Well 67-17





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Coso Well 67-17

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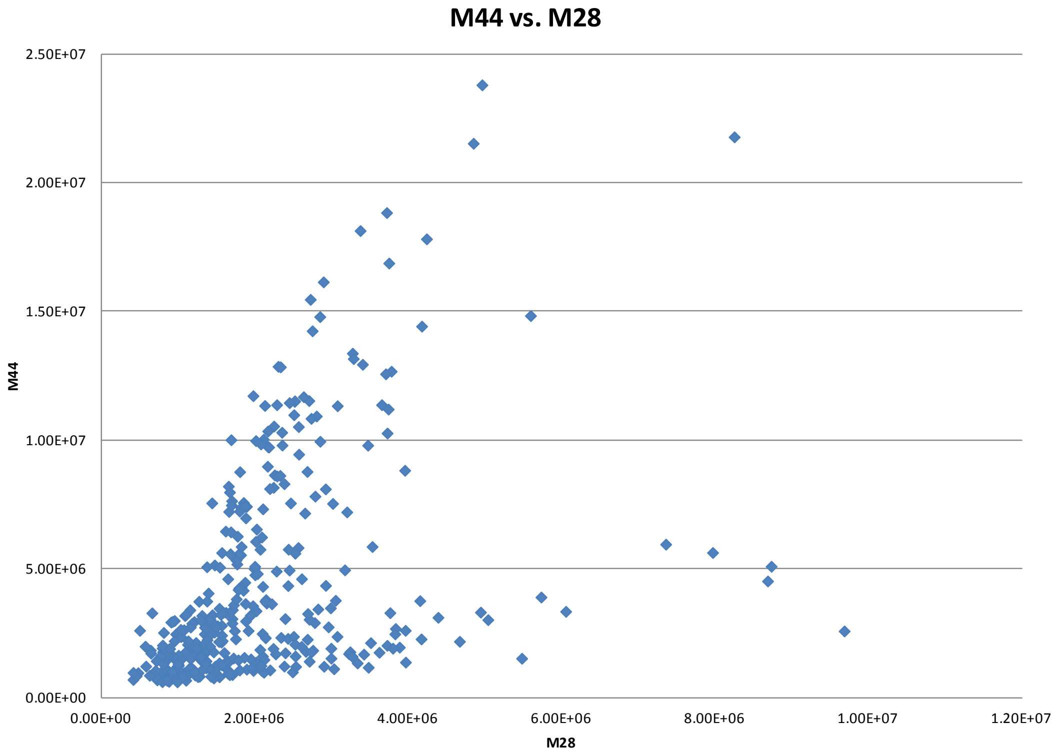
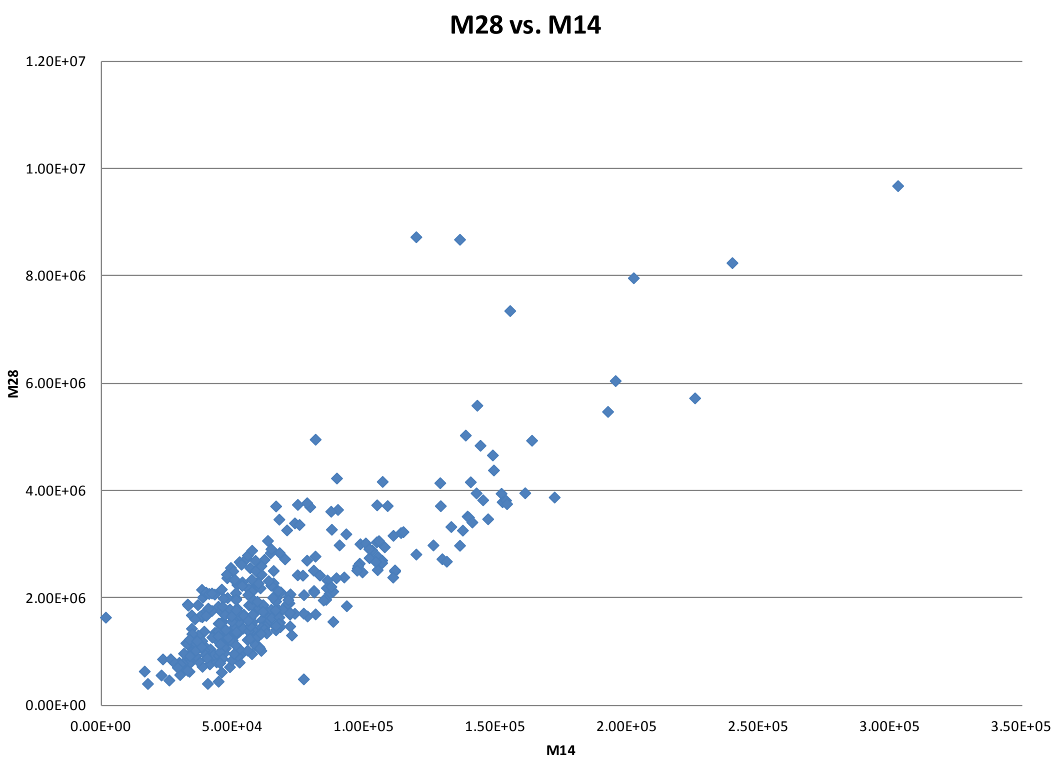
Figure 36

Coso Well 67C-17





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Coso Well 67C-17

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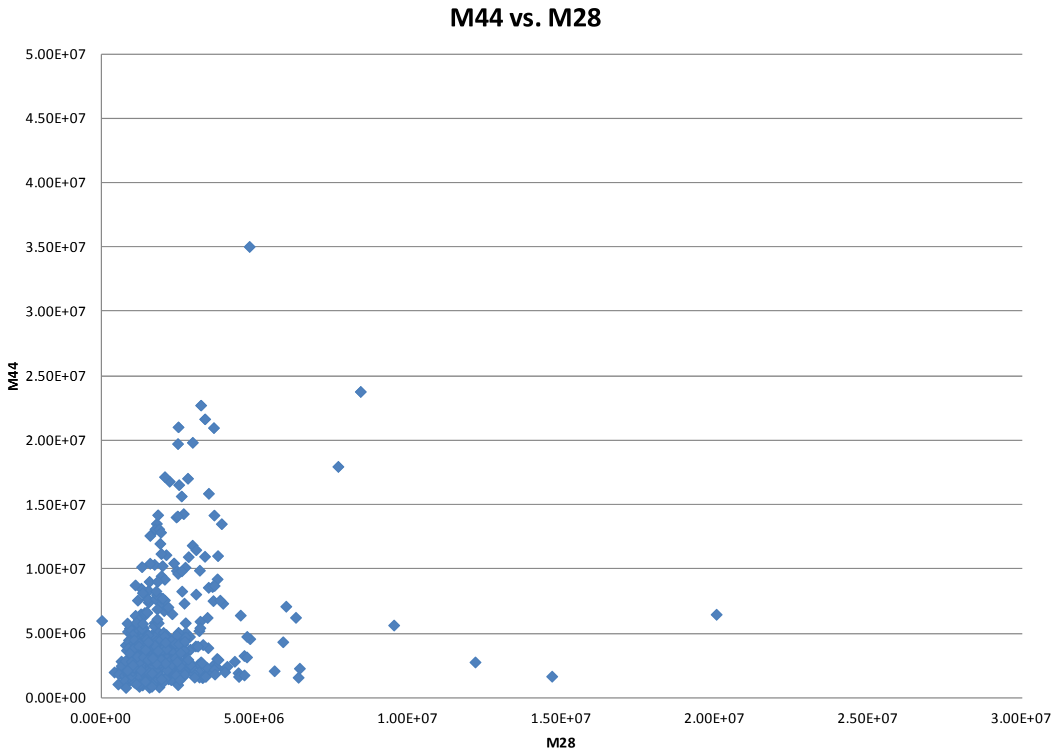
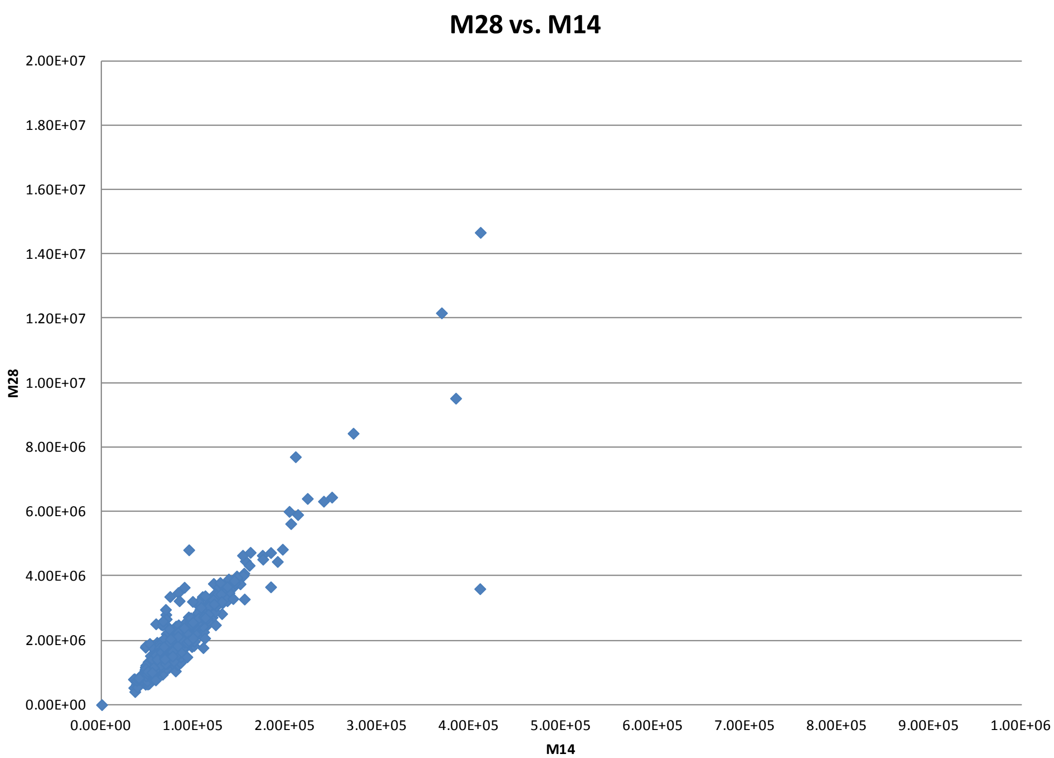
Figure 37

Coso Well 68-6





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Coso Well 68-6

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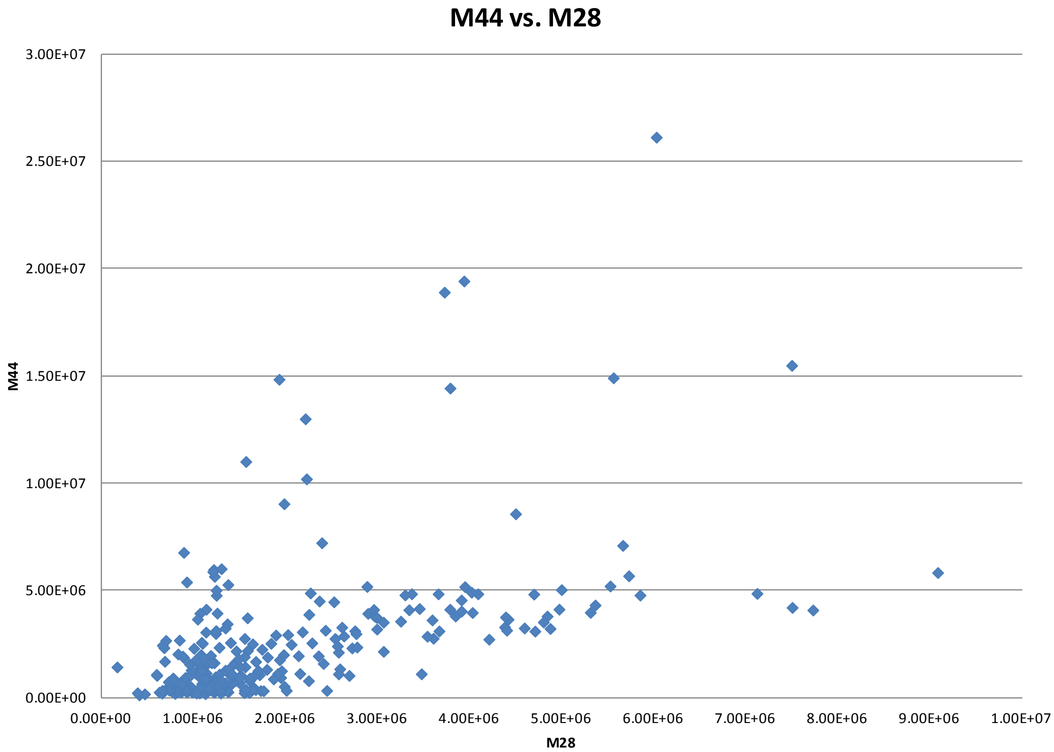
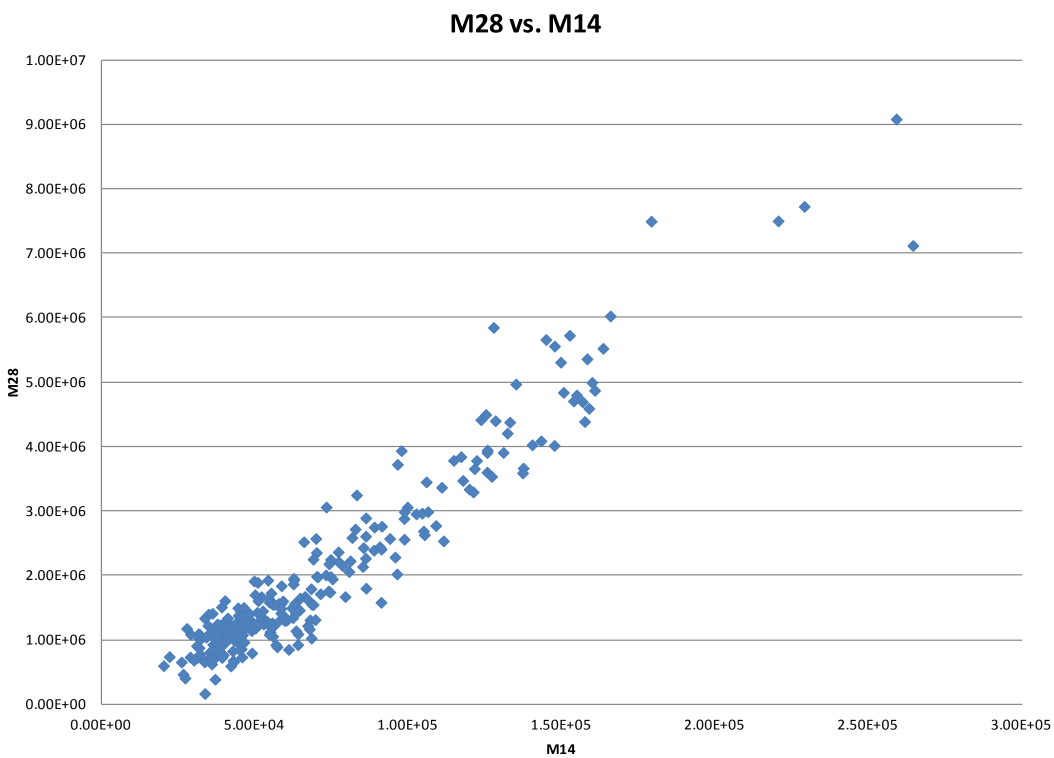
Figure 38

Coso Well 68-20





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Coso Well 68-20

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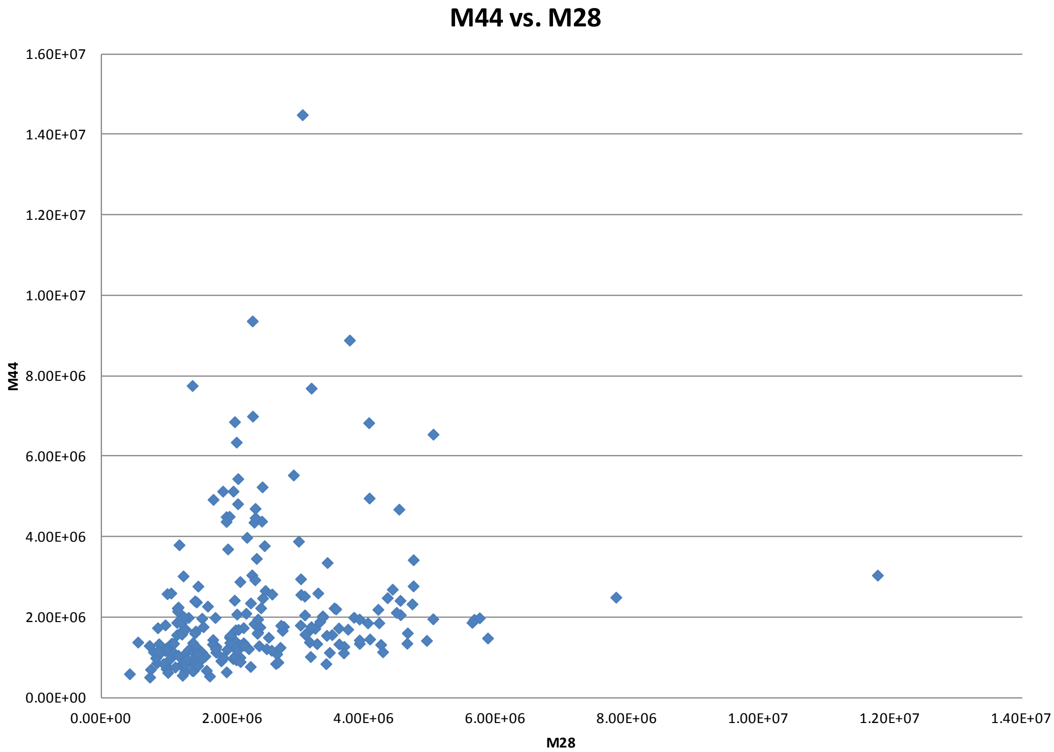
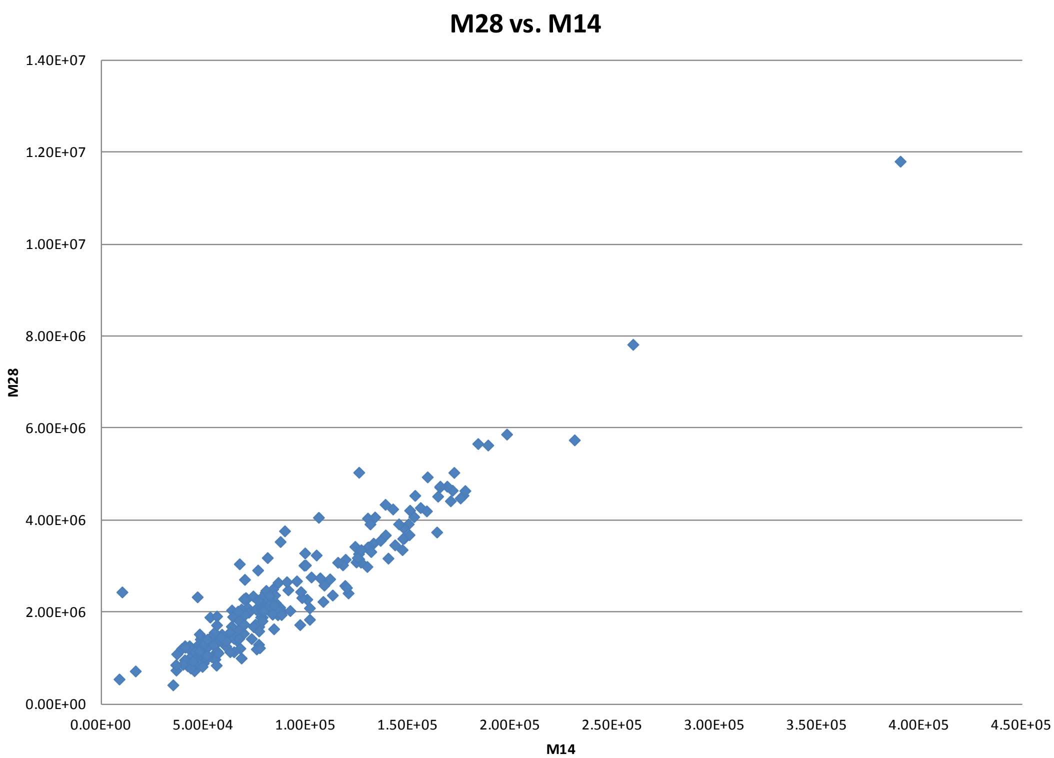
Figure 39

Coso Well 68-20RD





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Coso Well 68-20RD
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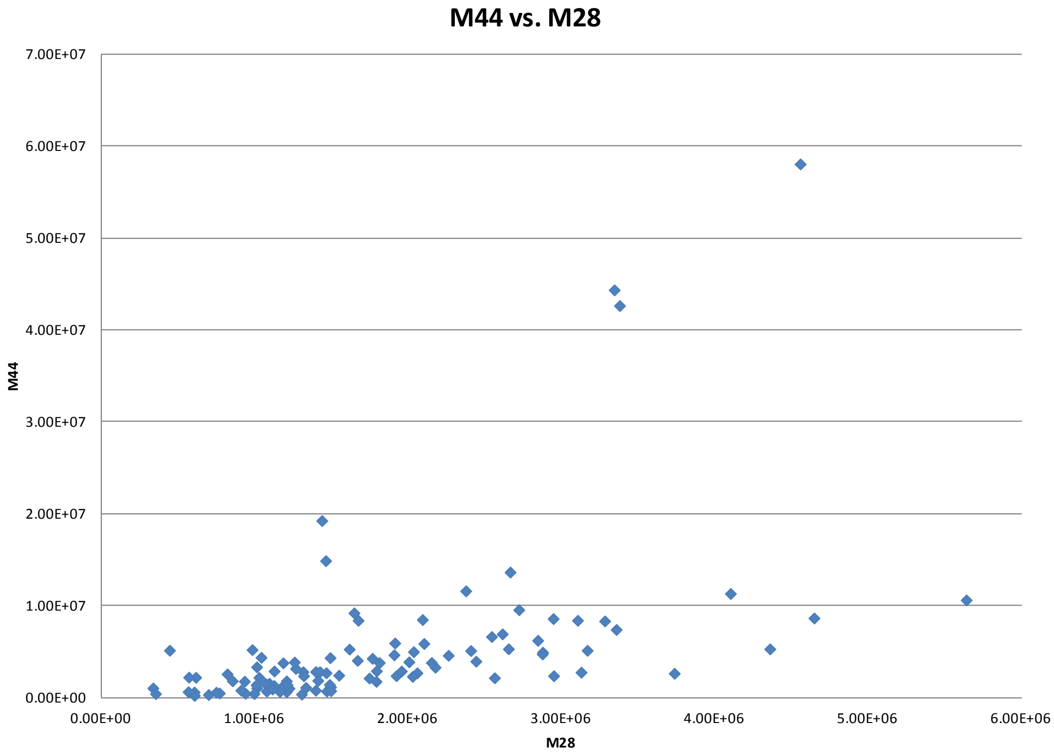
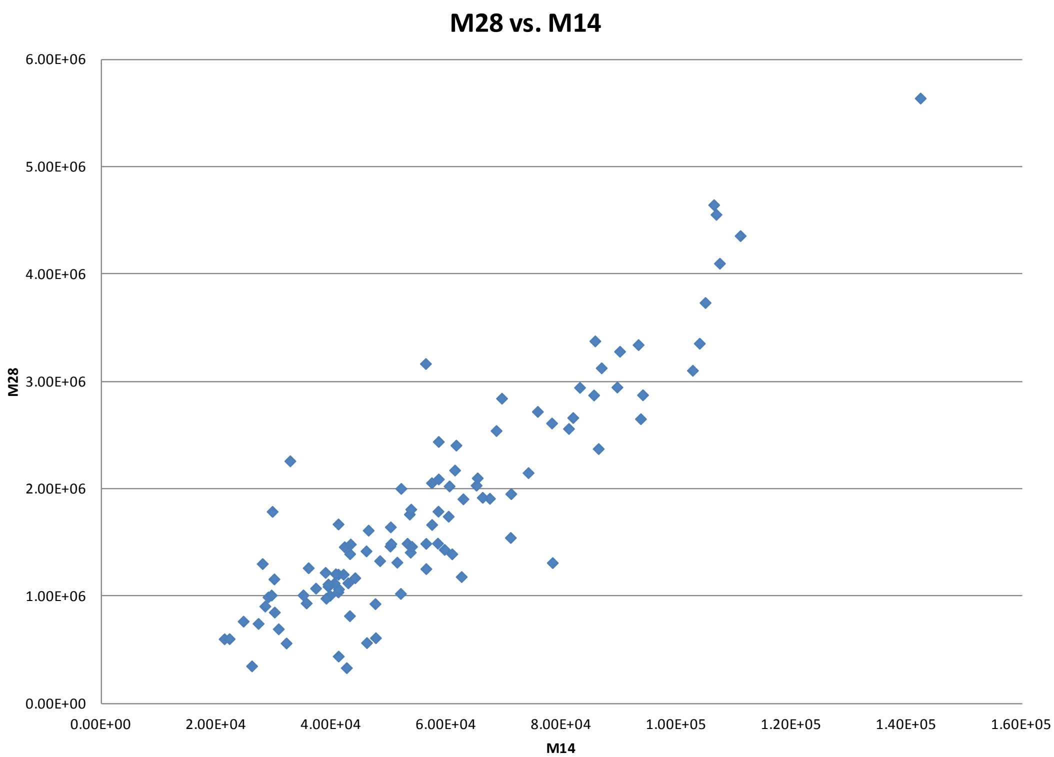
Figure 40

Coso Well 73-19





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Coso Well 73-19

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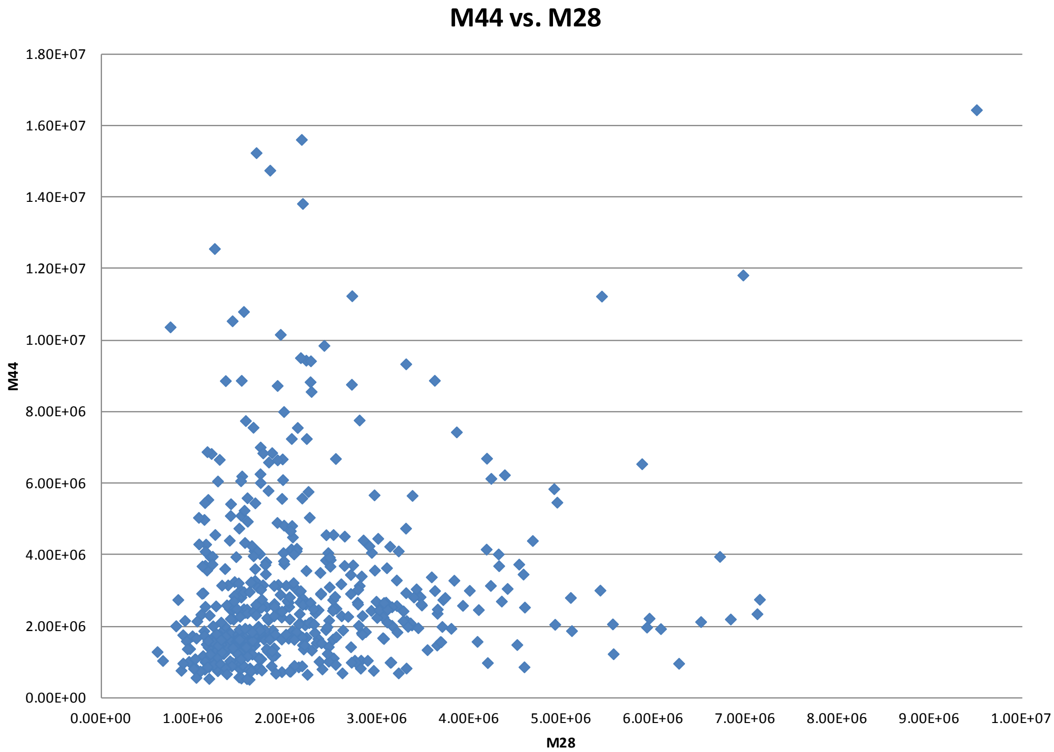
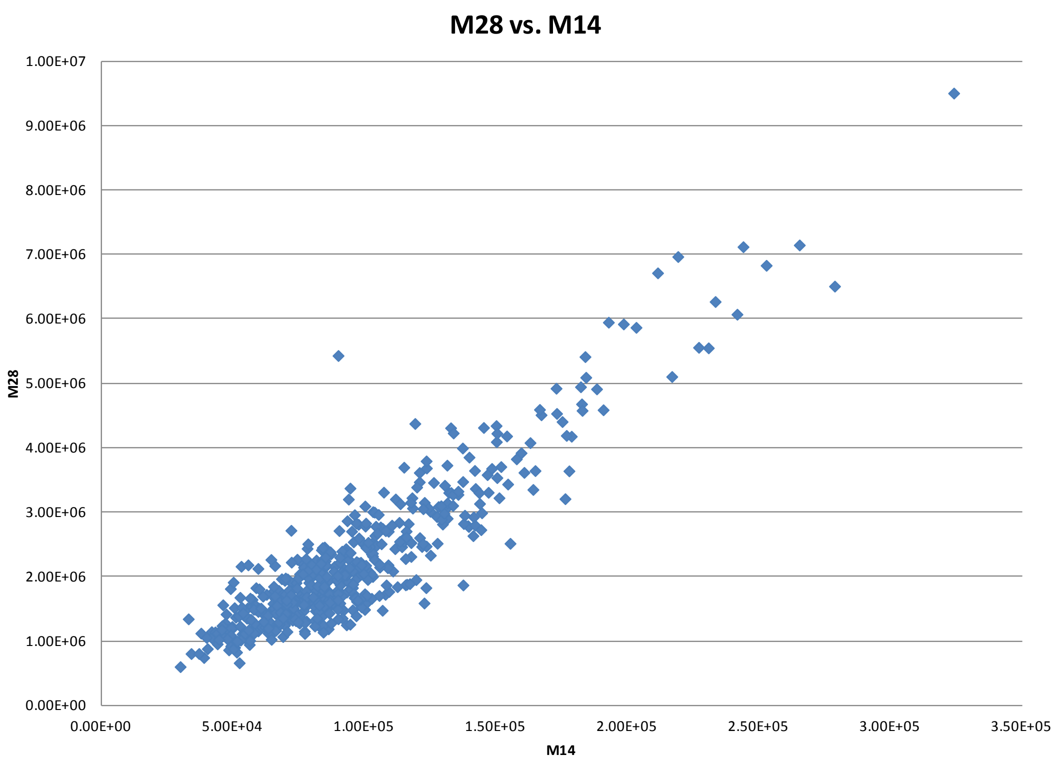
Figure 41

Coso Well 83B-16





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Coso Well 83B-16
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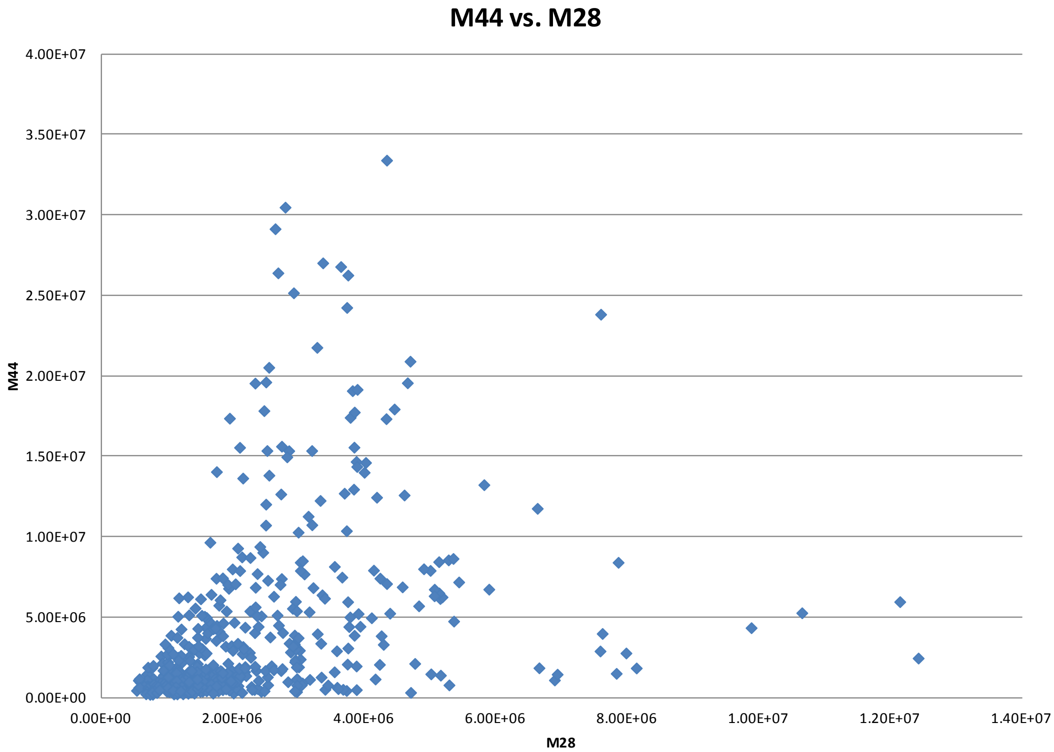
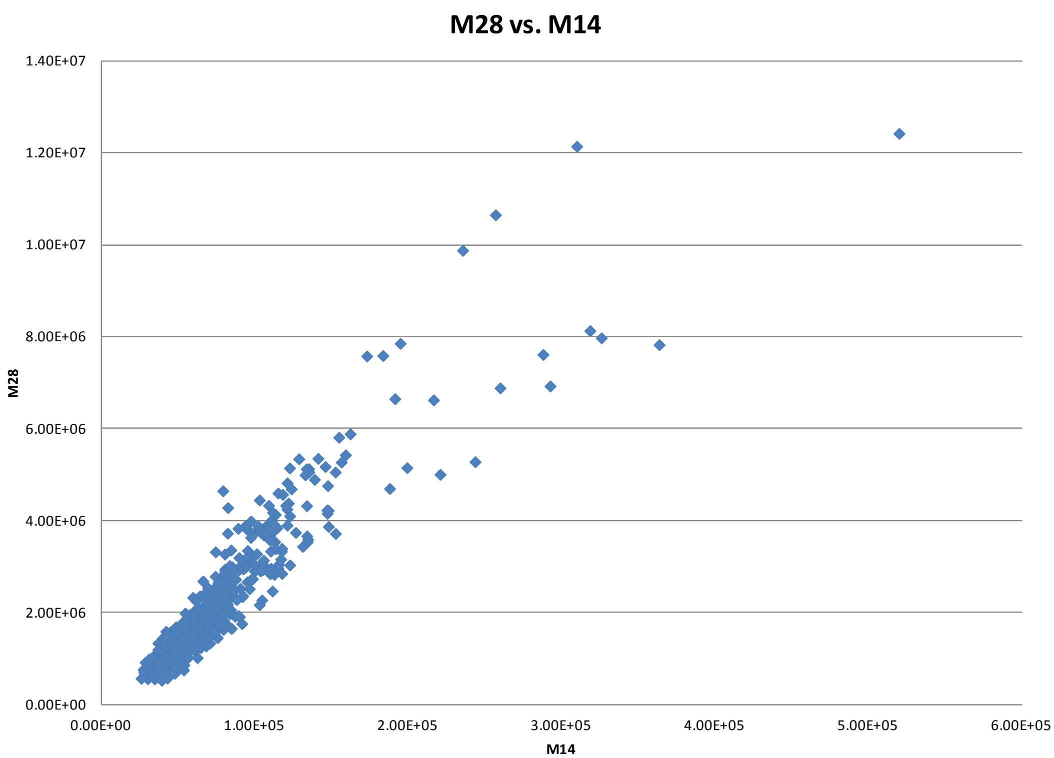
Figure 42

Coso Well 84-30





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Coso Well 84-30
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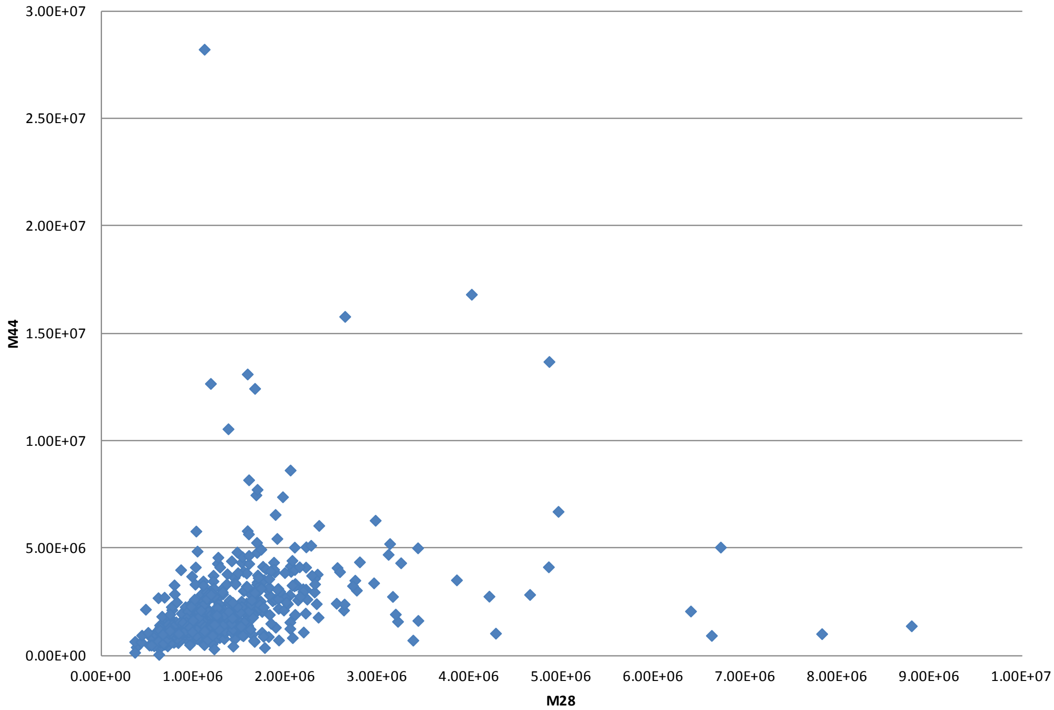
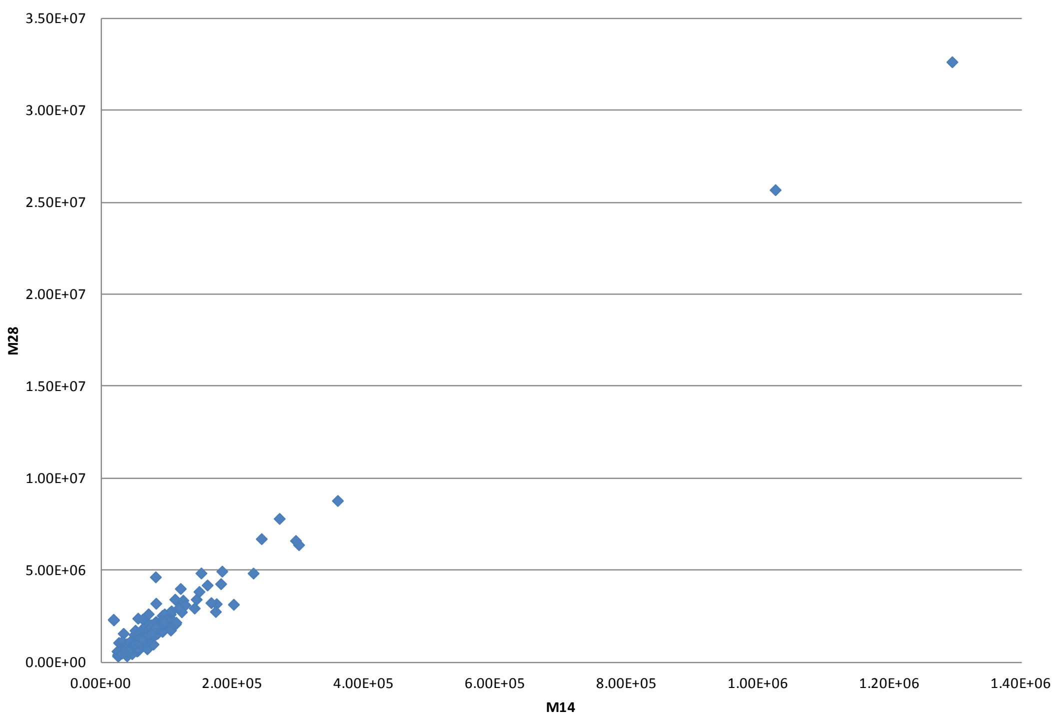
Figure 43

Coso Well 86-17

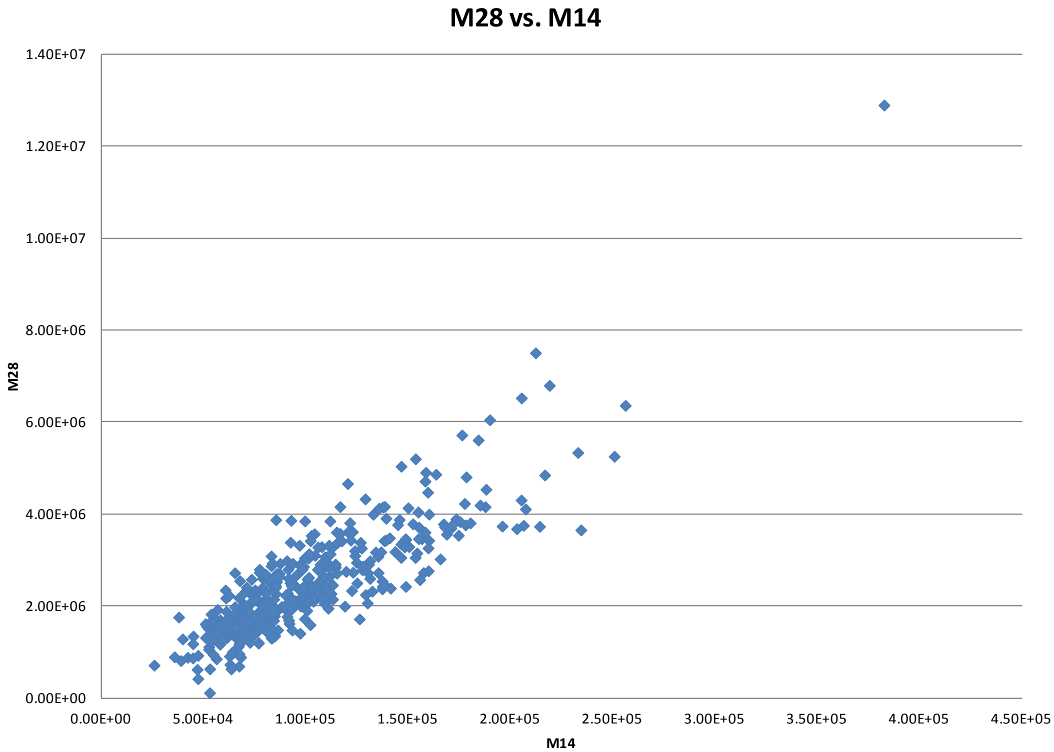
M44 vs. M28

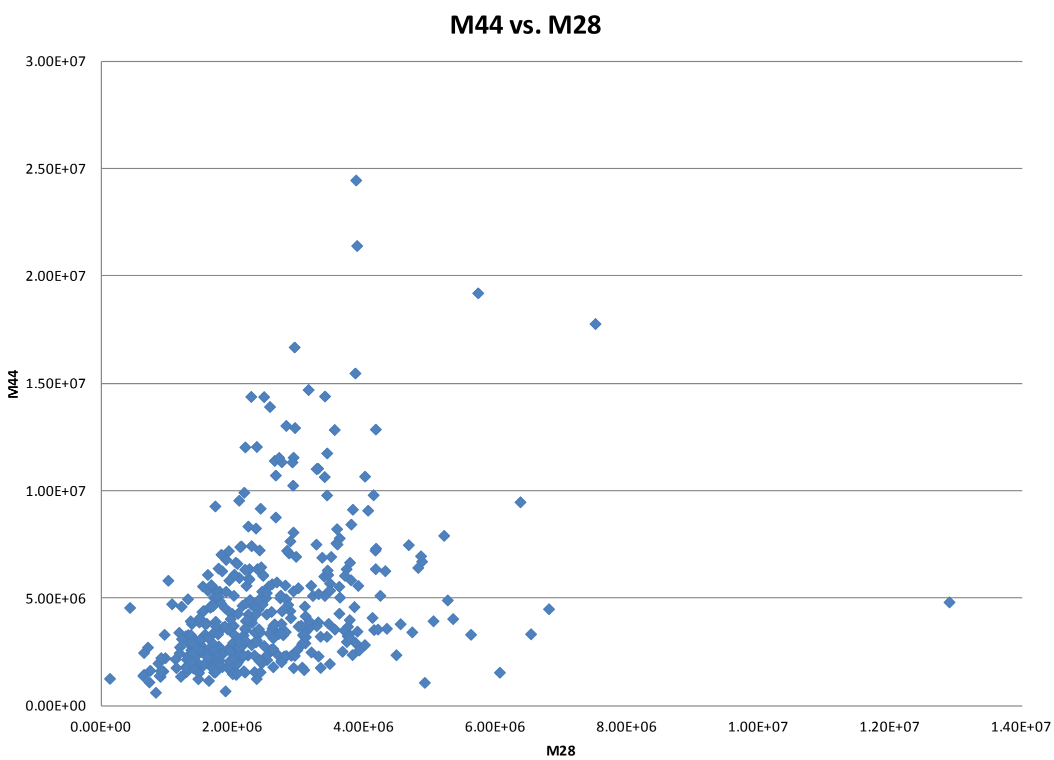


M28 vs. M14

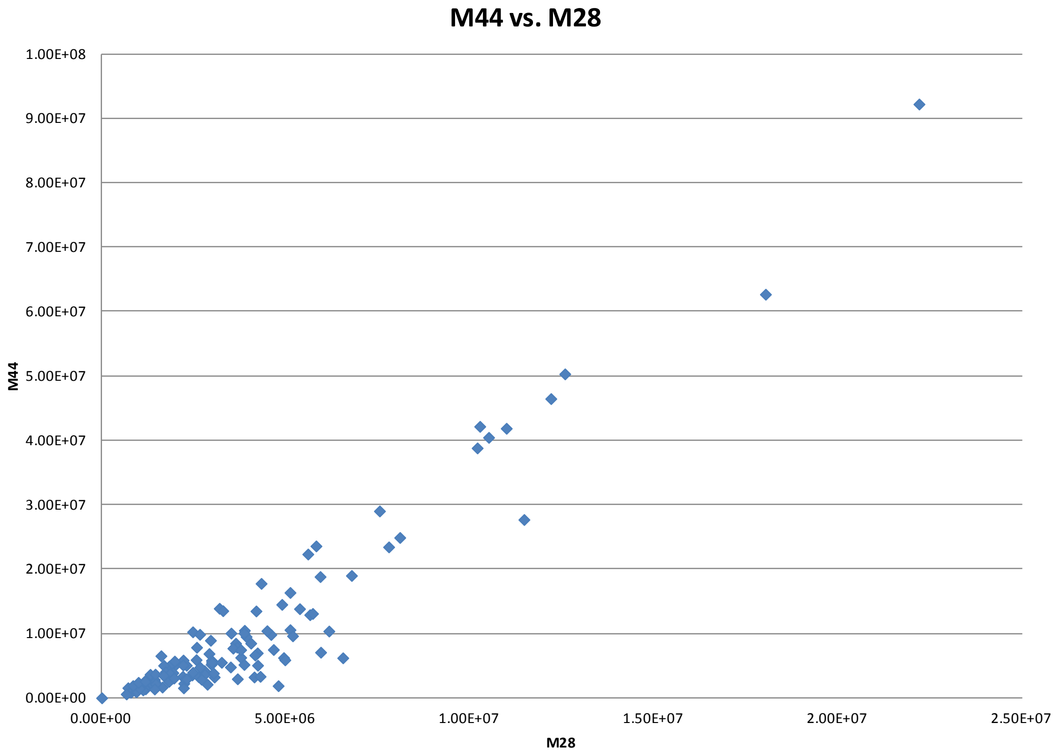


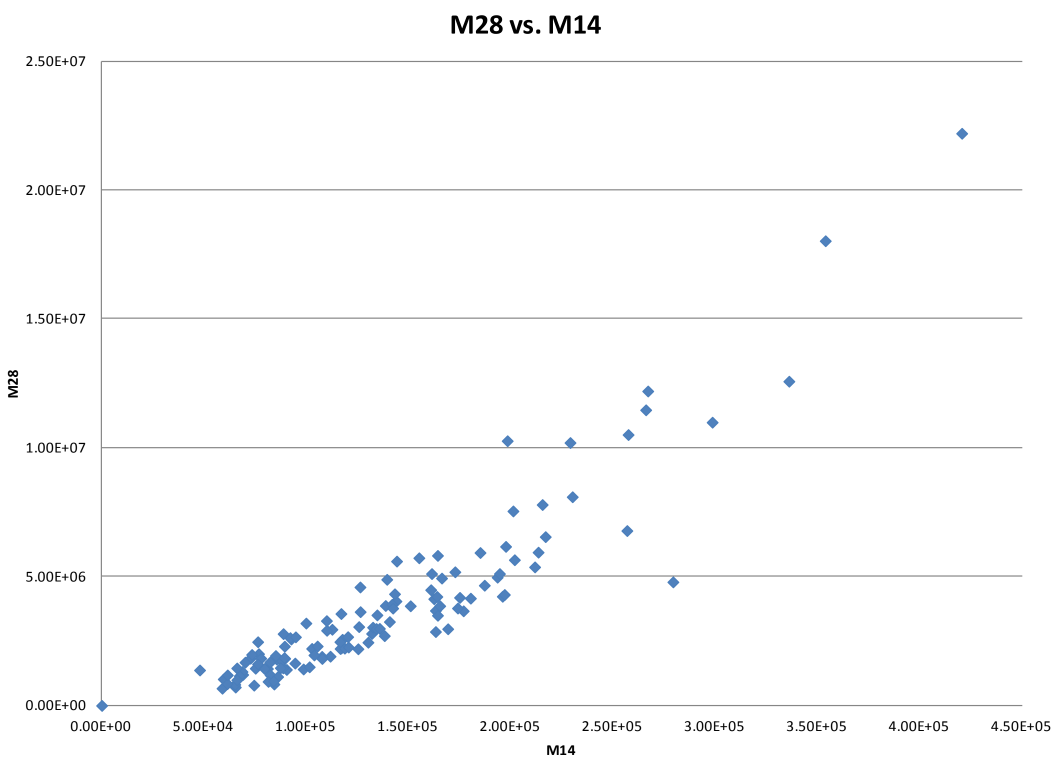
Coso Well 88-20



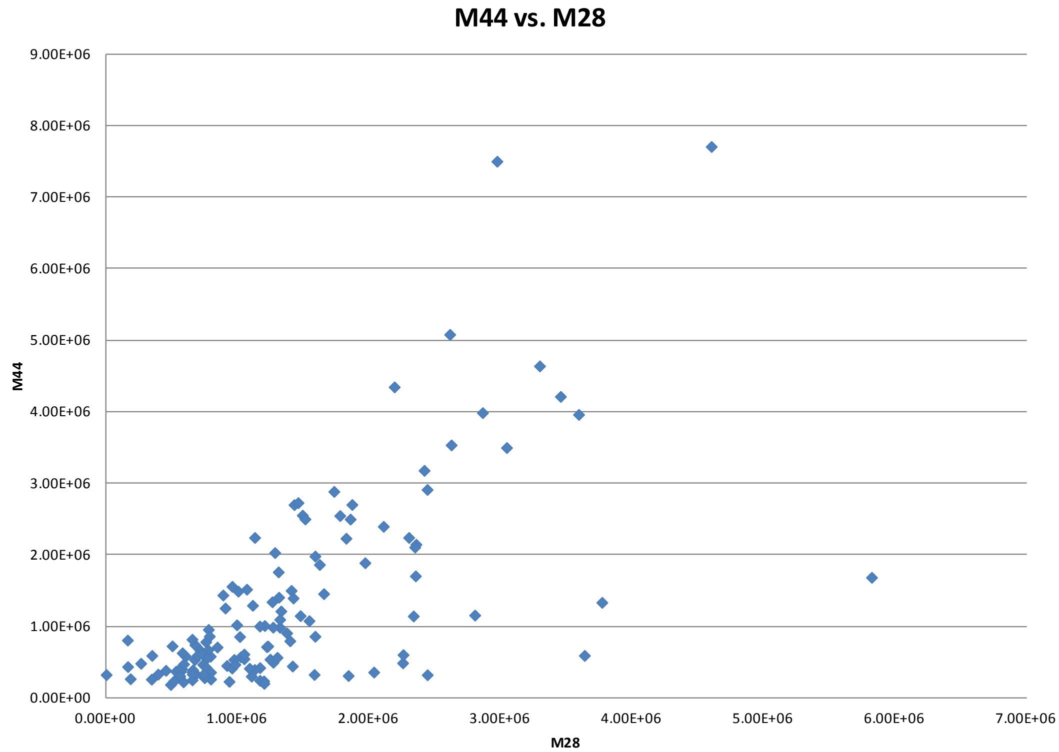


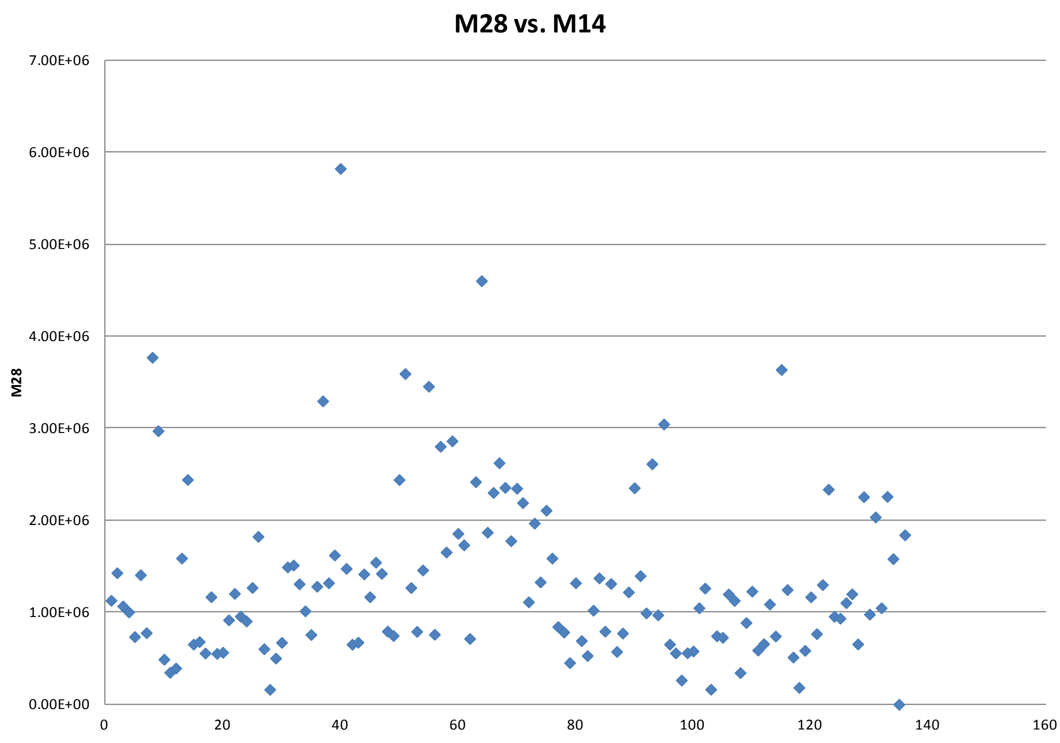
Coso Well 349-RD2





Hawaii Well SOH1





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Hawaii Well SOH1
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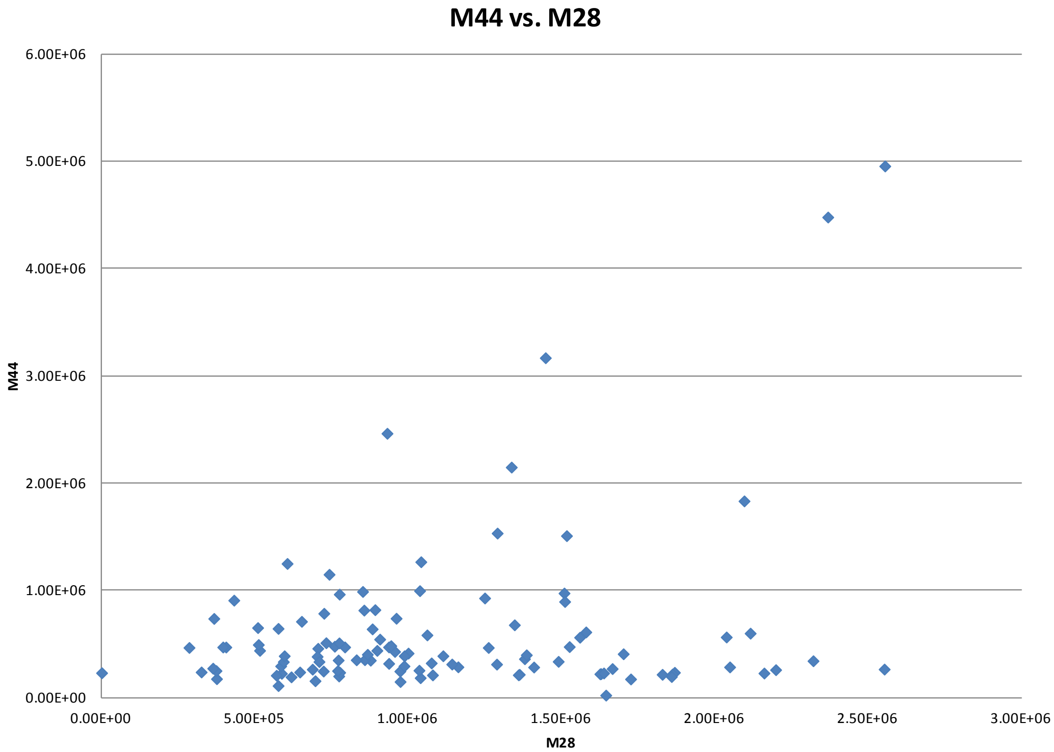
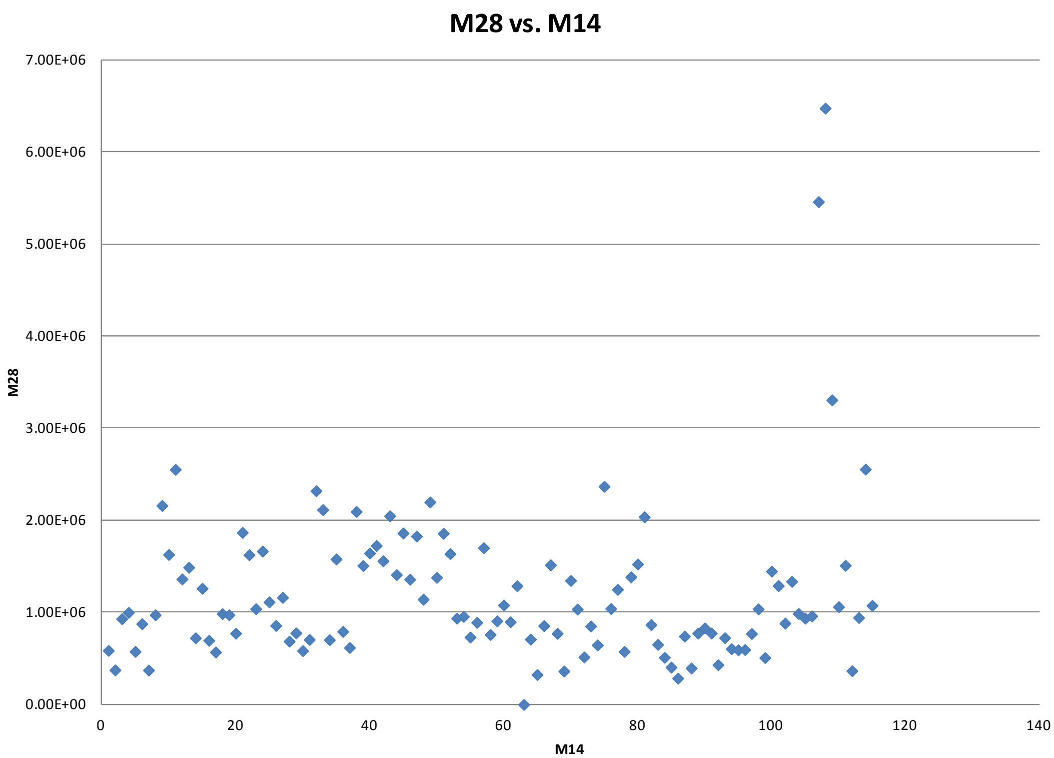
Figure 47

Hawaii Well SOH2





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Hawaii Well SOH2

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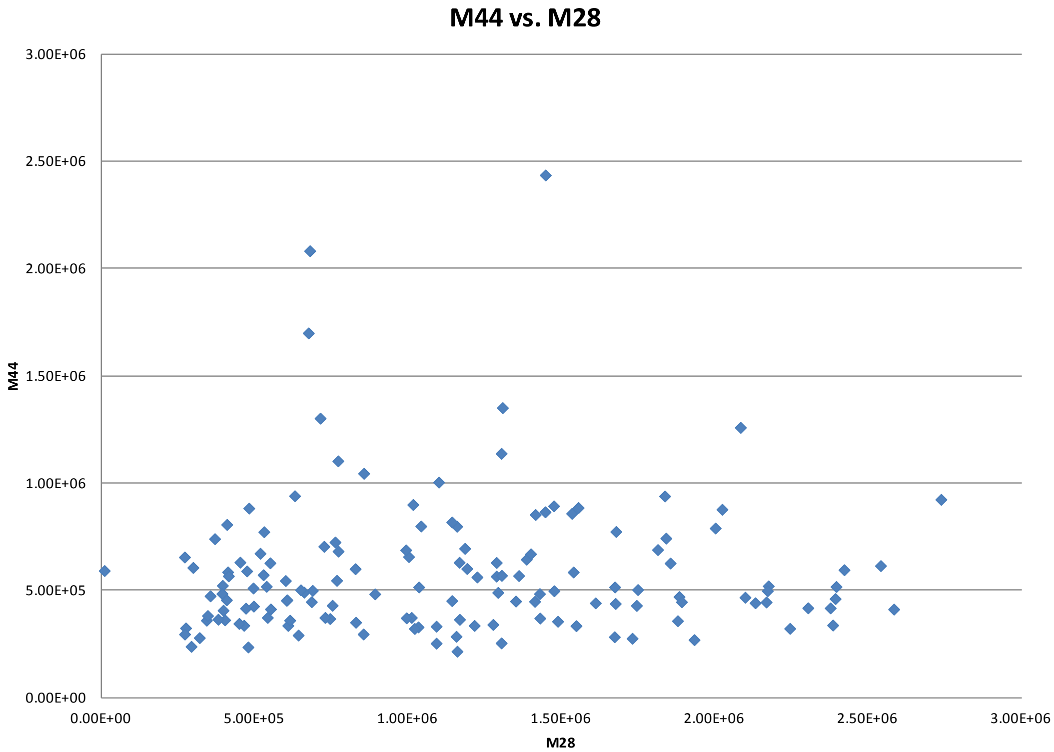
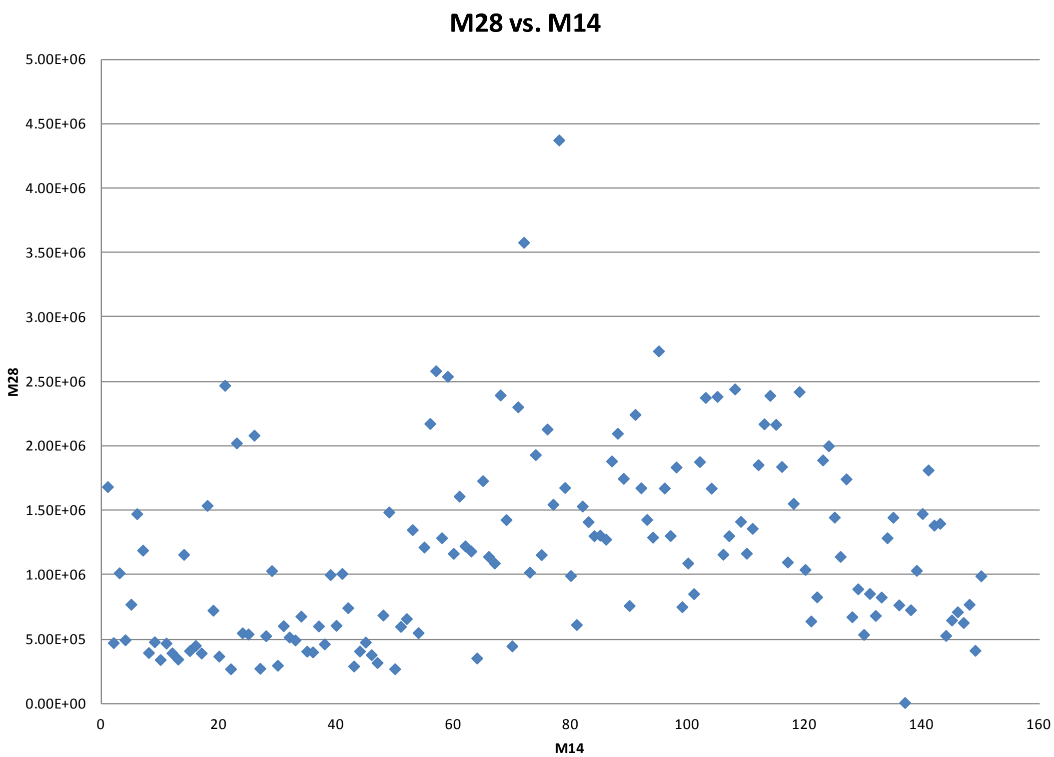
Figure 48

Hawaii Well SOH4





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Hawaii Well SOH4

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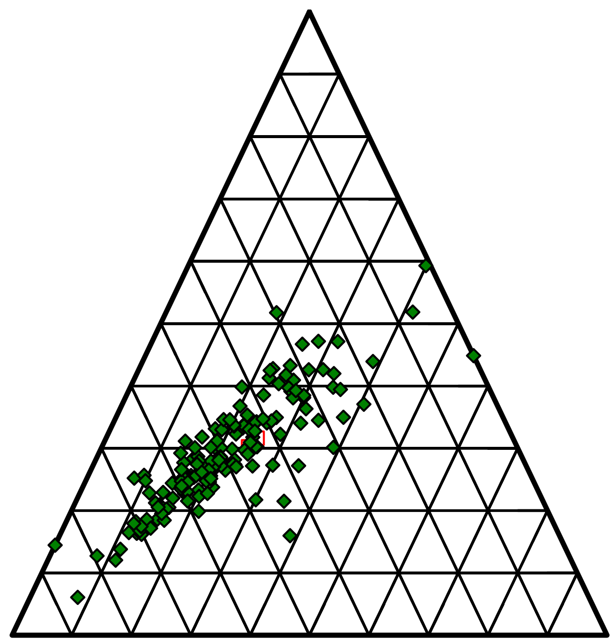
Figure 49

APPENDIX C
N_2-AR-HE TERNARY PLOTS

Chocolate Mountains Well 17-8



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Ternary Diagrams for Chocolate Mountains Well 17-8
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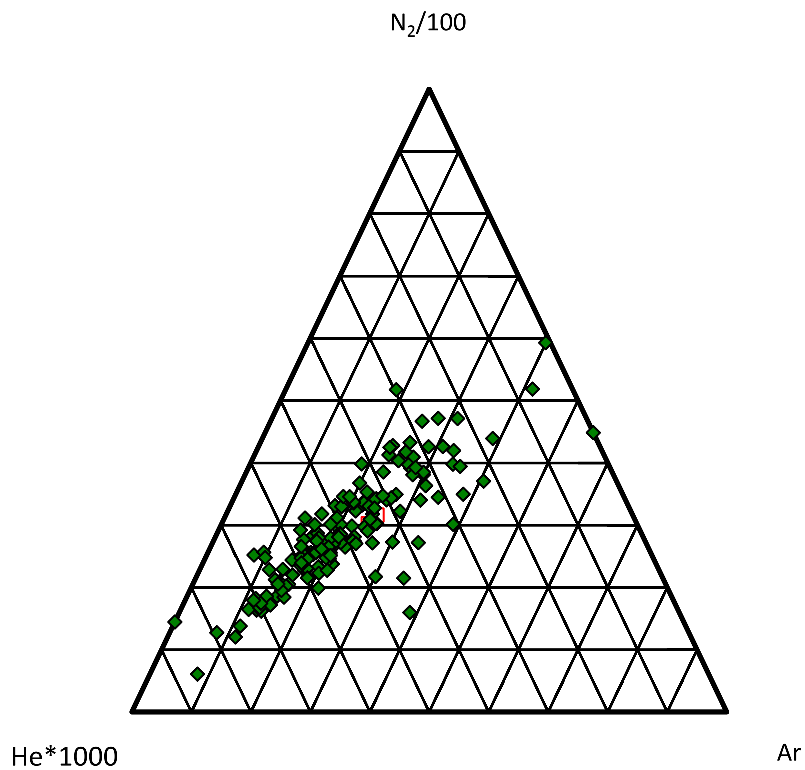
Figure C1

El Centro Well NAFEC 1



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Ternary Diagrams for El Centro Well NAFEC 1
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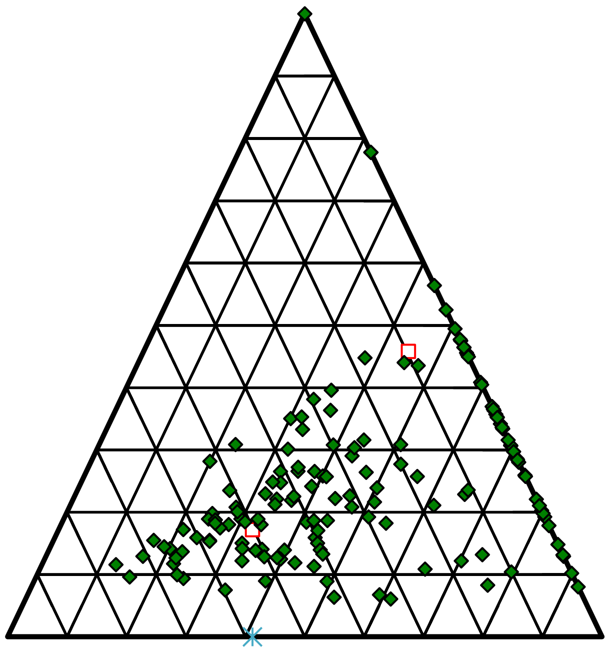
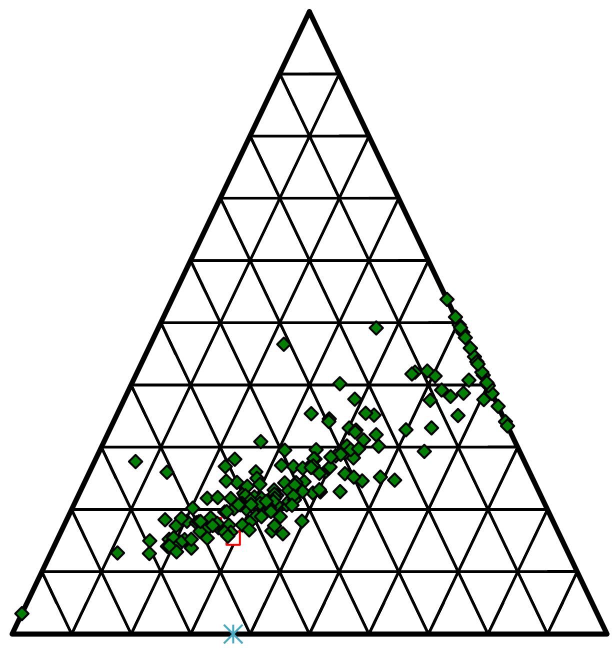
Figure C2

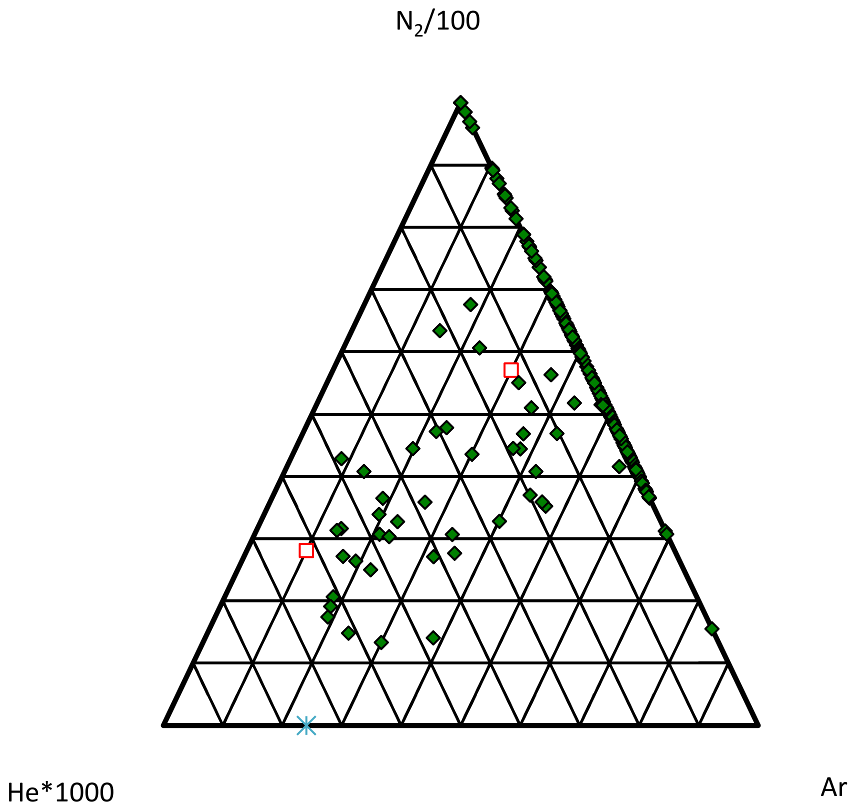
El Centro Well NAFEC 2



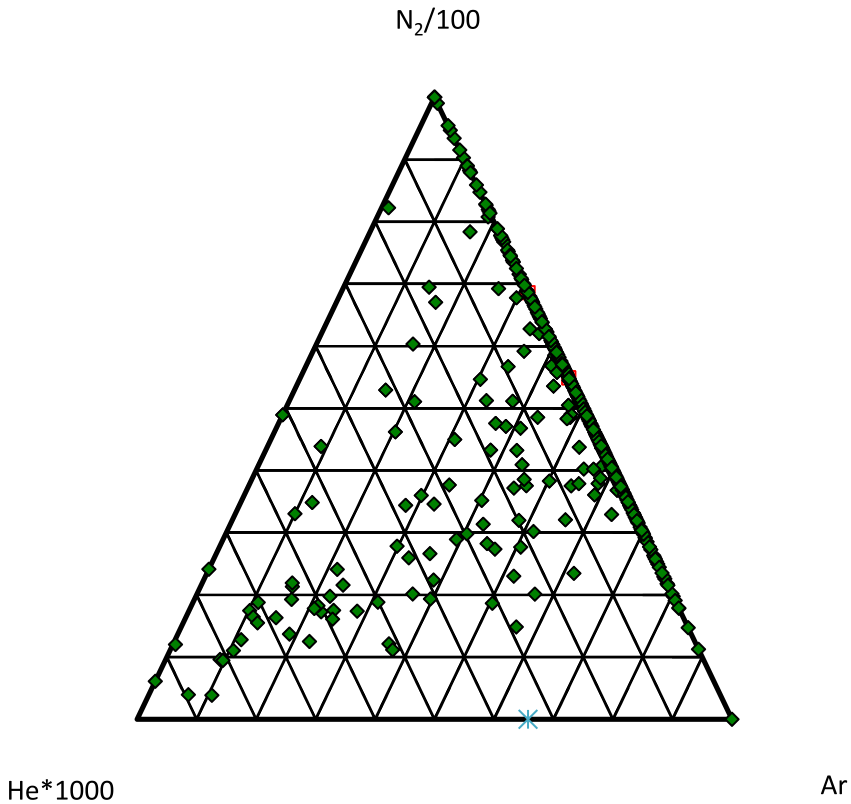
El Centro Well NAFEC 3



Fallon Well 11-NASF-01



Fallon Well 11-NASF-02



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Ternary Diagrams for Fallon Well 11-NASF-02
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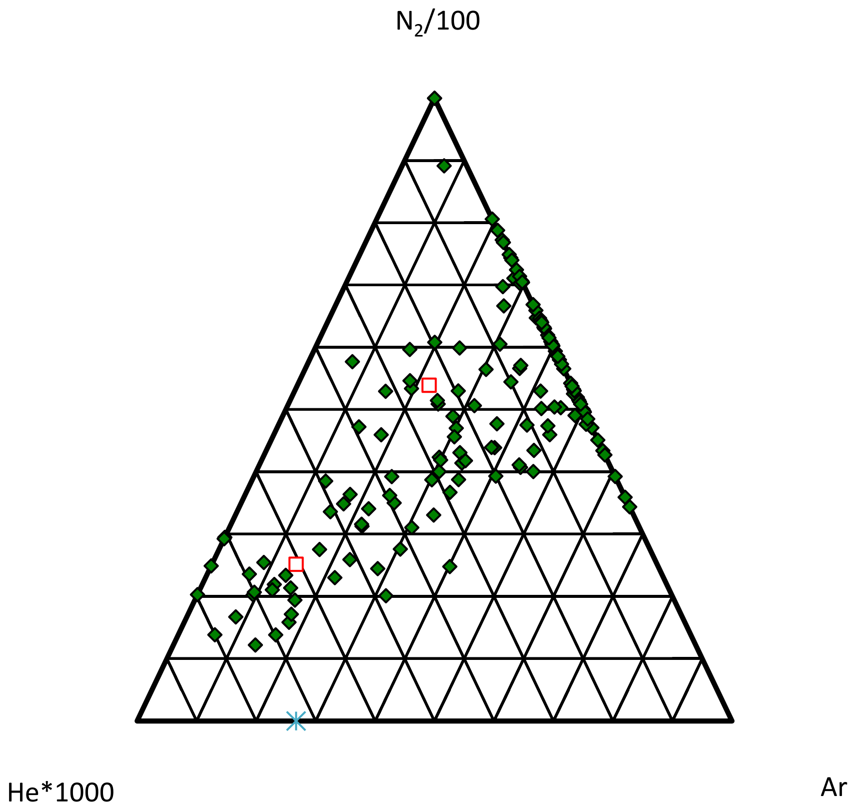
Figure C6

Fallon Well FDU2D



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Ternary Diagrams for Fallon Well FDU2D
US Department of Energy

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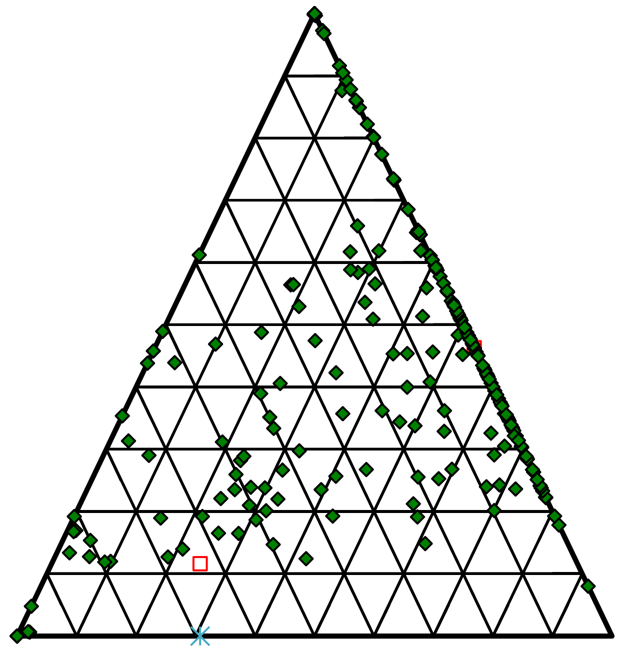
Figure C7

Fallon Well FLTH88-24



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Ternary Diagrams for Fallon Well FLTH88-24
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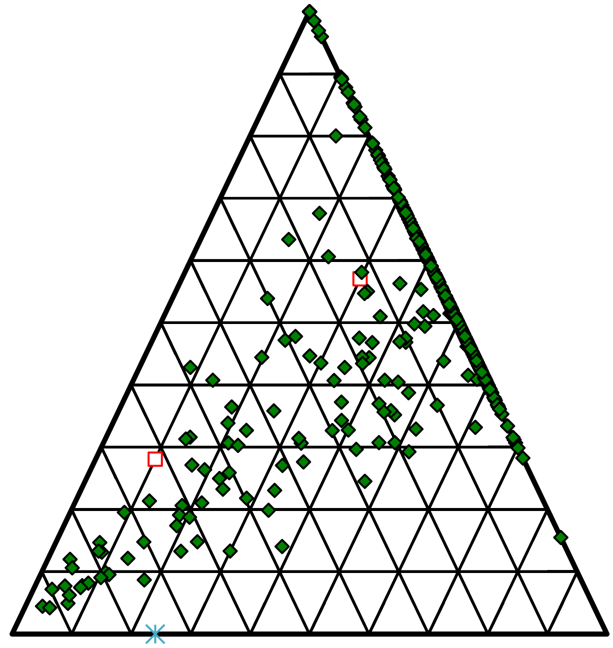
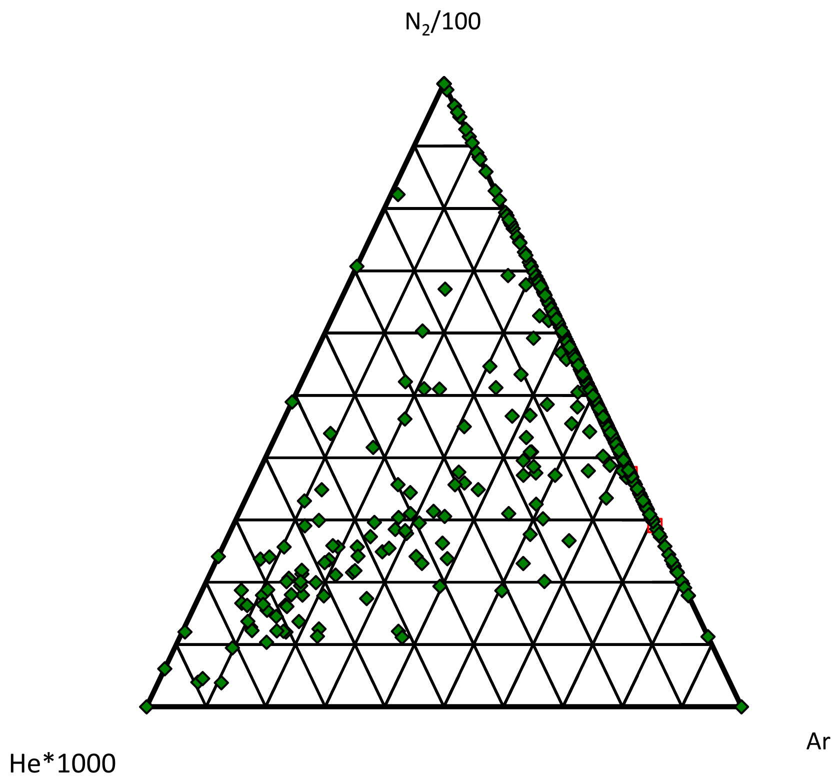
Figure C8

Fallon Well FOH3



Fallon Well 8236



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Ternary Diagrams for Fallon Well 8236
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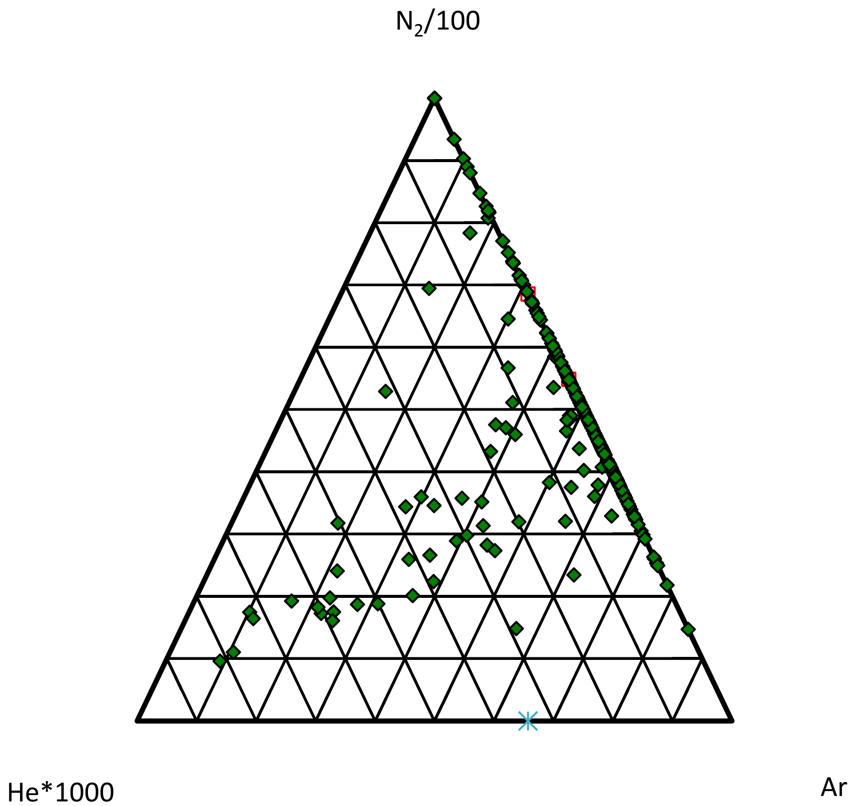
Figure C10

Fallon Well 8431



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Ternary Diagrams for Fallon Well 8431

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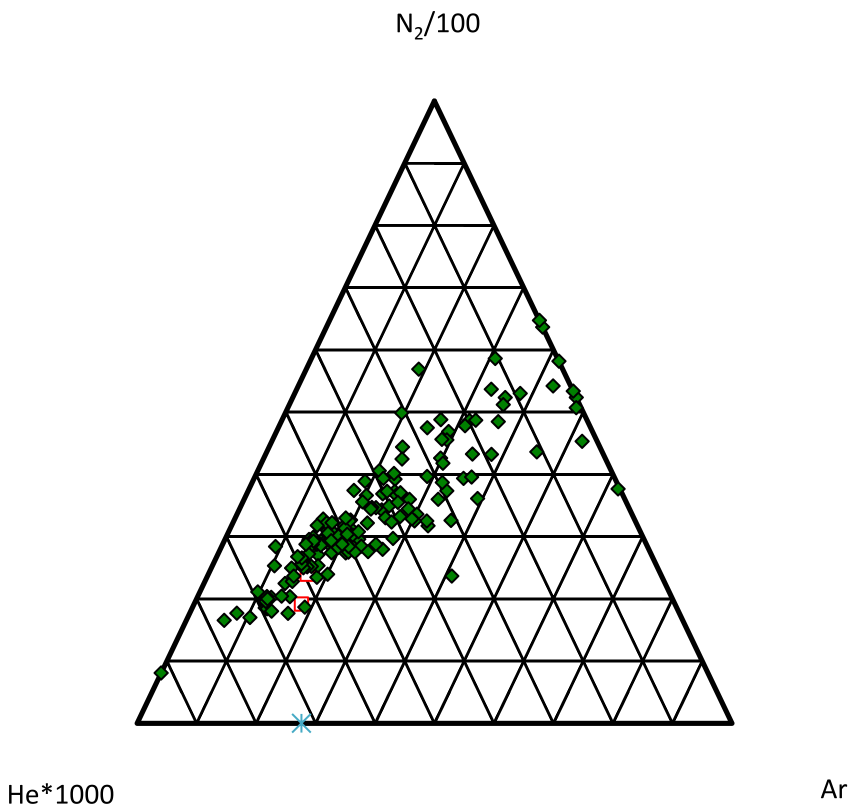
Figure C11

Hawthorne Well HAD 1



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Ternary Diagrams for Hawthorne Well HAD 1
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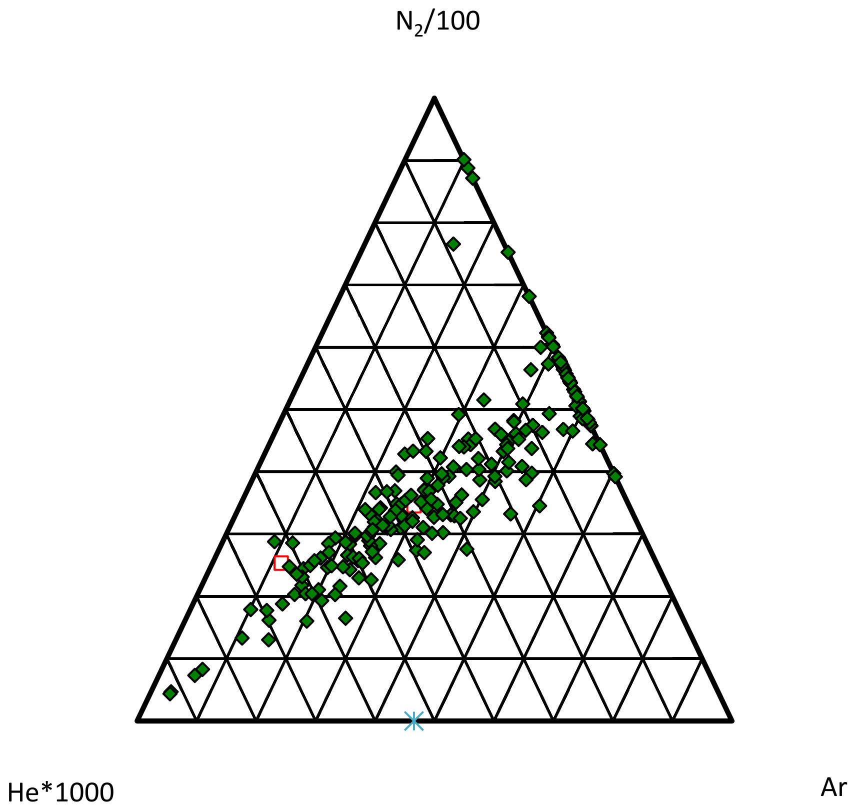
Figure C12

Hawthorne Well HWAAD 2



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Ternary Diagrams for Hawthorne Well HWAAD 2
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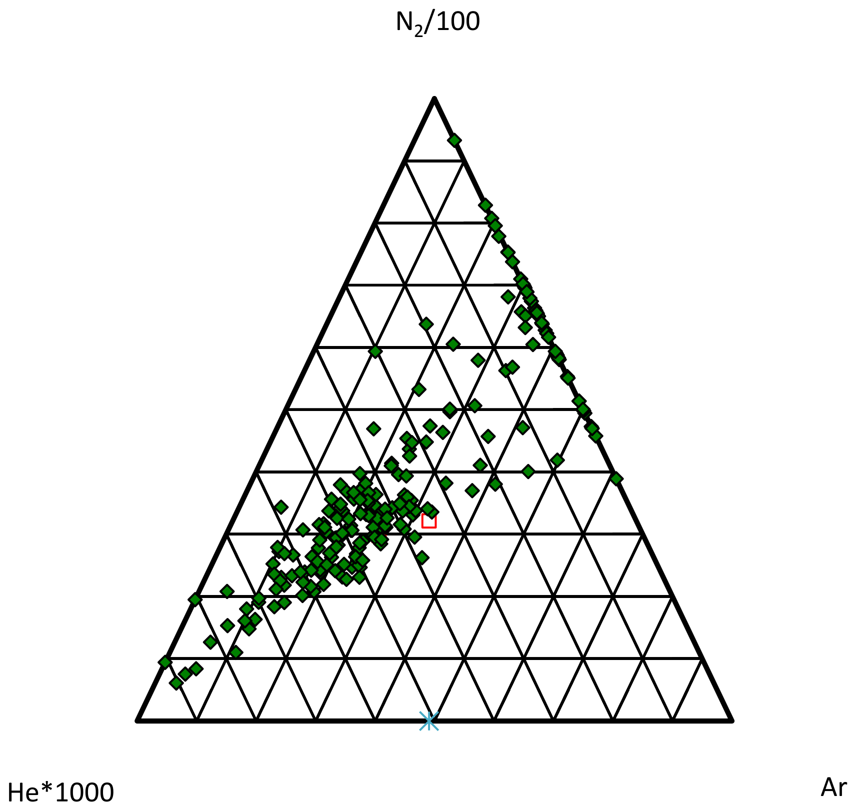
Figure C13

Hawthorne Well HWAAD 3



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Ternary Diagrams for Hawthorne Well HWAAD 3
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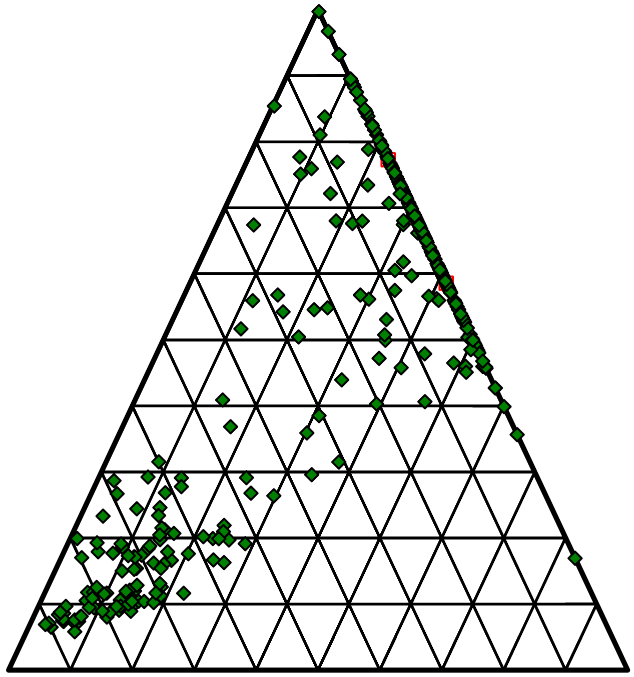
Figure C14

Beowawe Well 57-13



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Ternary Diagrams for Beowawe Well 57-13
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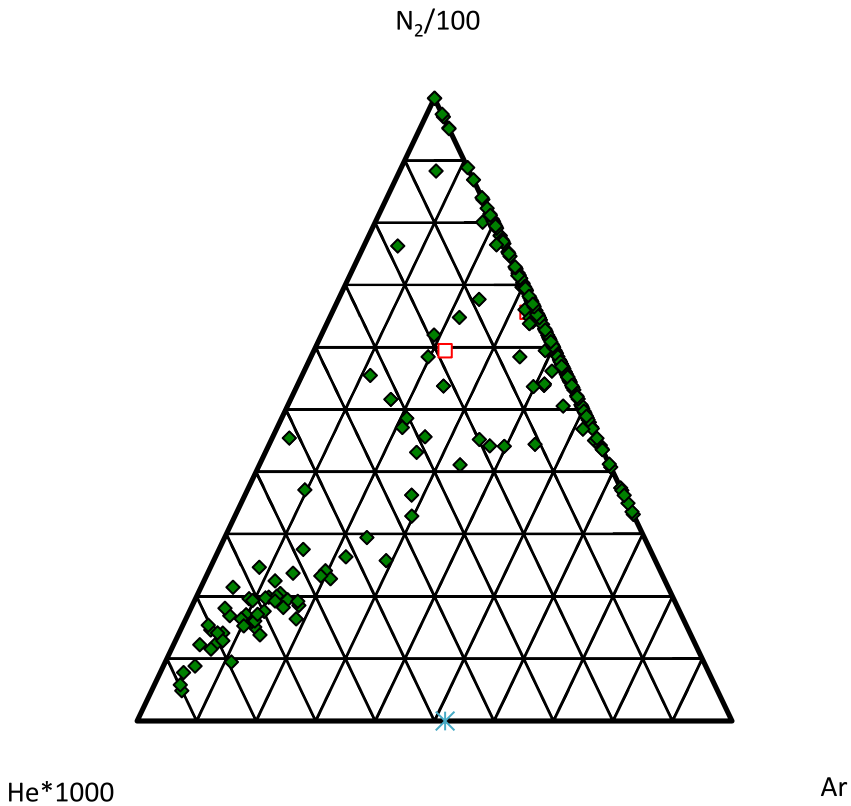
Figure C15

Beowawe Well 77-13



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Ternary Diagrams for Beowawe Well 77-13
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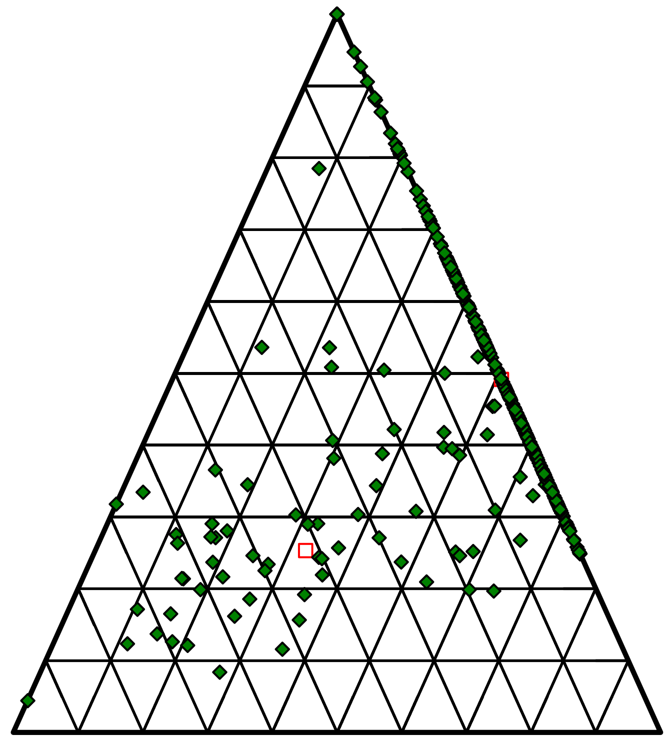
Figure C16

Salton Sea Well Del Ranch



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Ternary Diagrams for Salton Sea Well Del Ranch
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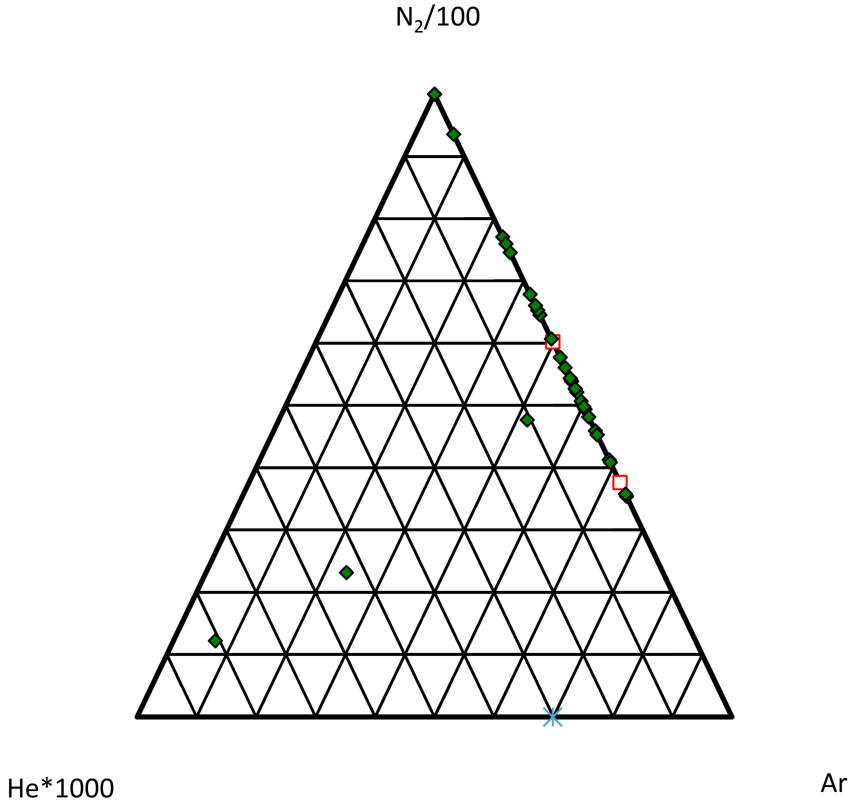
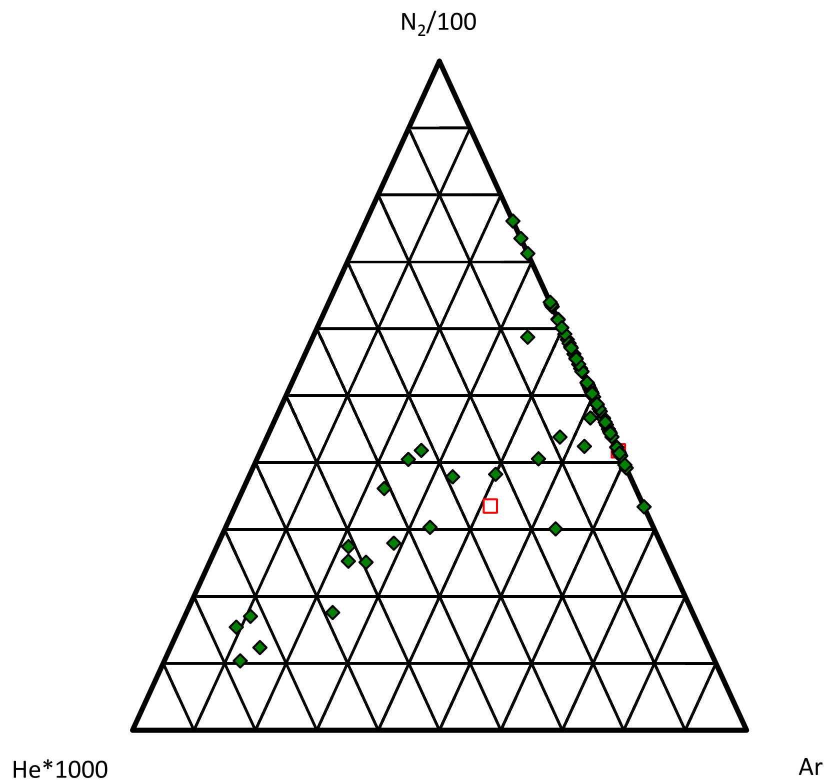
Figure C17

Salton Sea Well ELIW6



Salton Sea Well Vulcan



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Ternary Diagrams for Salton Sea Well Vulcan
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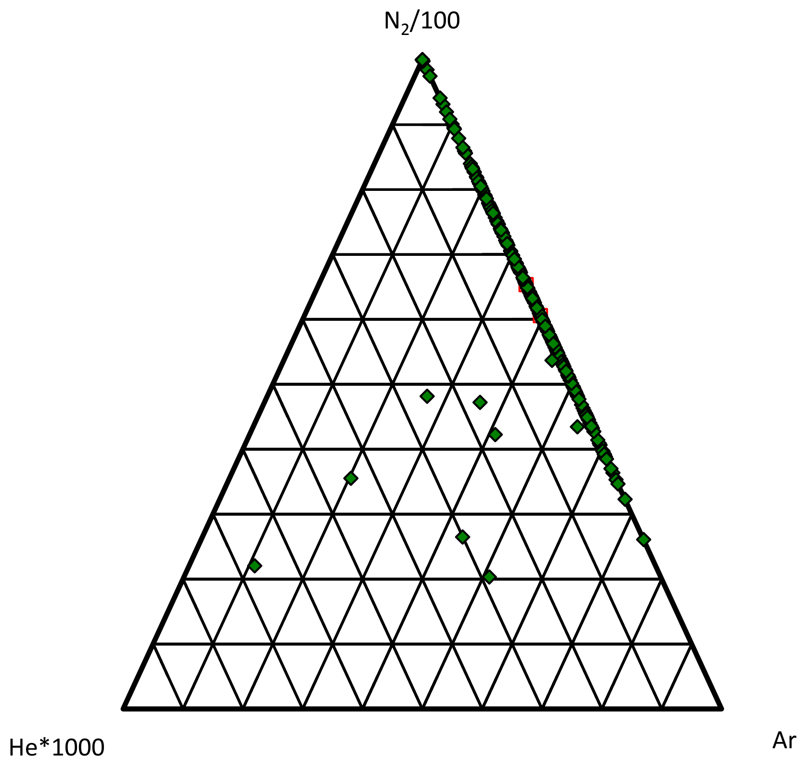
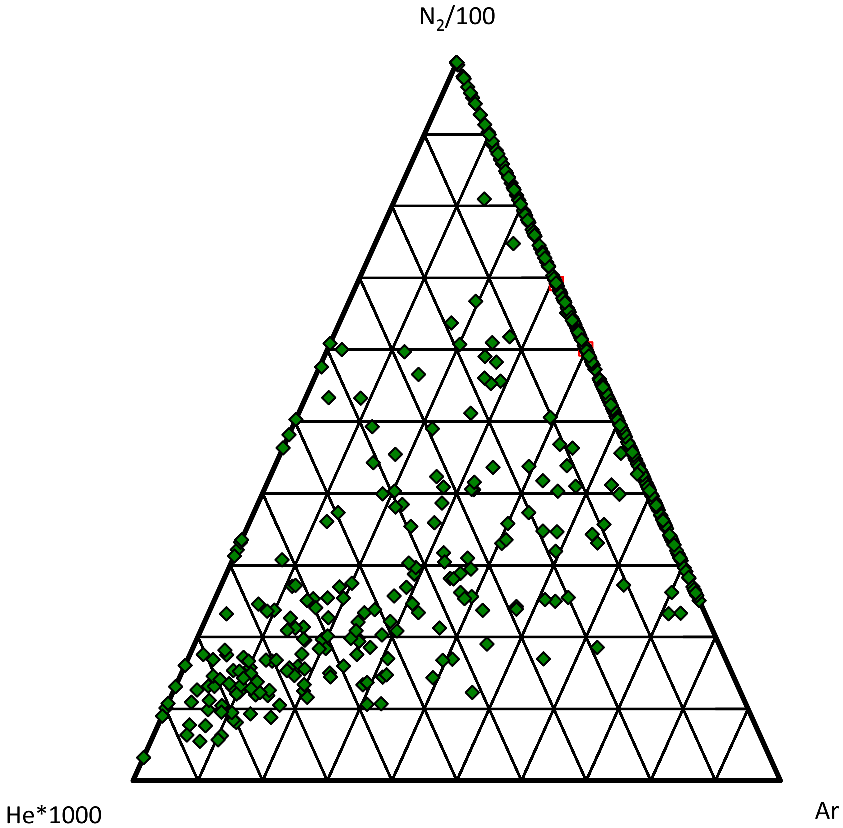
Figure C19

Salton Sea Well Elmore 12



Salton Sea Well Elmore 16



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Ternary Diagrams for Salton Sea Well Elmore 16

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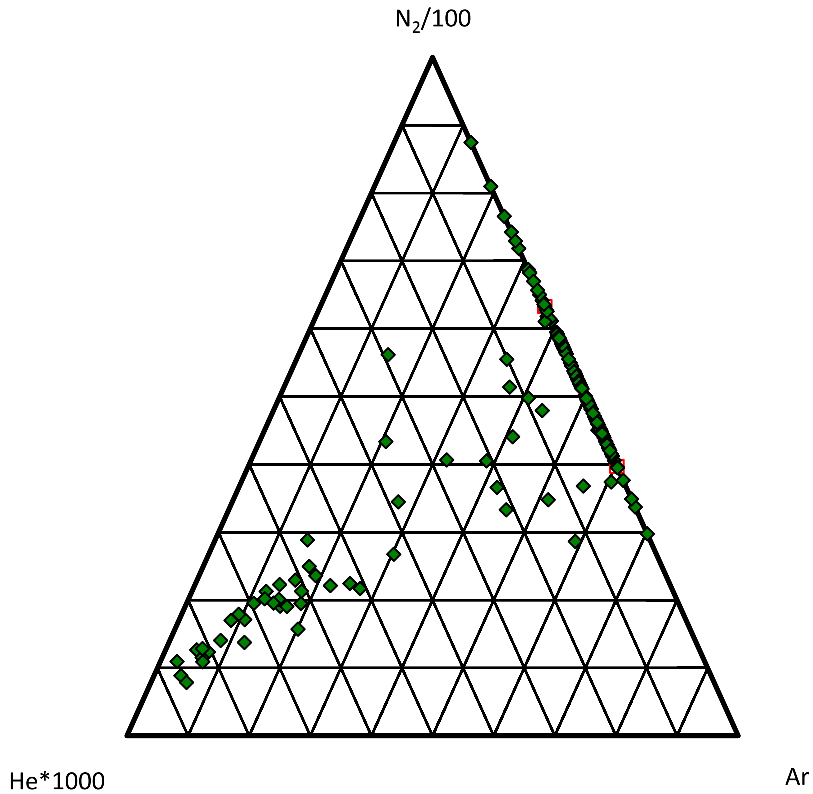
Figure C21

Salton Sea Well River Ranch 4



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Ternary Diagrams for Salton Sea Well Ranch River 4
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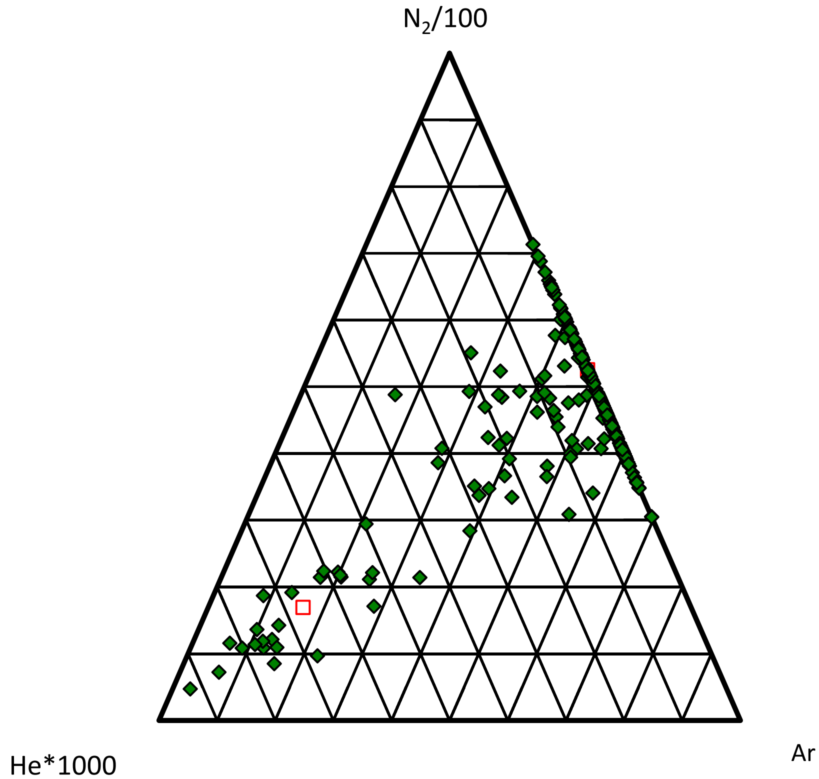
Figure C22

Salton Sea Well River Ranch 5



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Ternary Diagrams for Salton Sea Well Ranch River 5
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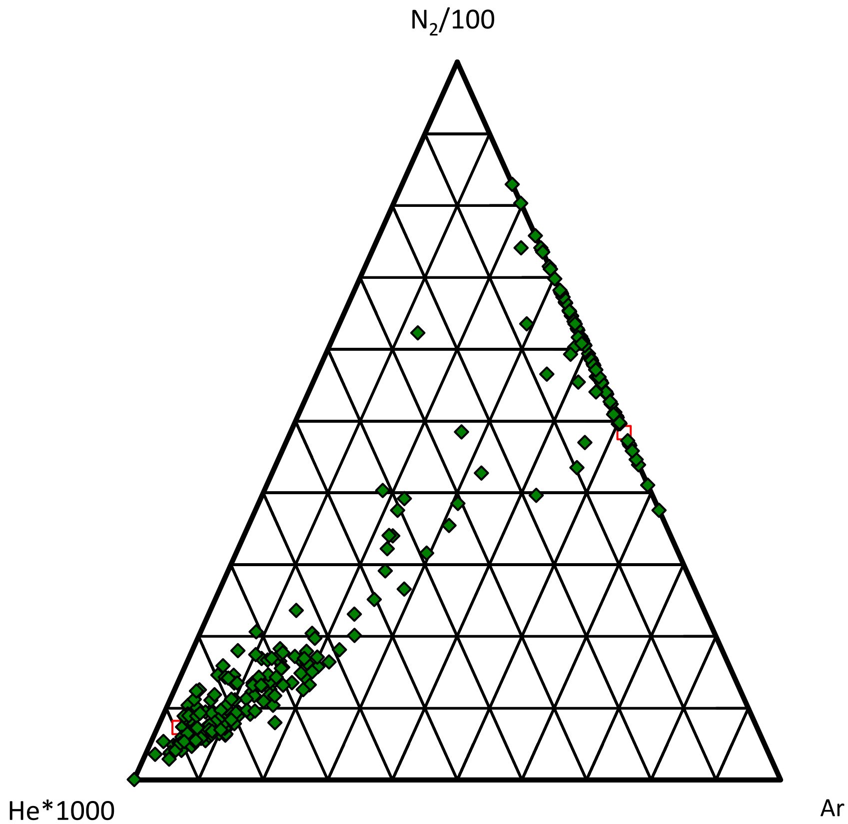
Figure C23

Salton Sea Well Sinclair 24



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Ternary Diagrams for Salton Sea Well Sinclair 24

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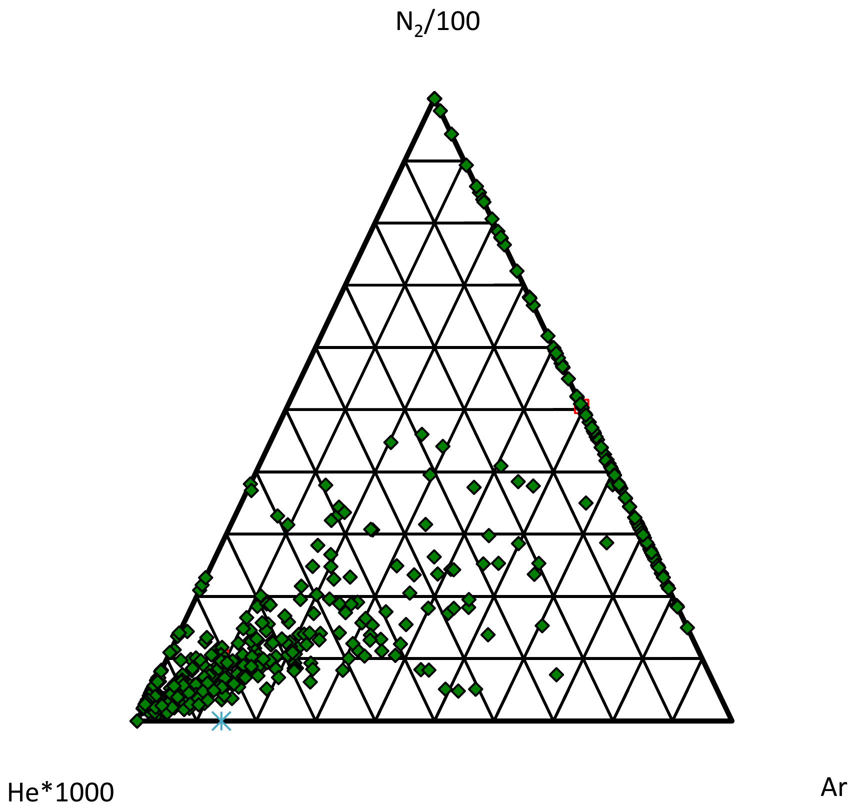
Figure C24

Kahara Tela Bodegas Well K33



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Ternary Diagrams for Kahara Telga Bodegas Well K33

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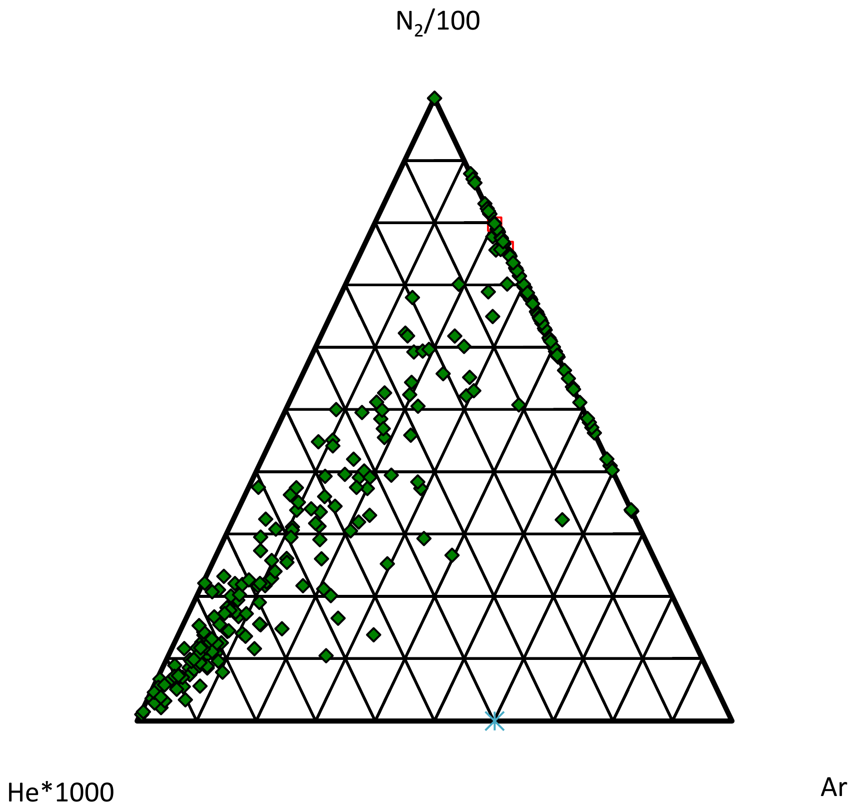
Figure C25

Kahara Tela Bodegas Well T2



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Ternary Diagrams for Kahara Telga Bodegas Well T2
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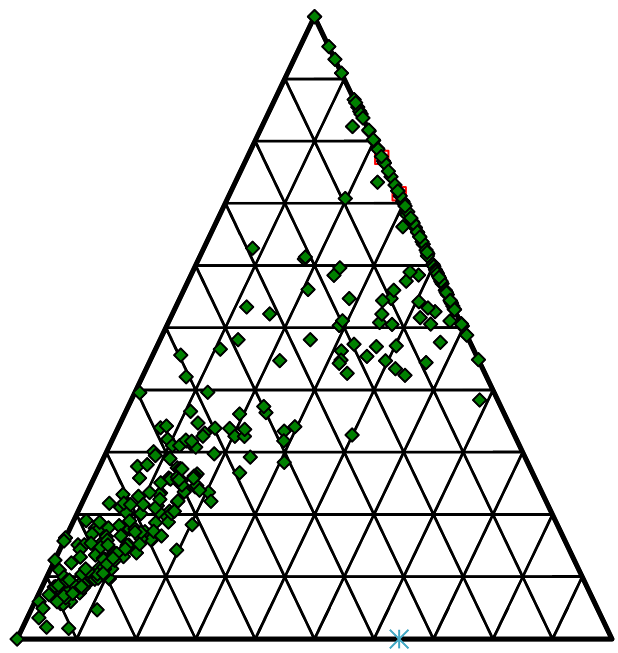
Figure C26

COSO Well 15A-17



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Ternary Diagrams for COSO Well 15A-17
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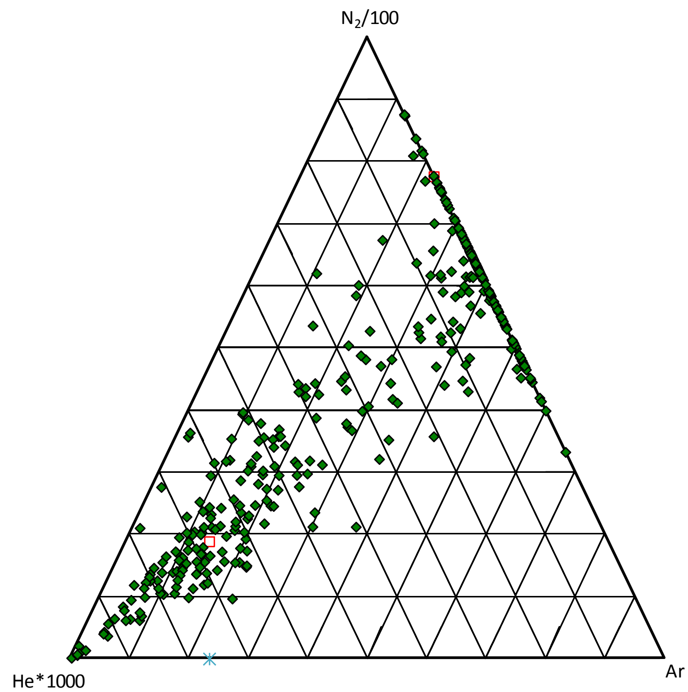
Figure C27

COSO Well 23A-17



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Ternary Diagrams for COSO Well 23A-17
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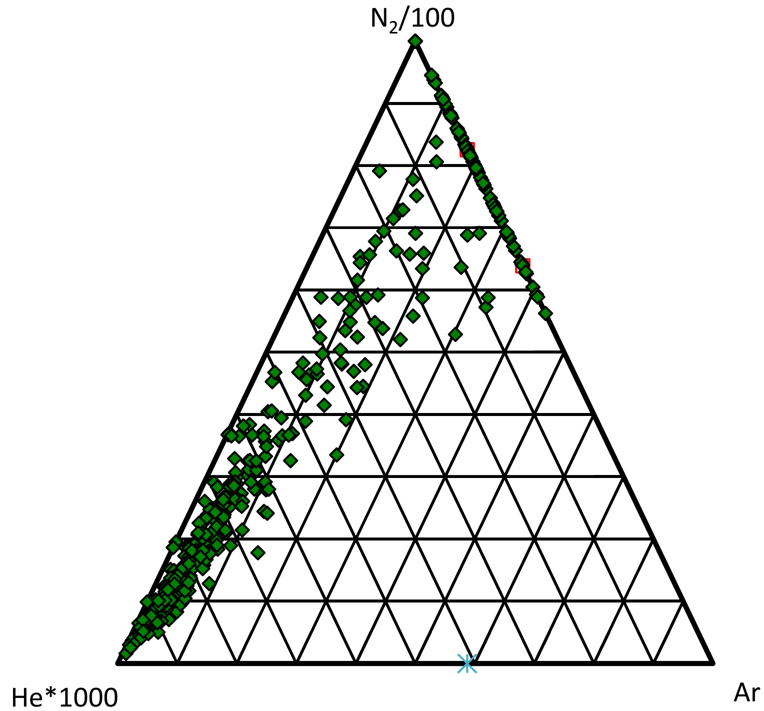
Figure C28

COSO Well 23A-19



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Ternary Diagrams for COSO Well 23A-19

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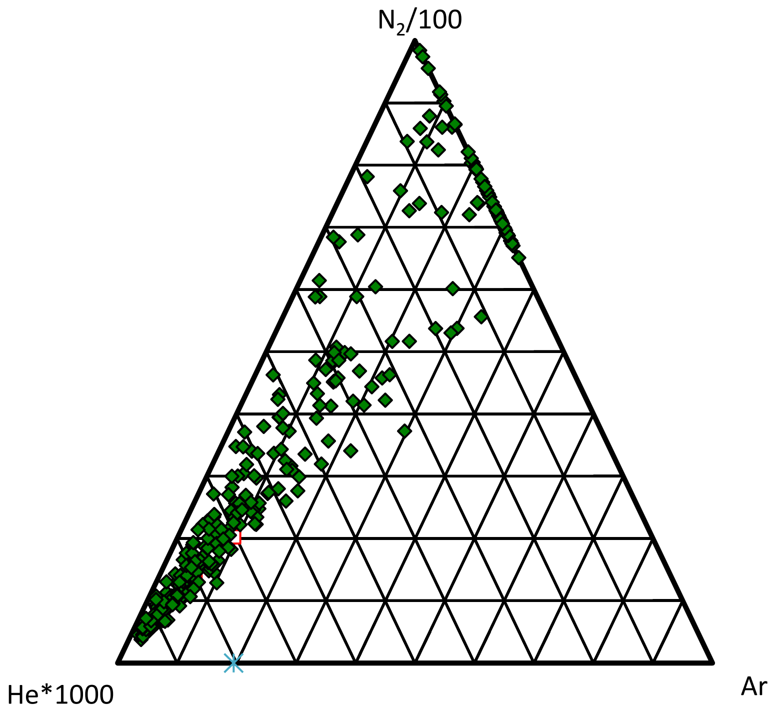
Figure C29

COSO Well 24A-8



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Ternary Diagrams for COSO Well 24A-8
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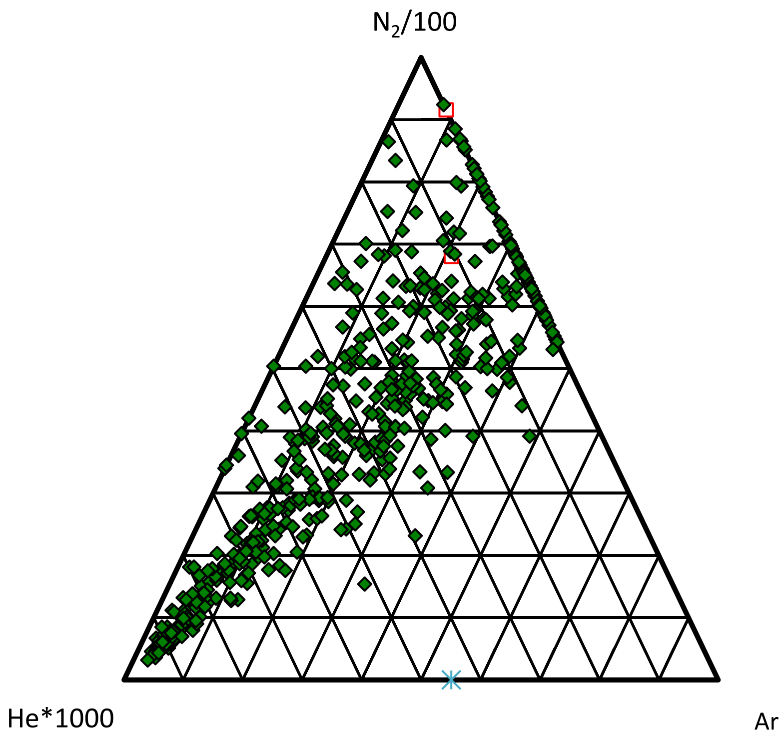
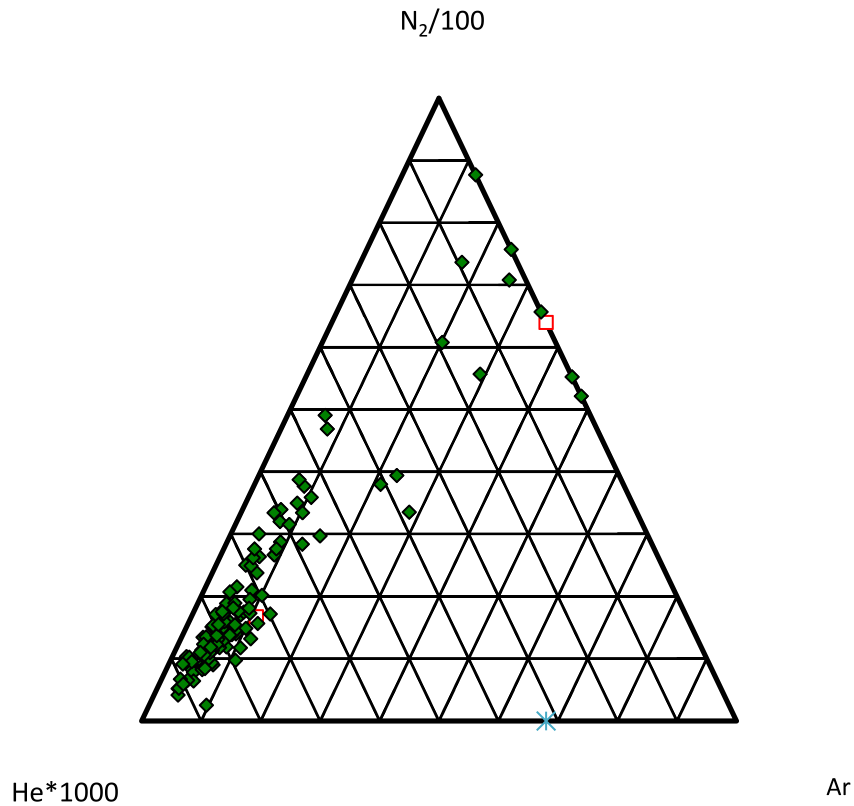
Figure C30

COSO Well 33-7



COSO Well 349RD2



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Ternary Diagrams for COSO Well 349RD2
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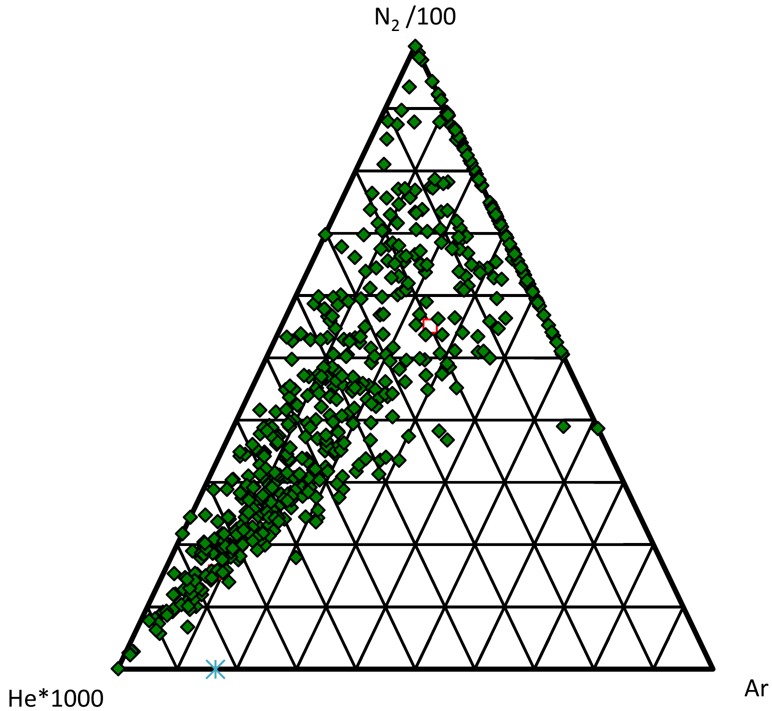
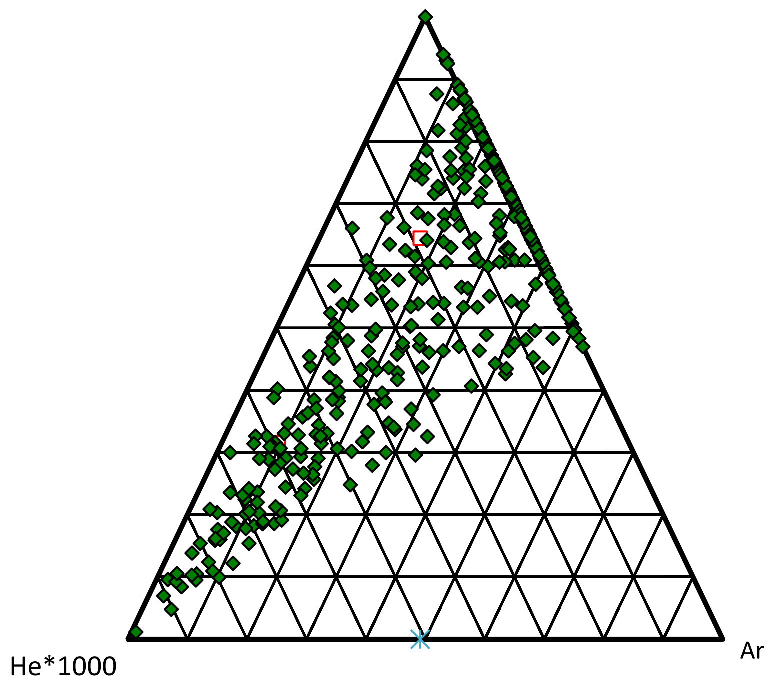
Figure C32

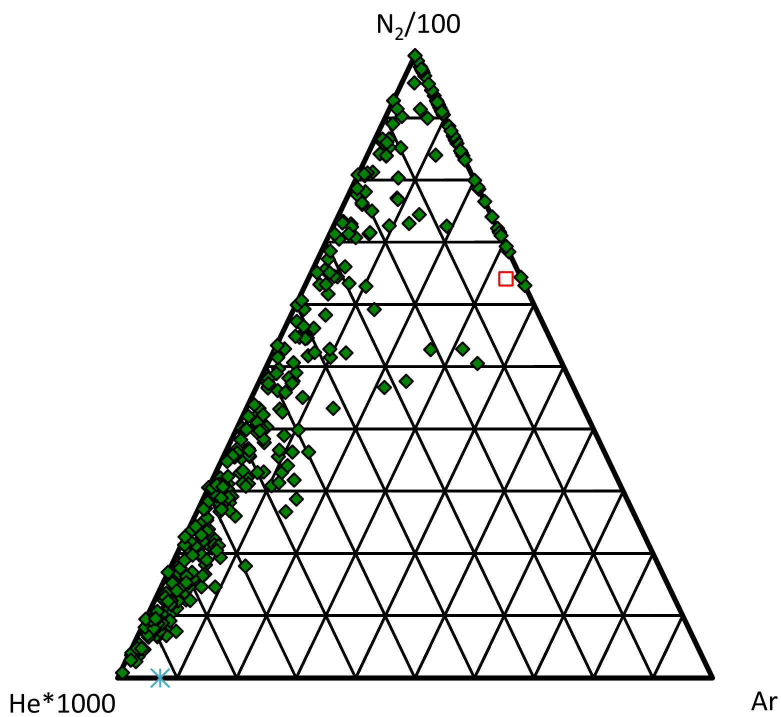
COSO Well 38C-9



COSO Well 38D-9



COSO Well 41B-8



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Ternary Diagrams for COSO Well 41B-8
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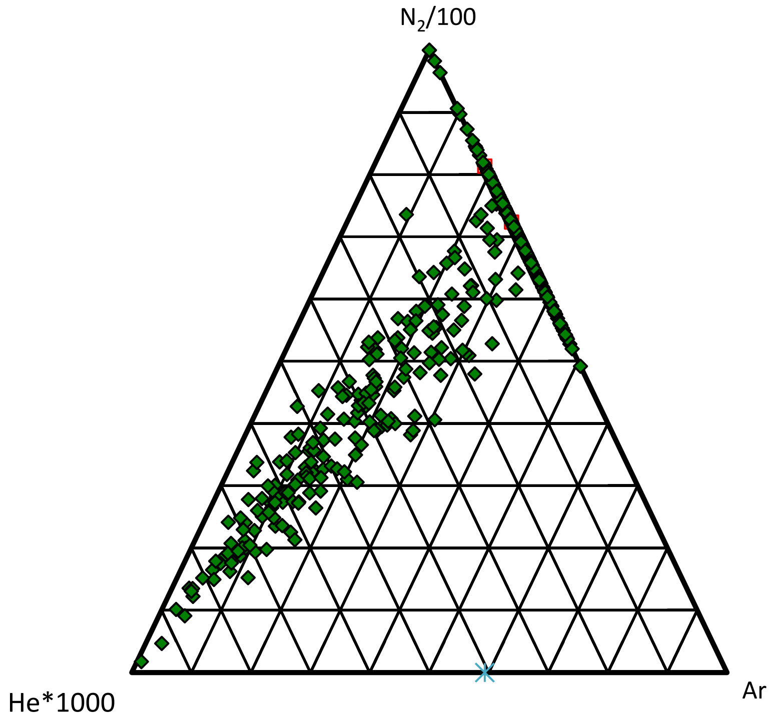
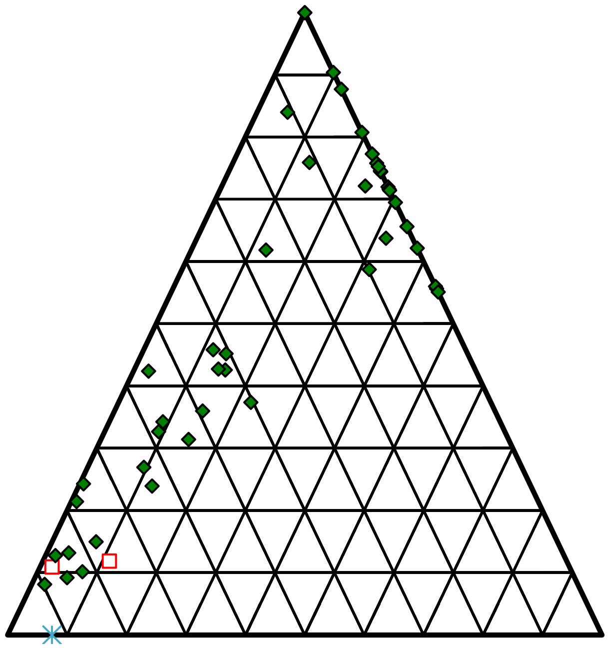
Figure C35

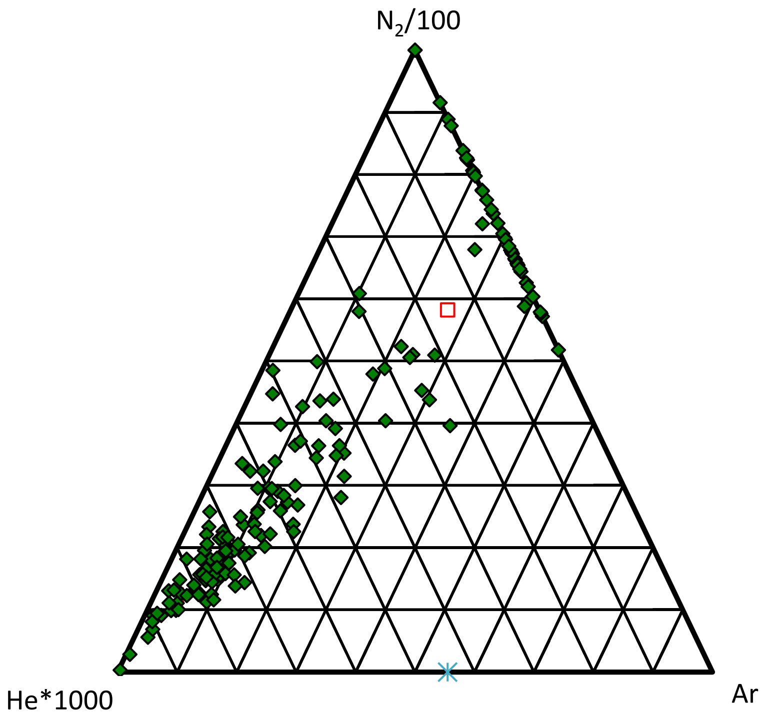
COSO Well 46A-19RD



COSO Well 47A-8



COSO Well 47A-8RD



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Ternary Diagrams for COSO Well 47A-8RD
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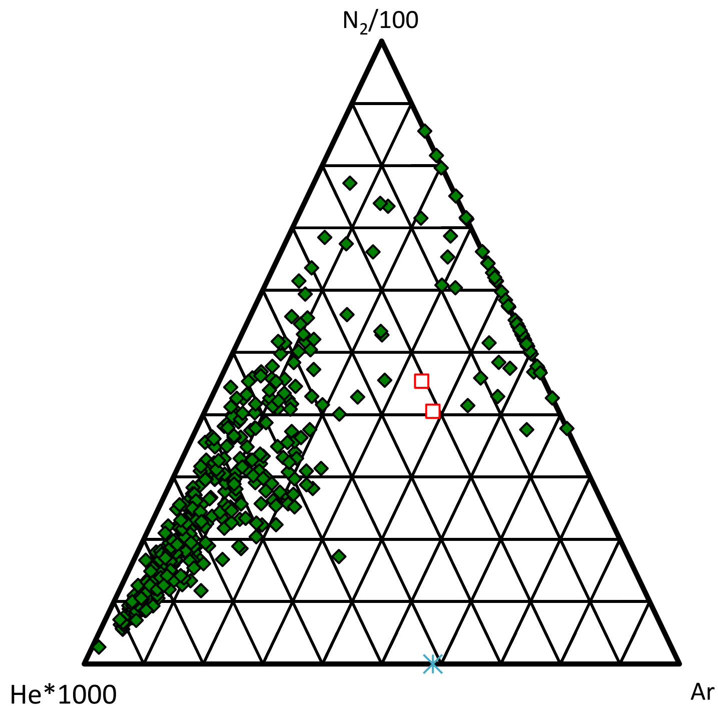
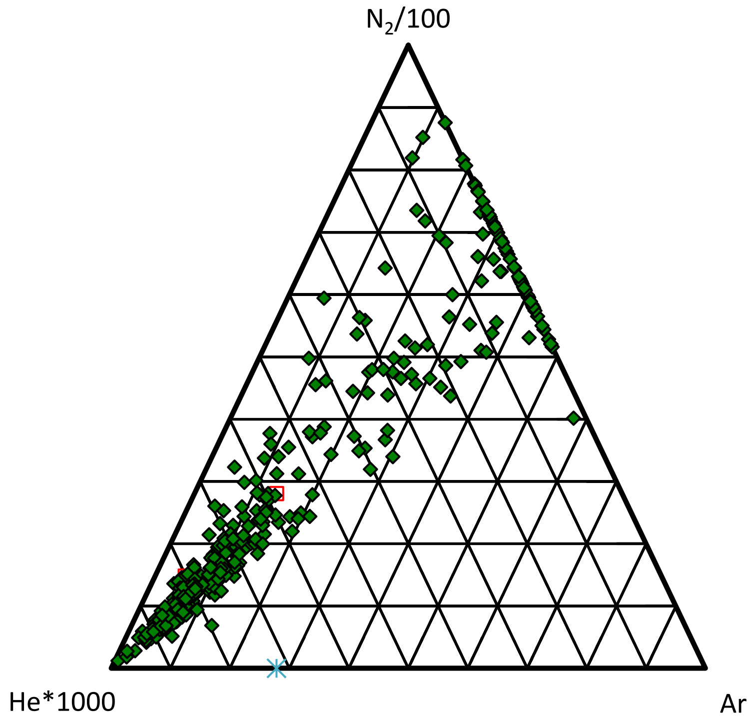
Figure C38

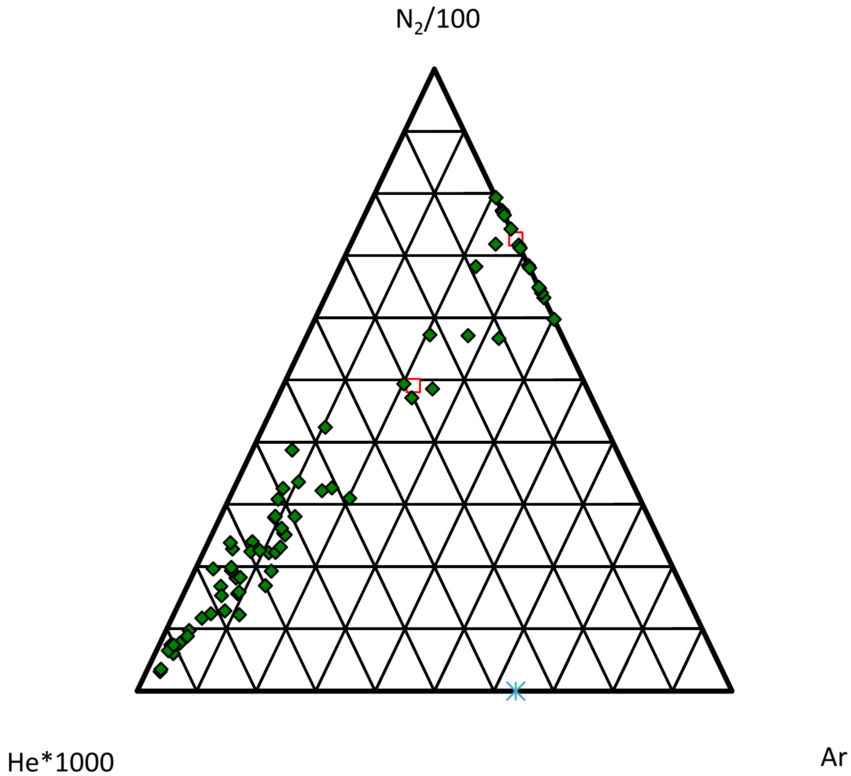
COSO Well 51B-16



COSO Well 52-20



COSO Well 54-7



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Ternary Diagrams for COSO Well 54-7
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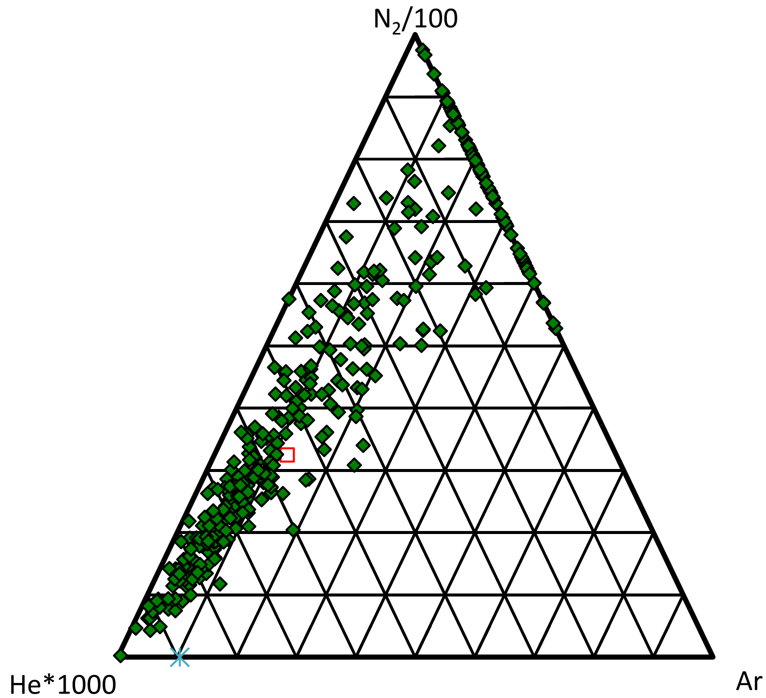
Figure C41

COSO Well 54-7RD



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Ternary Diagrams for COSO Well 54-7RD
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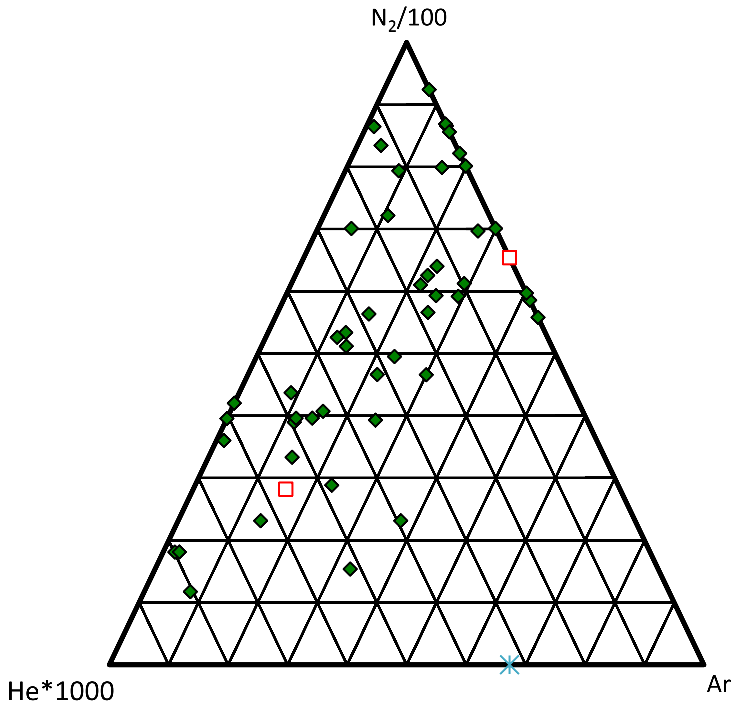
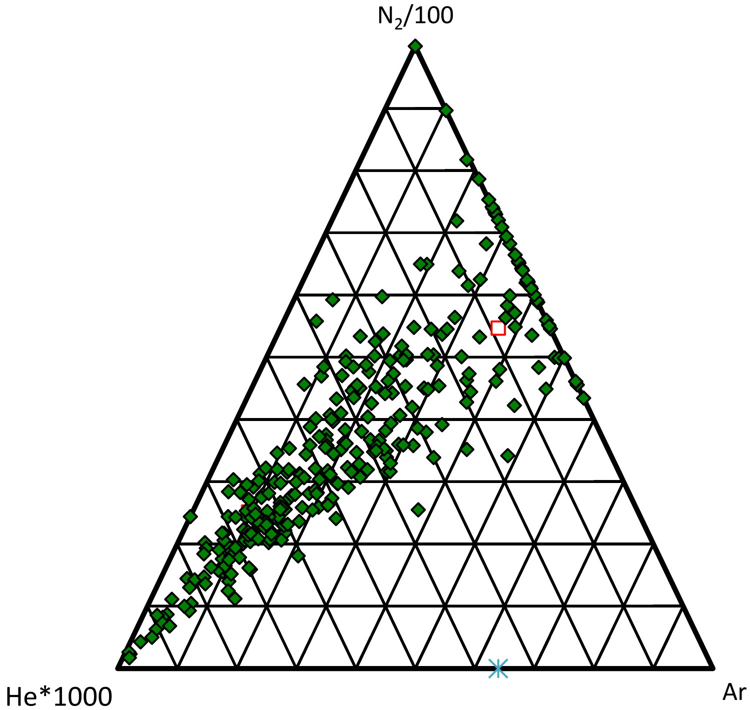
Figure C42

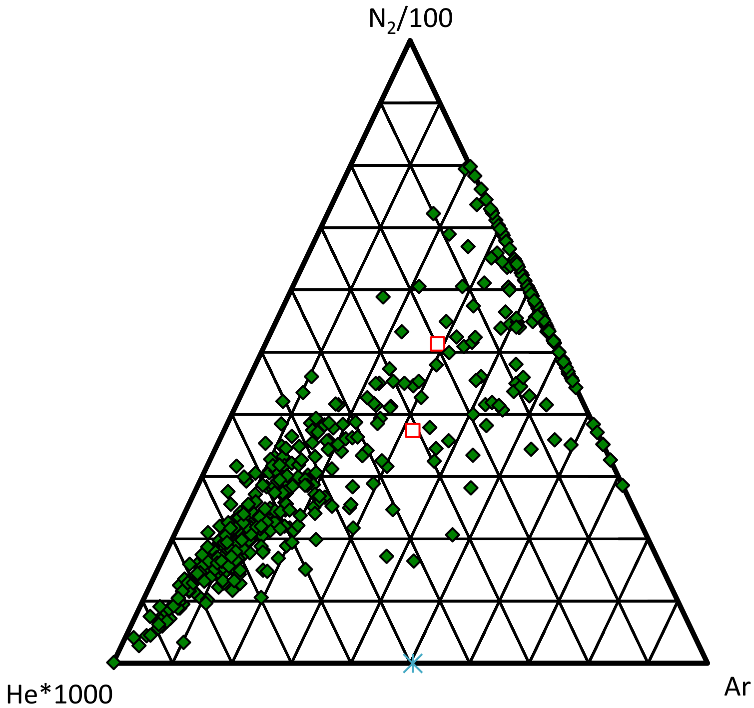
COSO Well 58A-10



COSO Well 58A-18



COSO Well 67-17



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Ternary Diagrams for COSO Well 67-17
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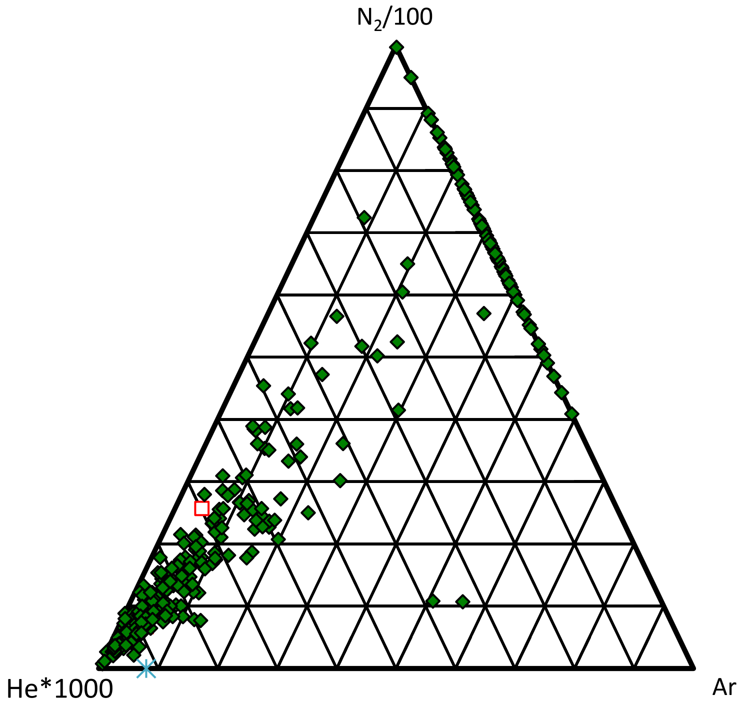
Figure C45

COSO Well 67C-17



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Ternary Diagrams for COSO Well 67C-17

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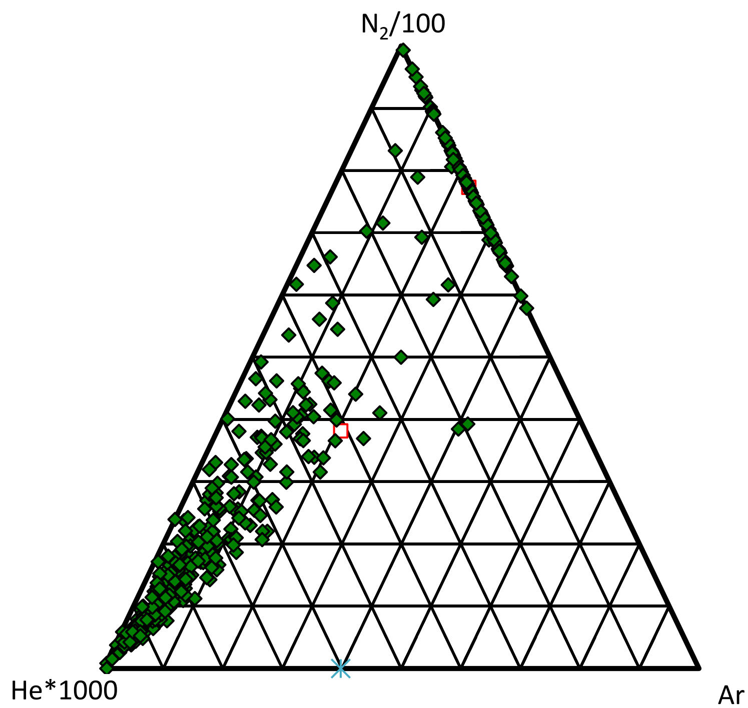
Figure C46

COSO Well 68-6



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Ternary Diagrams for COSO Well 68-6

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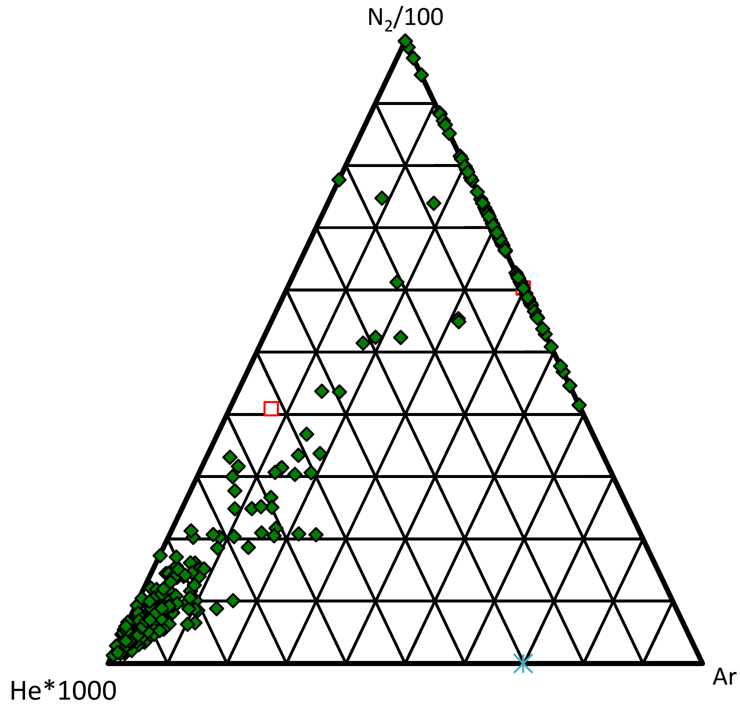
Figure C47

COSO Well 68-20



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Ternary Diagrams for COSO Well 68-20

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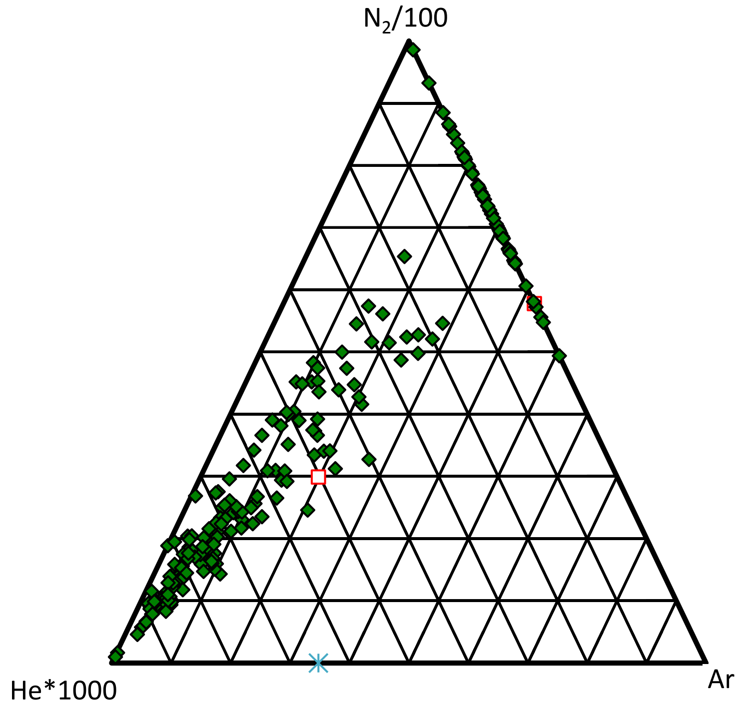
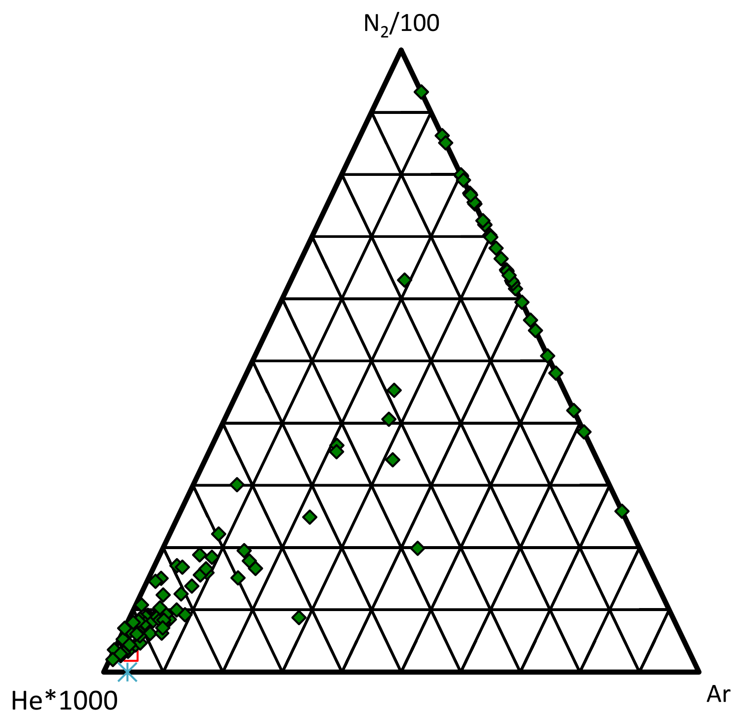
Figure C48

COSO Well 68-20RD



COSO Well 73-19



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Ternary Diagrams for COSO Well 73-19
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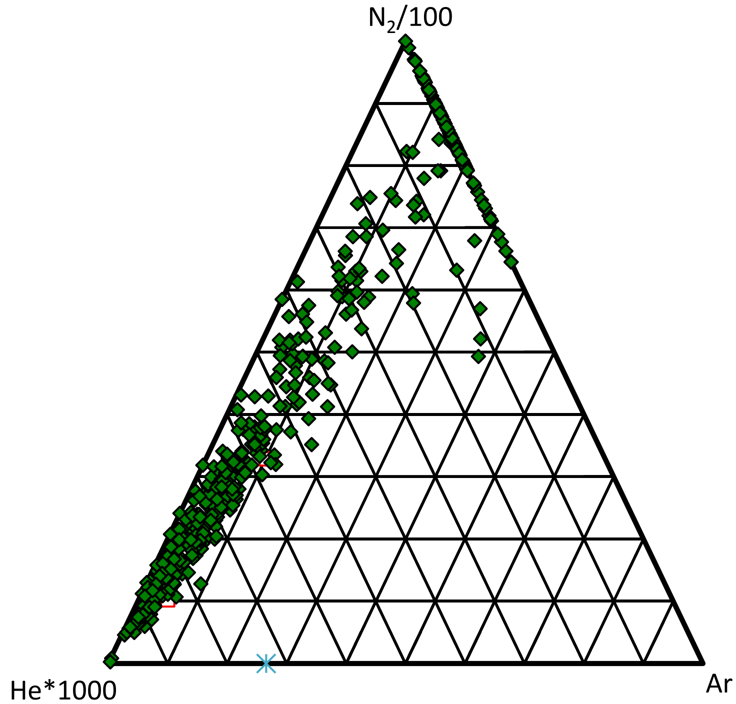
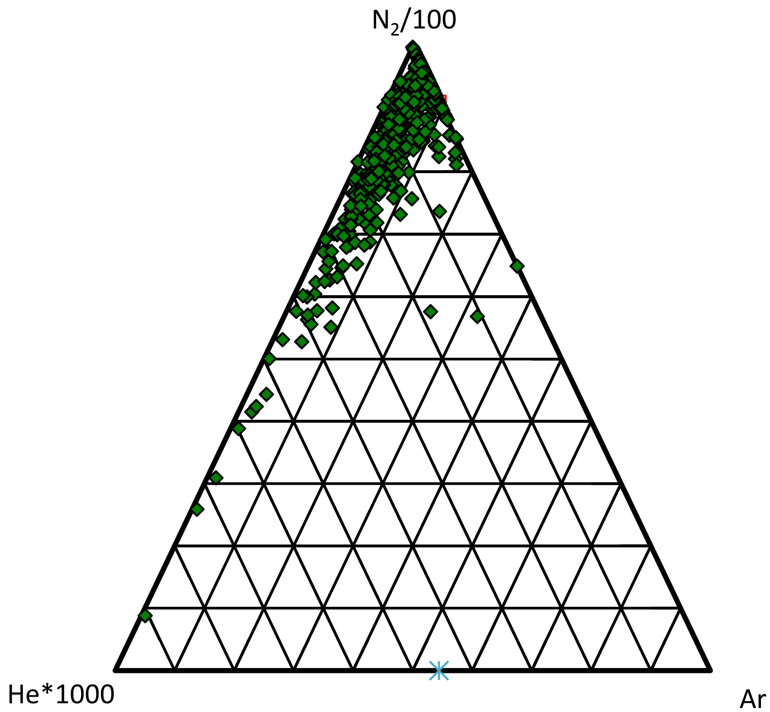
Figure C50

COSO Well 83B-16



COSO Well 84-30



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Ternary Diagrams for COSO Well 84-30
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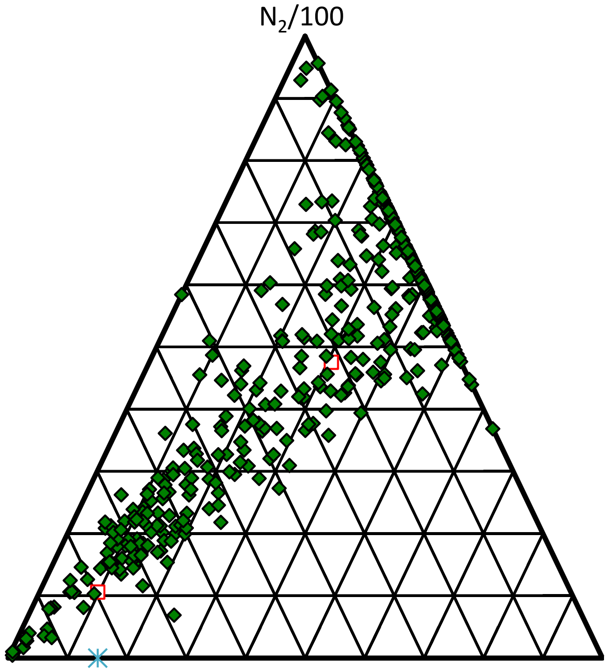
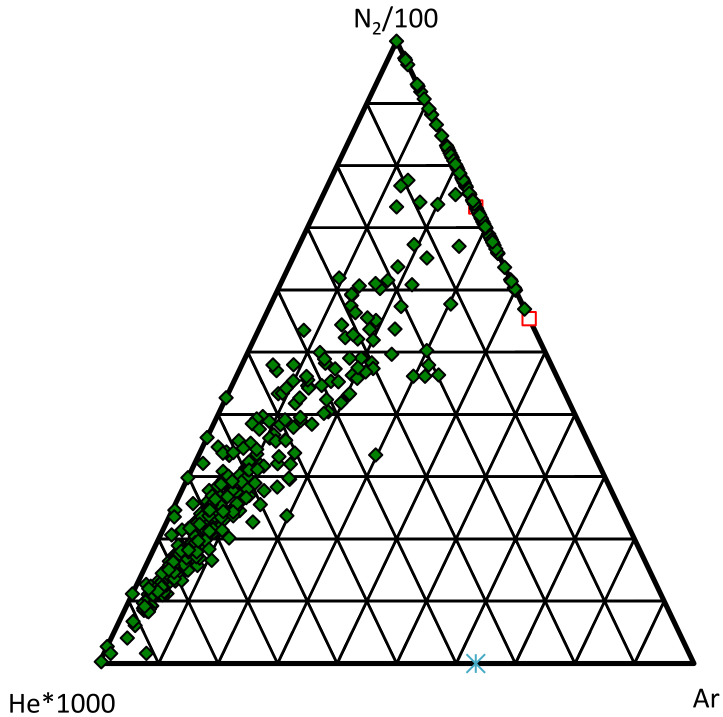
Figure C52

COSO Well 86-17



COSO Well 88-20



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Ternary Diagrams for COSO Well 88-20
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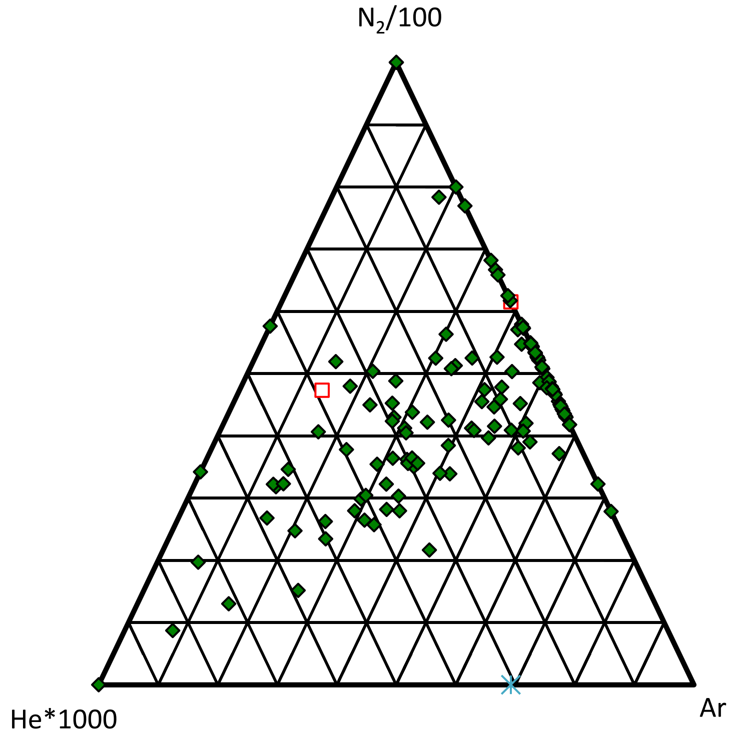
Figure C54

Hawaii Well SOH1



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Ternary Diagrams for Hawaii Well SOH1
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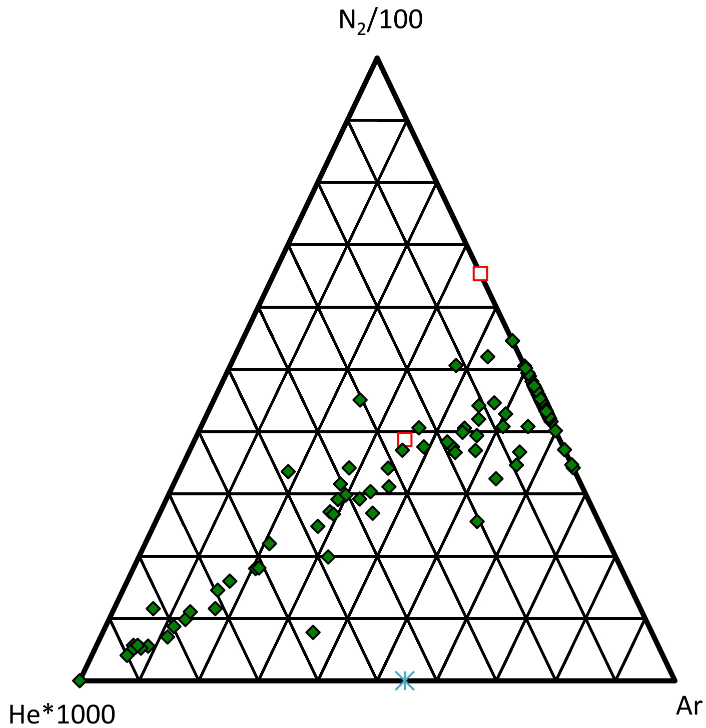
Figure C55

Hawaii Well SOH2



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Ternary Diagrams for Hawaii Well SOH2

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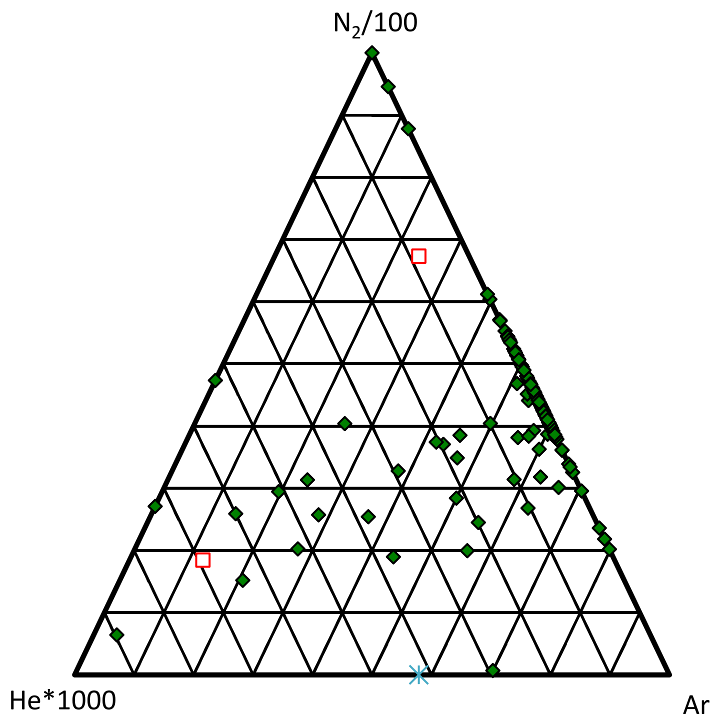
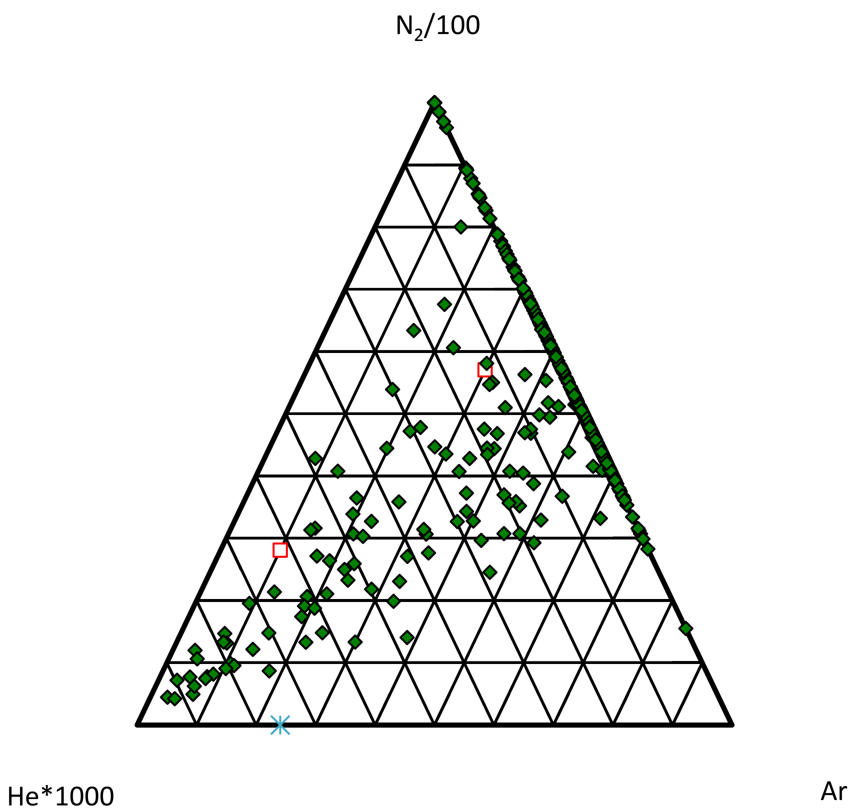
Figure C56

Hawaii Well SOH4



Glass Mountain Well 88-28



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Ternary Diagrams for Glass Mountain Well 88-28

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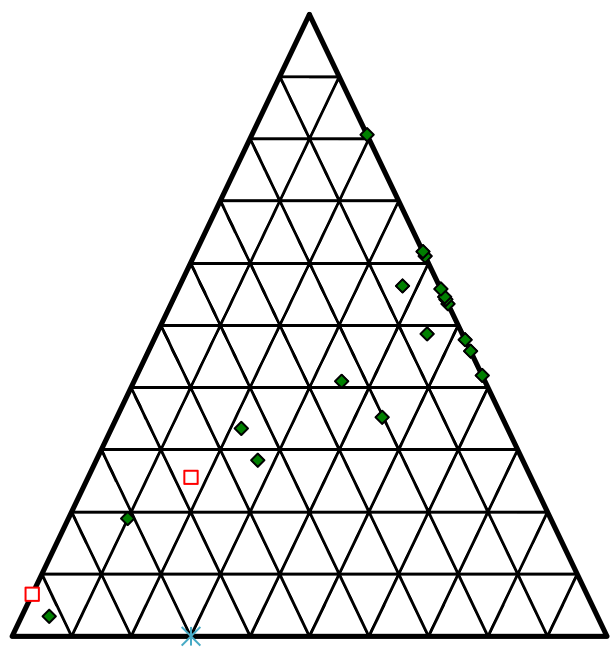
Figure C58

Iceland Well NG07



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Ternary Diagrams for Iceland Well NG07
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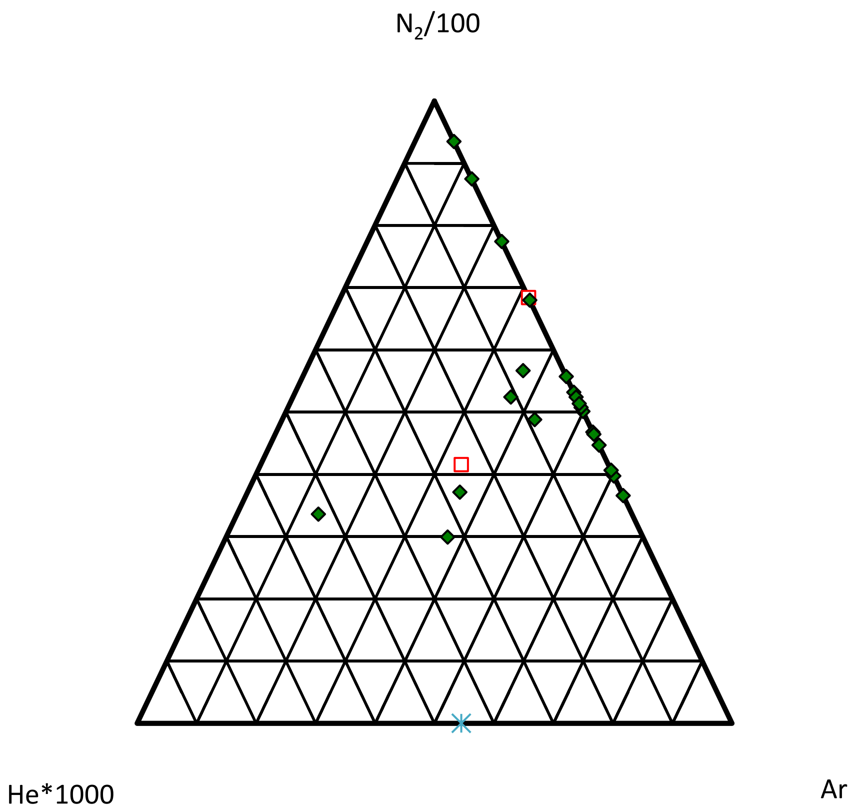
Figure C59

Iceland Well NJ11



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Ternary Diagrams for Iceland Well NJ11
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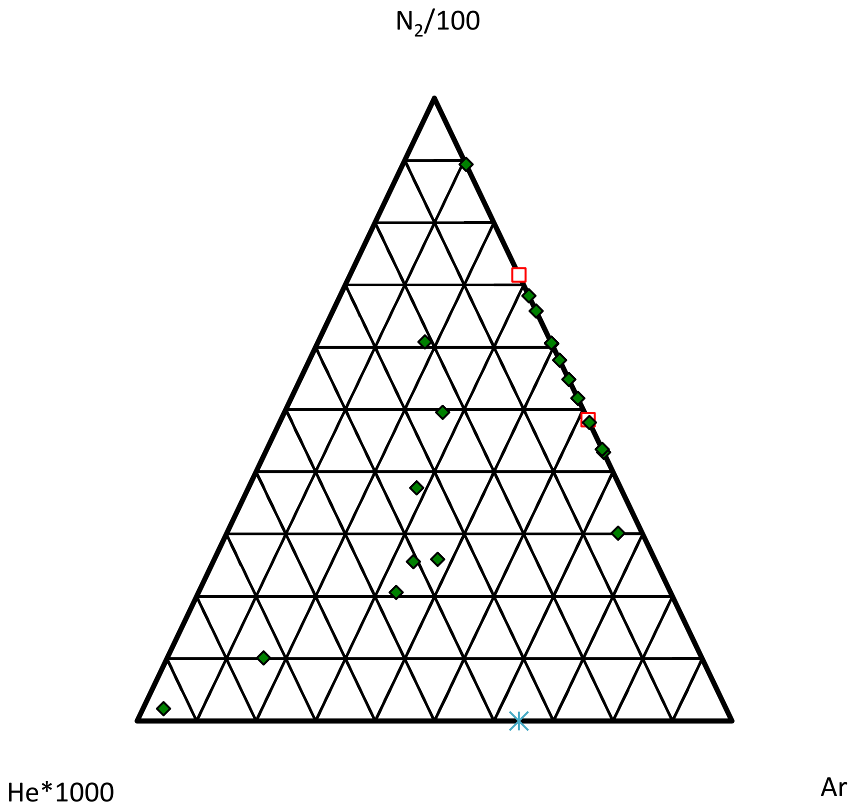
Figure C60

Iceland Well RN10



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Ternary Diagrams for Iceland Well RN10

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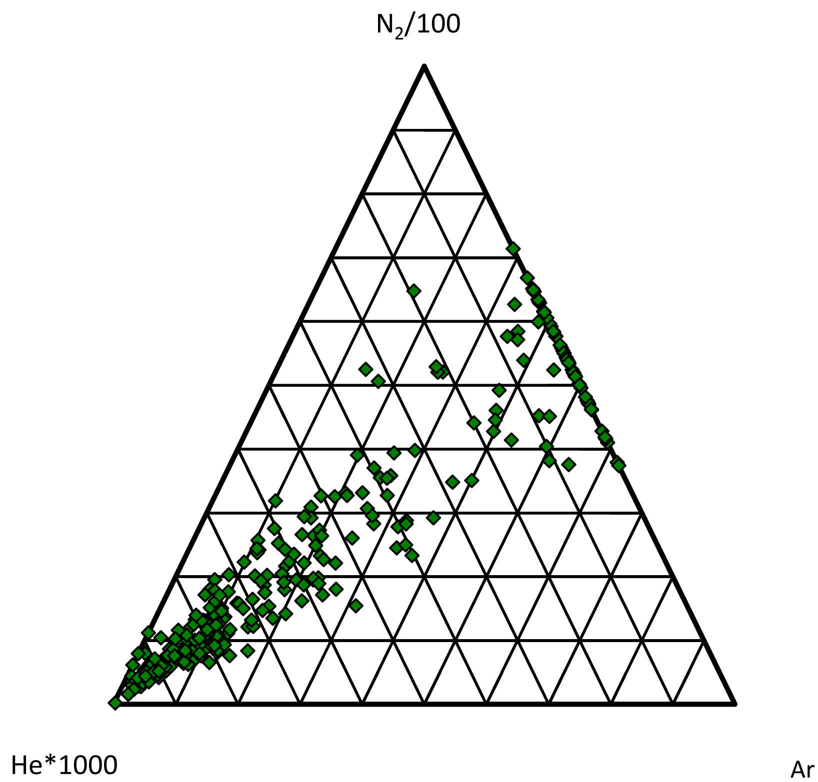
Figure C61

Steamboat Springs Well 87-29



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Ternary Diagrams for Steamboat Springs Well 87-29

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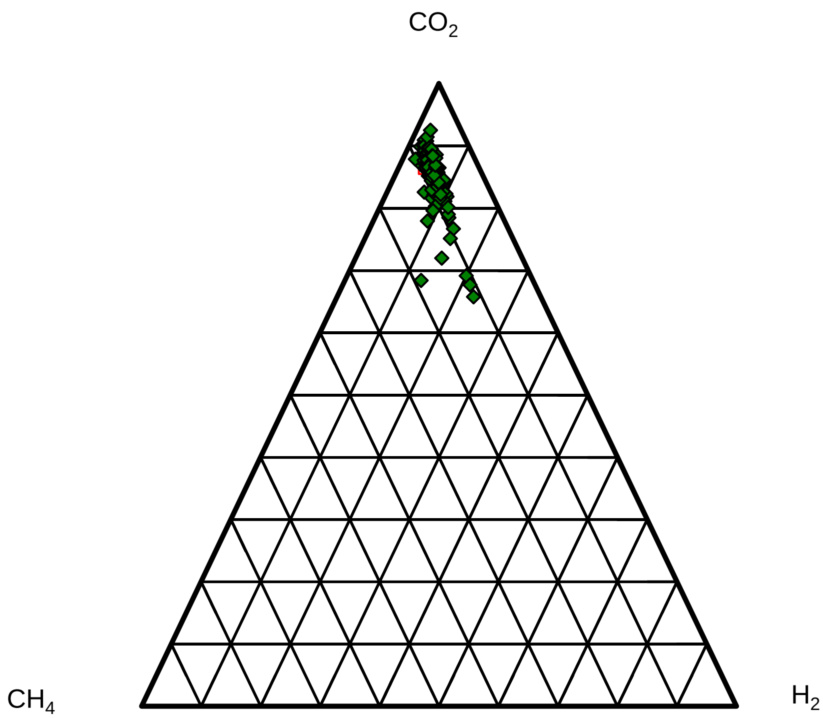
Figure C62

APPENDIX D
CO_2 - CH_4 - H_2 TERNARY PLOTS

Chocolate Mountains Well 17-8



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Ternary Diagrams for Chocolate Mountains Well 17-8
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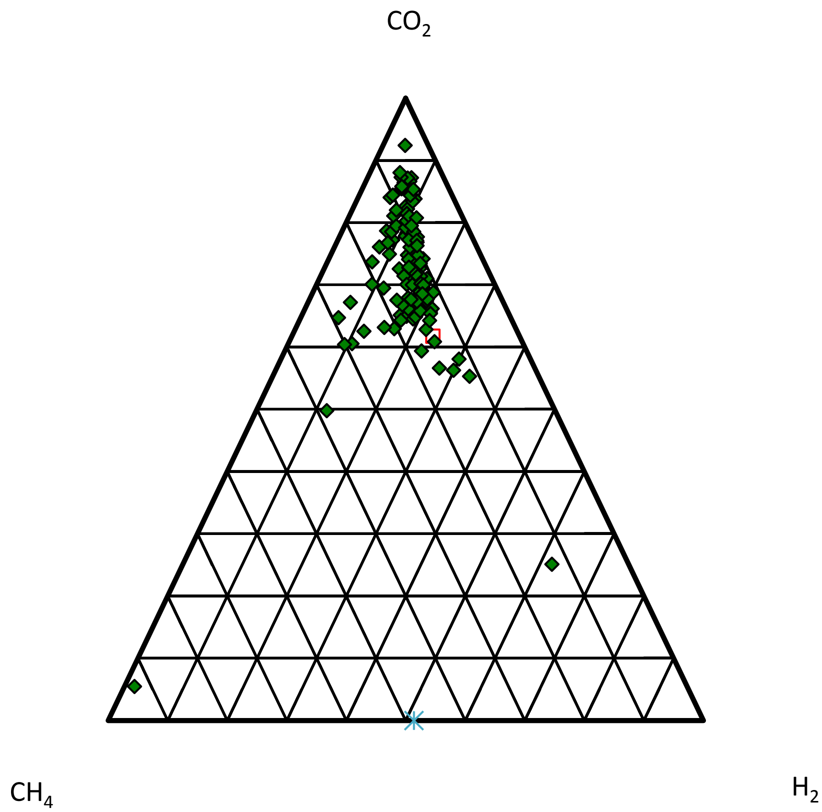
Figure D1

El Centro Well NAFEC 1



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Ternary Diagrams for El Centro Well NAFEC 1
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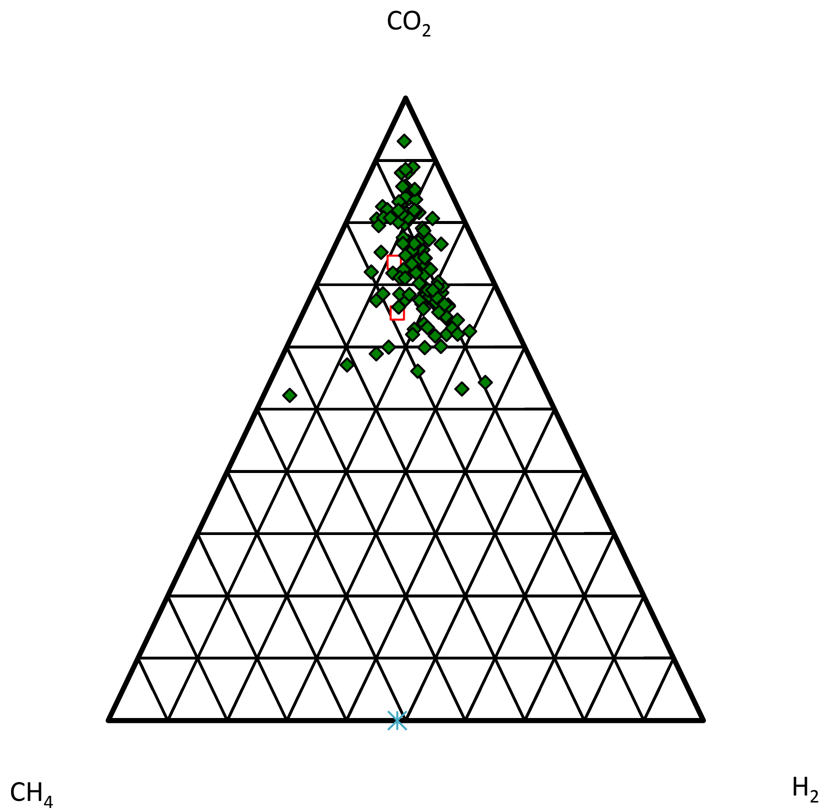
Figure D2

El Centro Well NAFEC 2



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Ternary Diagrams for El Centro Well NAFEC 11
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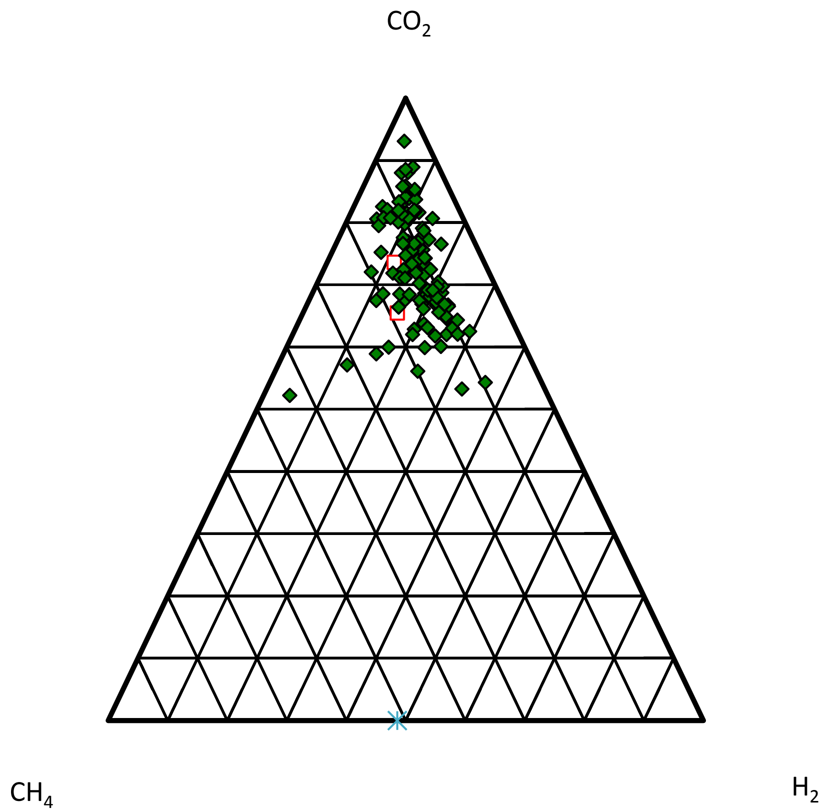
Figure D3

Fallon Well 11-NASF-01



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Ternary Diagrams for Fallon Well 11-NASF-01
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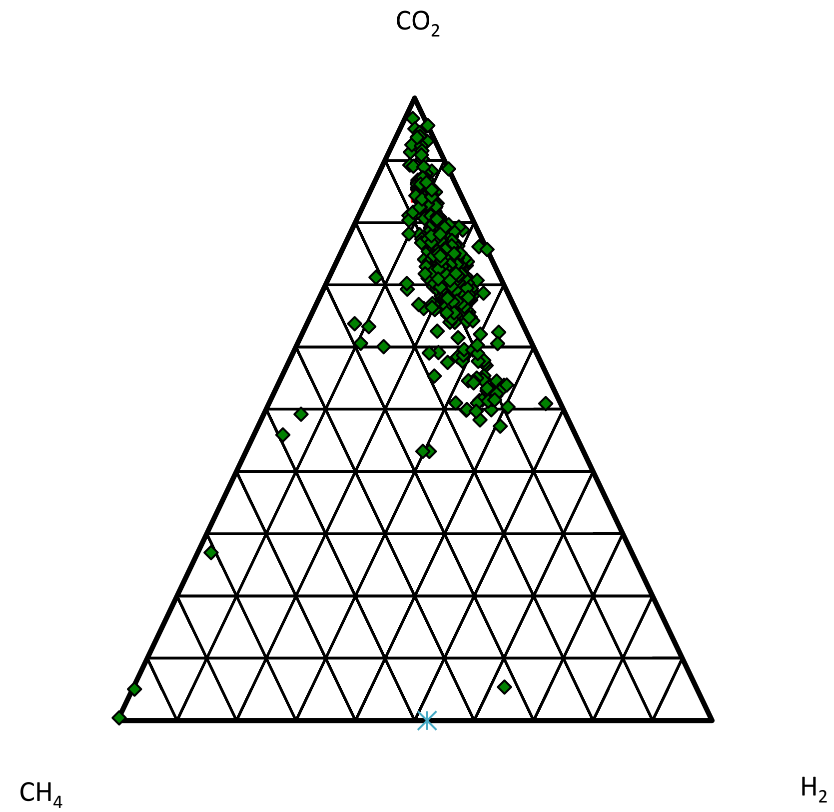
Figure D5

Fallon Well 11-NASF-02



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Ternary Diagrams for Fallon Well 11-NASF-02
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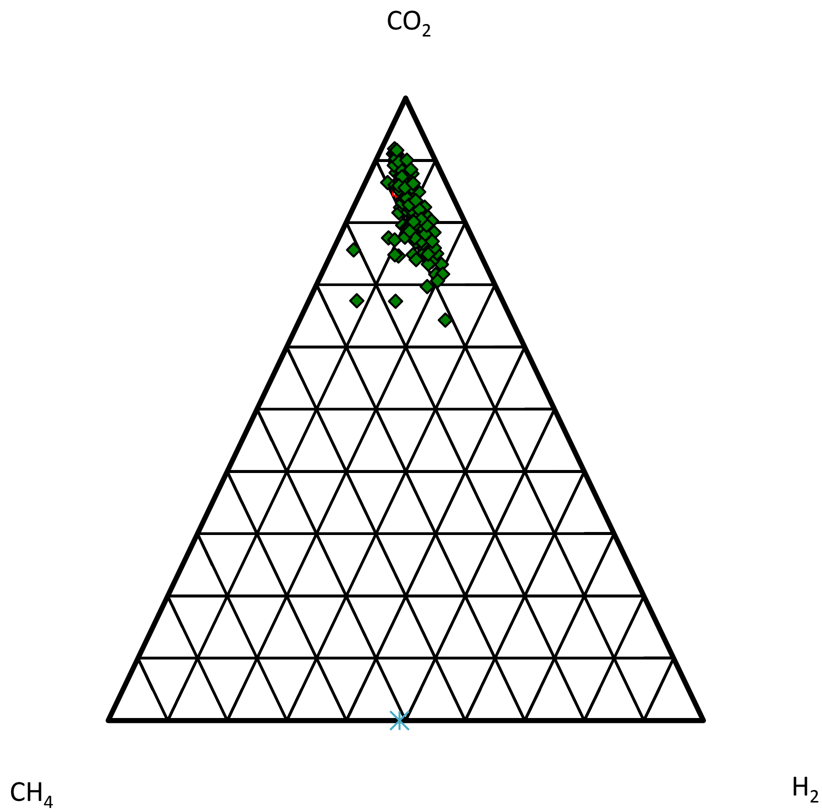
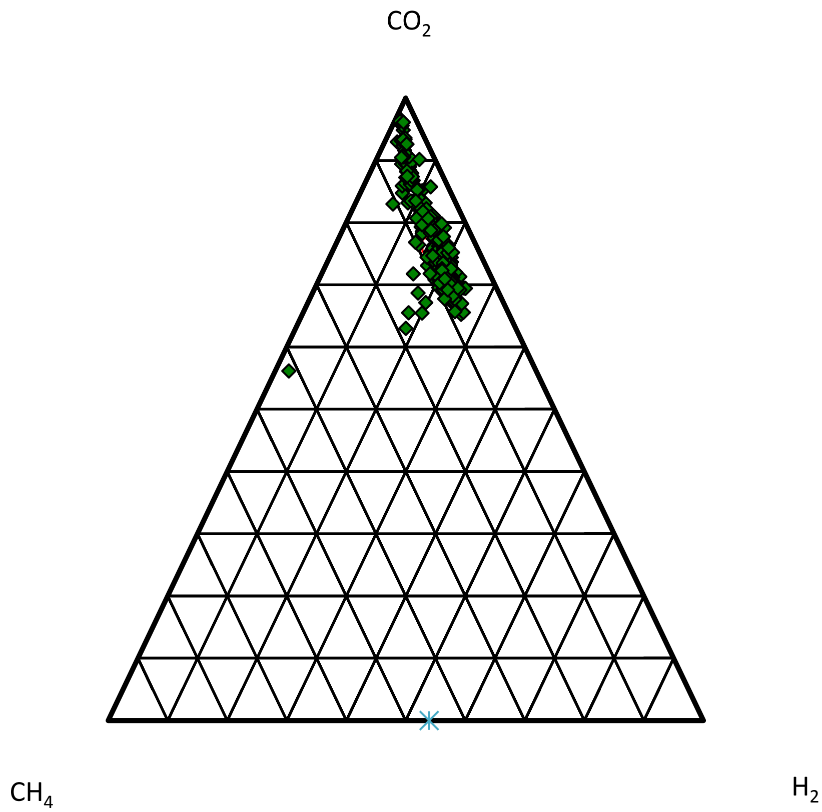
Figure D6

Fallon Well FDU2D



Fallon Well FLTH88-24



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Ternary Diagrams for Fallon Well FLTH88-24
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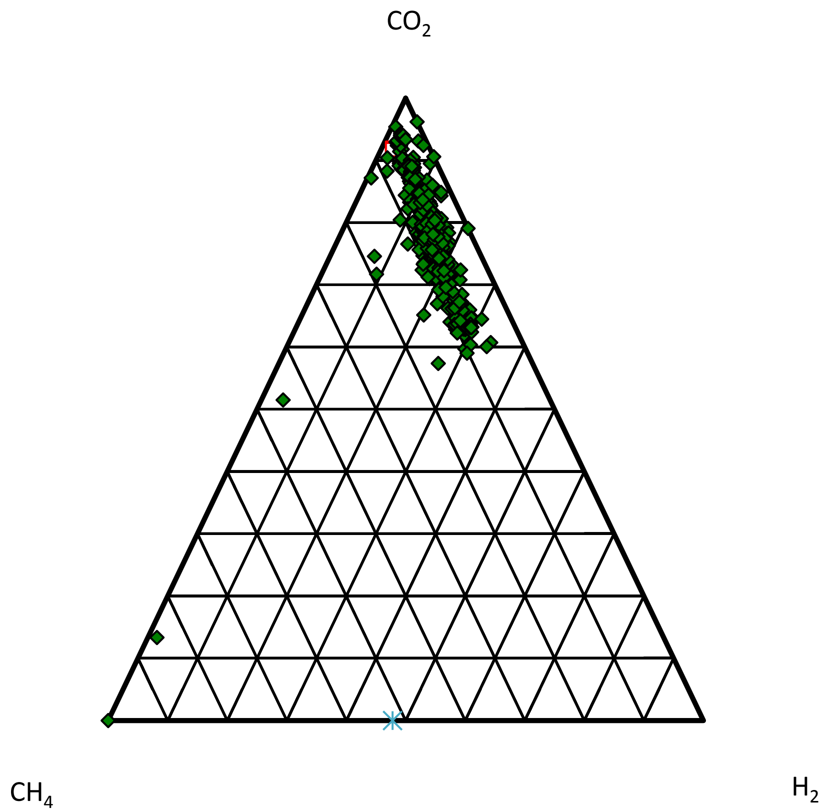
Figure D8

Fallon Well FOH3



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Ternary Diagrams for Fallon Well FOH3
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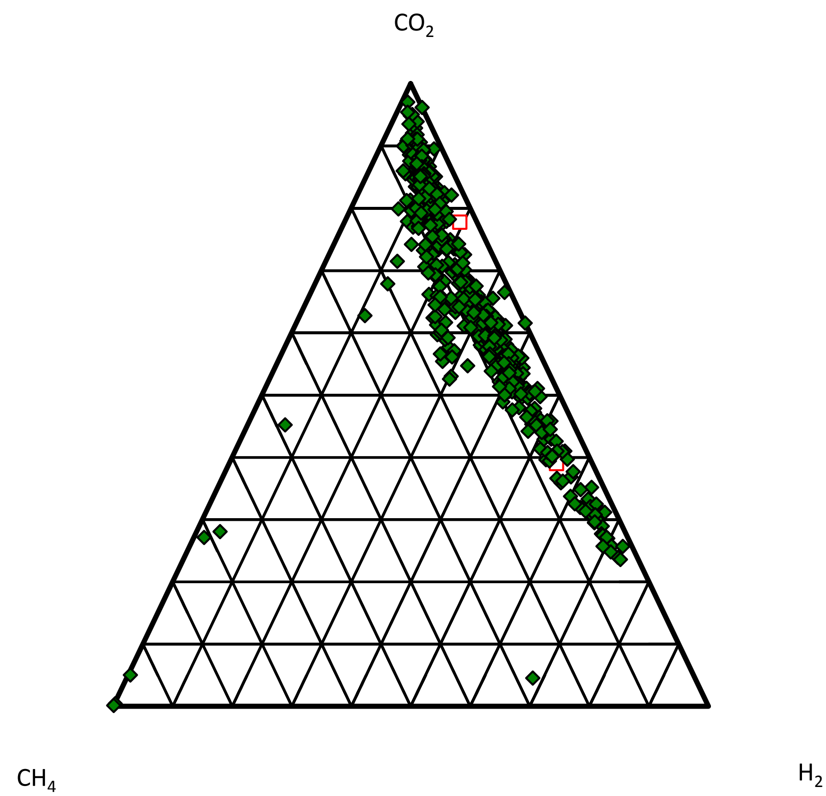
Figure D9

Fallon Well 8236



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Ternary Diagrams for Fallon Well 8236
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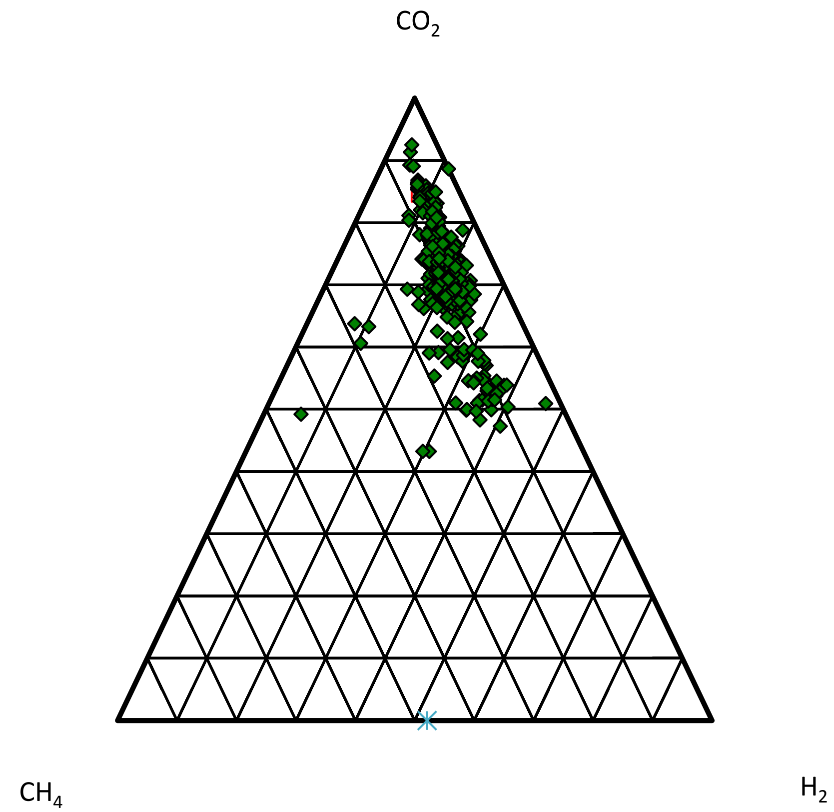
Figure D10

Fallon Well 8431



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Ternary Diagrams for Fallon Well 8431
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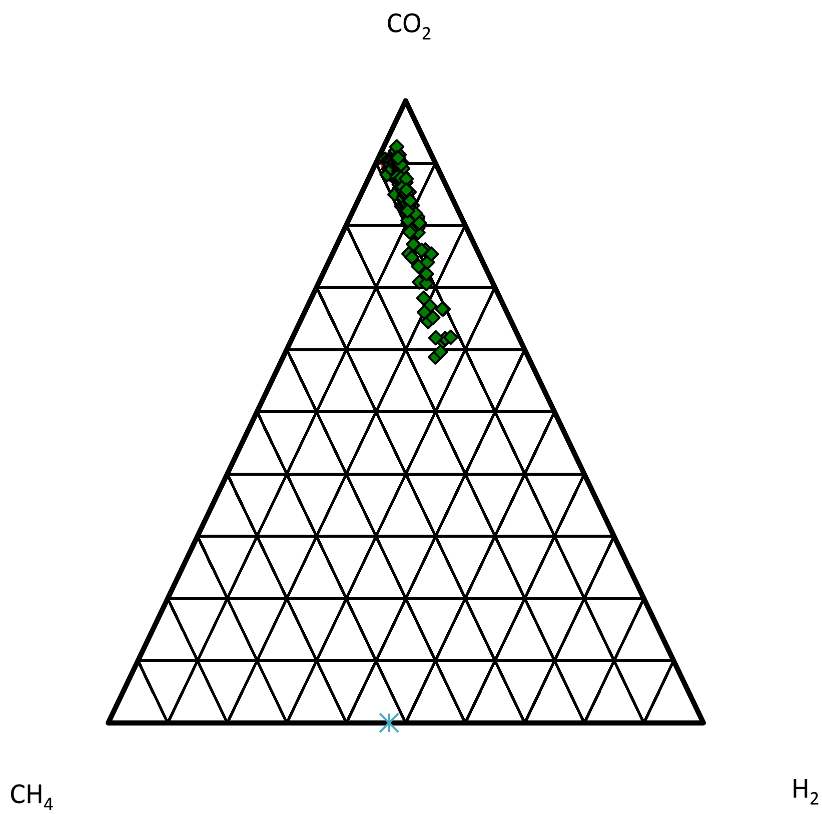
Figure D11

Hawthorne Well HAD 1



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Ternary Diagrams for Hawthorne Well HAD 1

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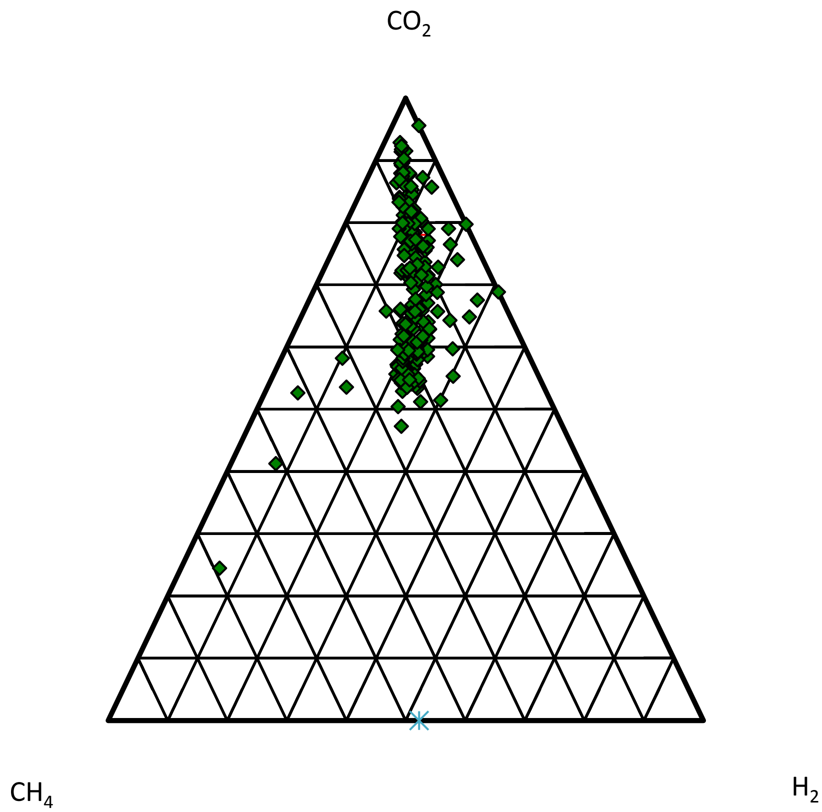
Figure D12

Hawthorne Well HWAAD 2



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Ternary Diagrams for Hawthorne Well HWAAD 2

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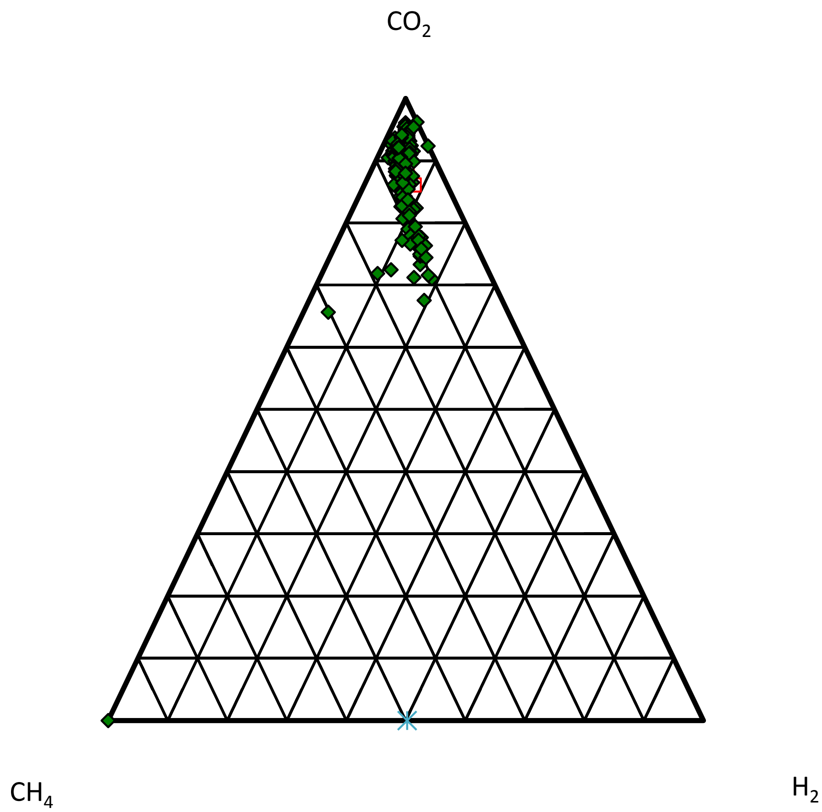
Figure D13

Hawthorne Well HWAAD 3



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Ternary Diagrams for Hawthorne Well HWAAD 3
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Figure D14

Beowawe Well 57-13

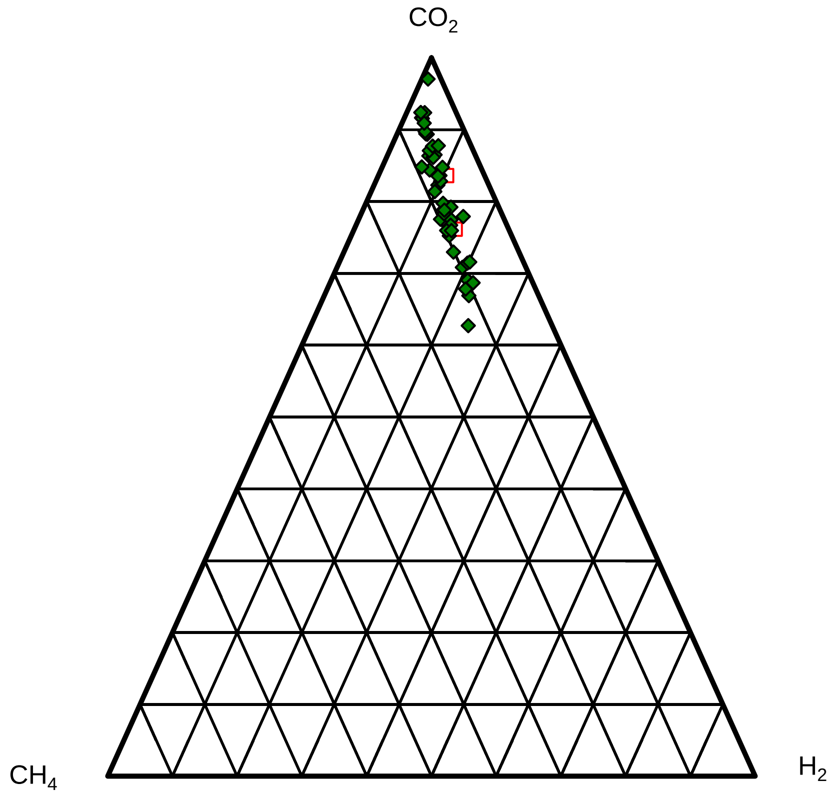

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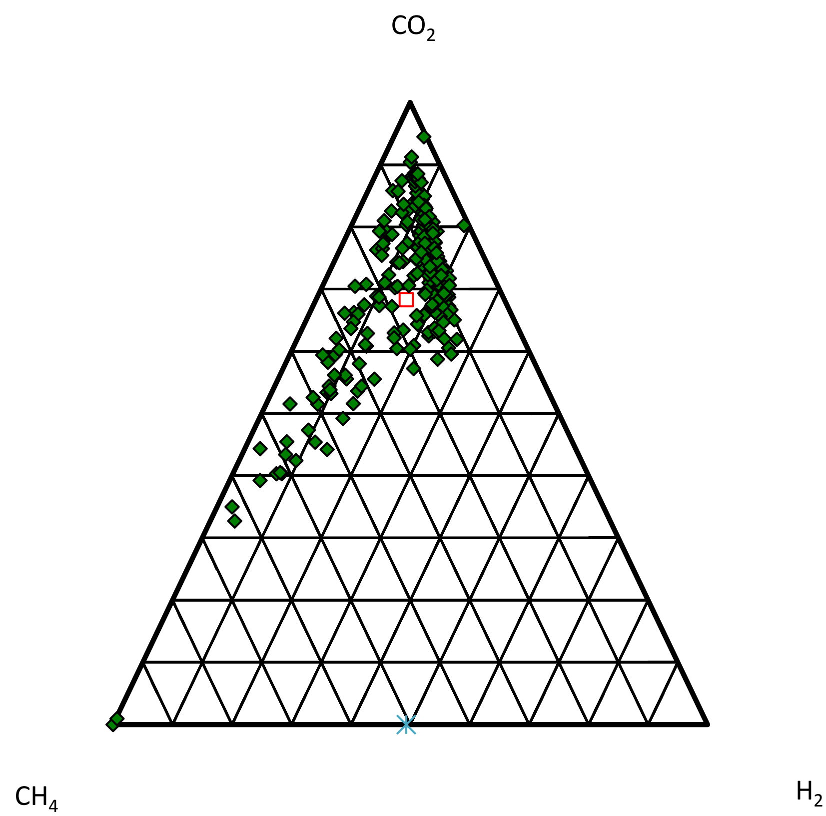
Figure D15

Beowawe Well 77-13



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Ternary Diagrams for Beowawe Well 77-13

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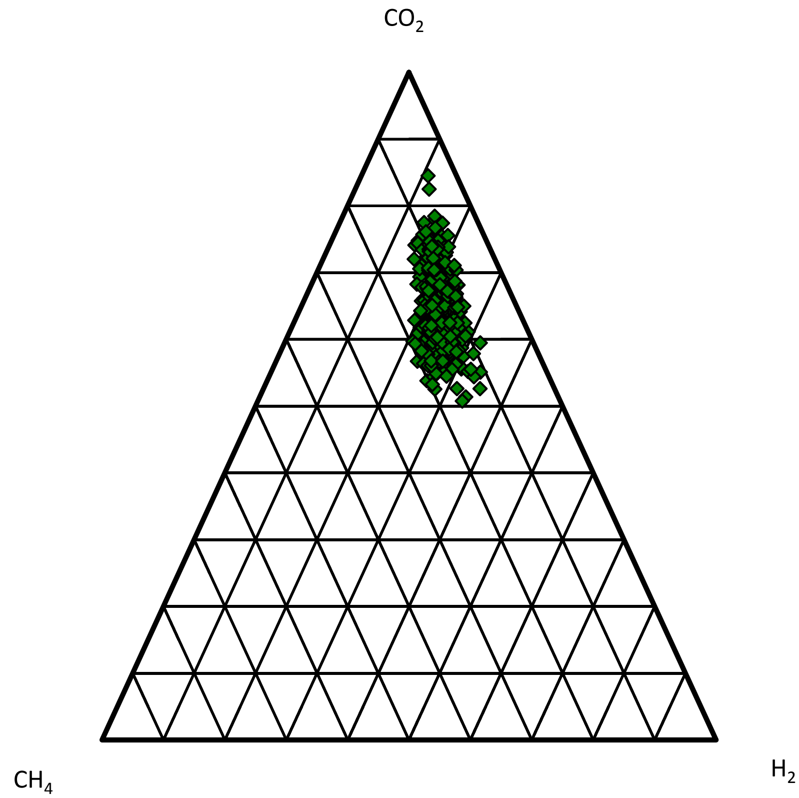
Figure D16

Salton Sea Well Del Ranch



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Ternary Diagrams for Salton Sea Well Del Ranch
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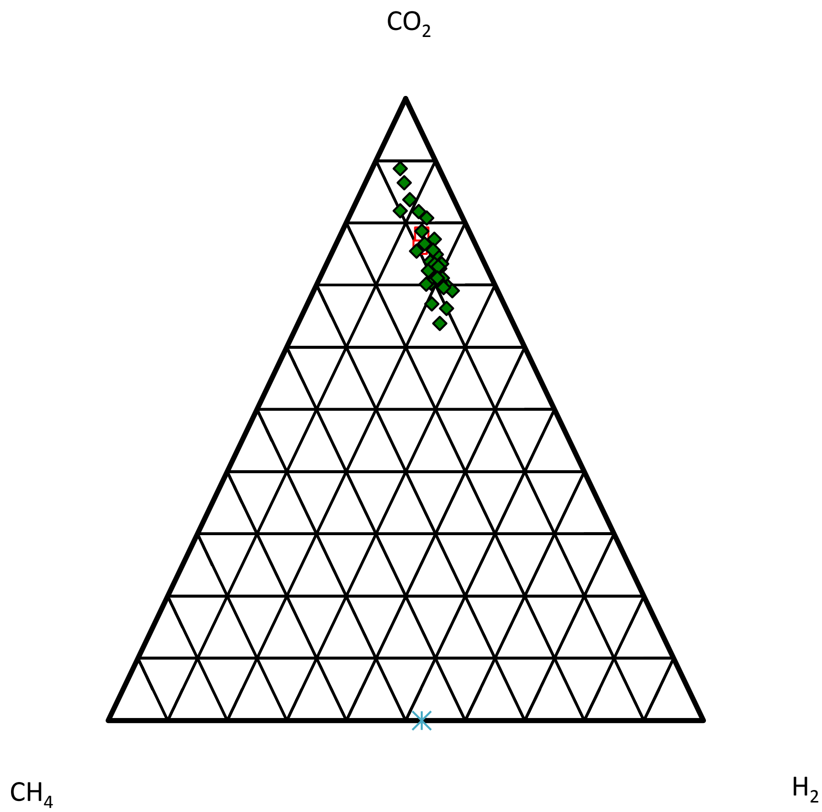
Figure D17

Salton Sea Well ELIW6



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Ternary Diagrams for Salton Sea Well ELIW6
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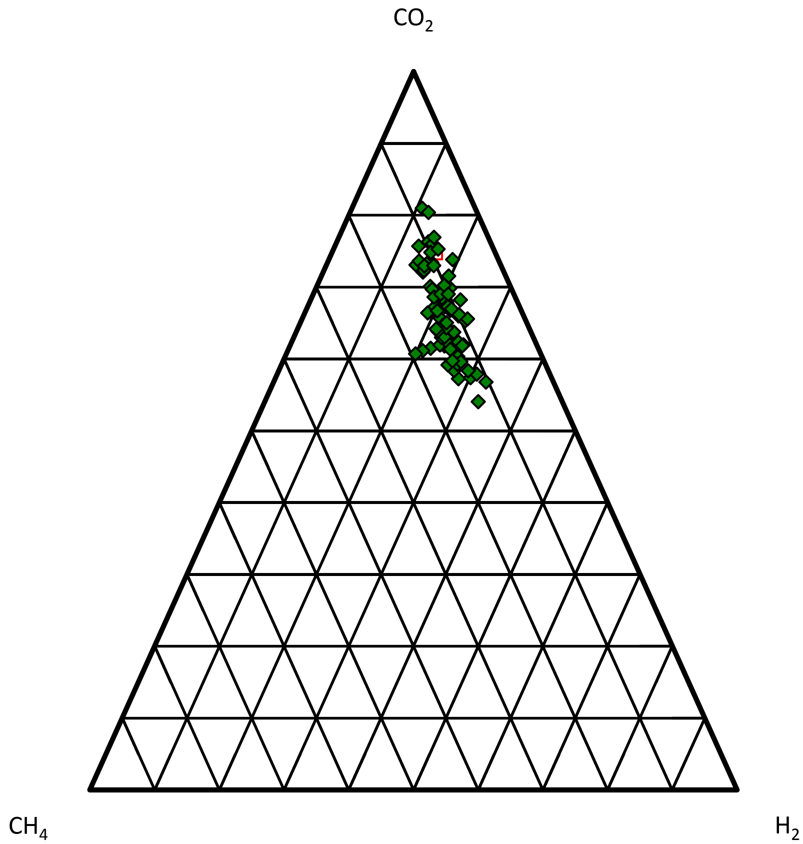
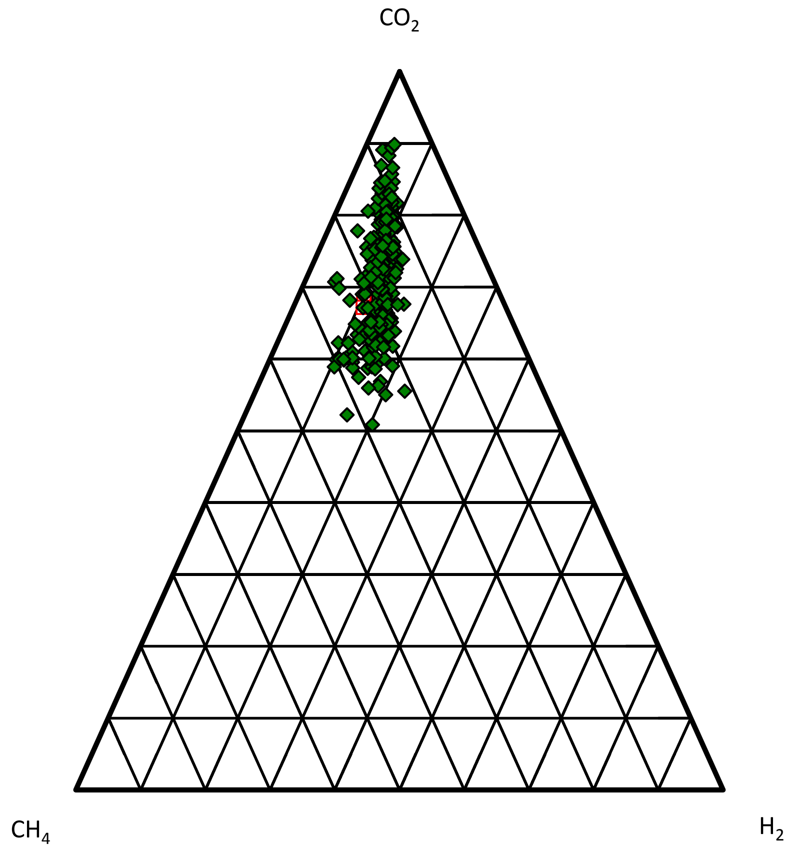
Figure D18

Salton Sea Well Vulcan



Salton Sea Well Elmore 12



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Ternary Diagrams for Salton Sea Well Elmore 12
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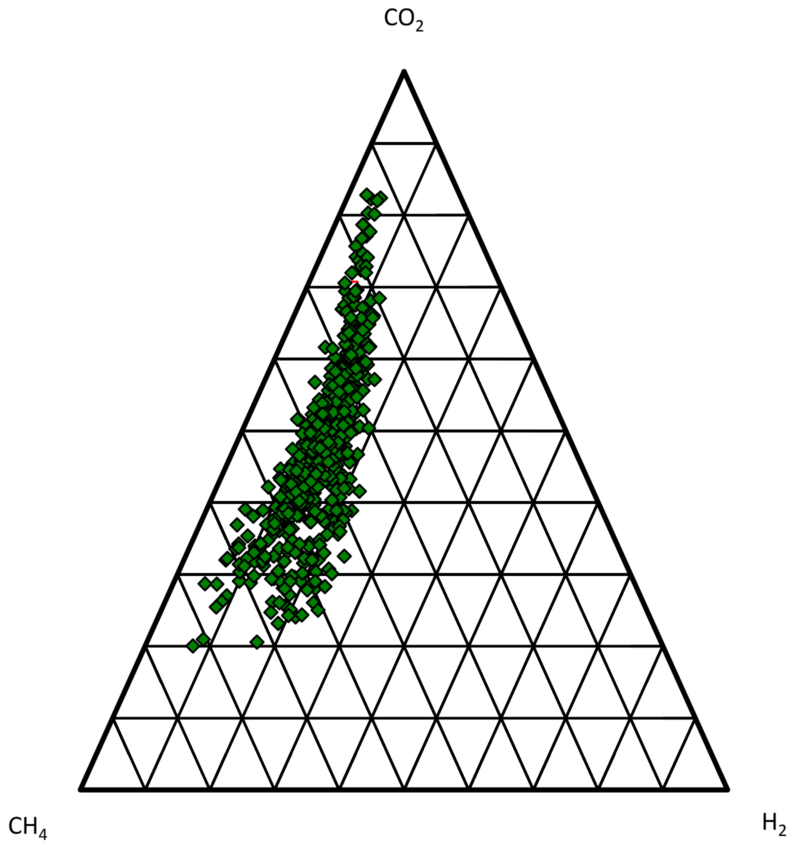
Figure D20

Salton Sea Well Elmore 16



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Ternary Diagrams for Salton Sea Well Elmore 16
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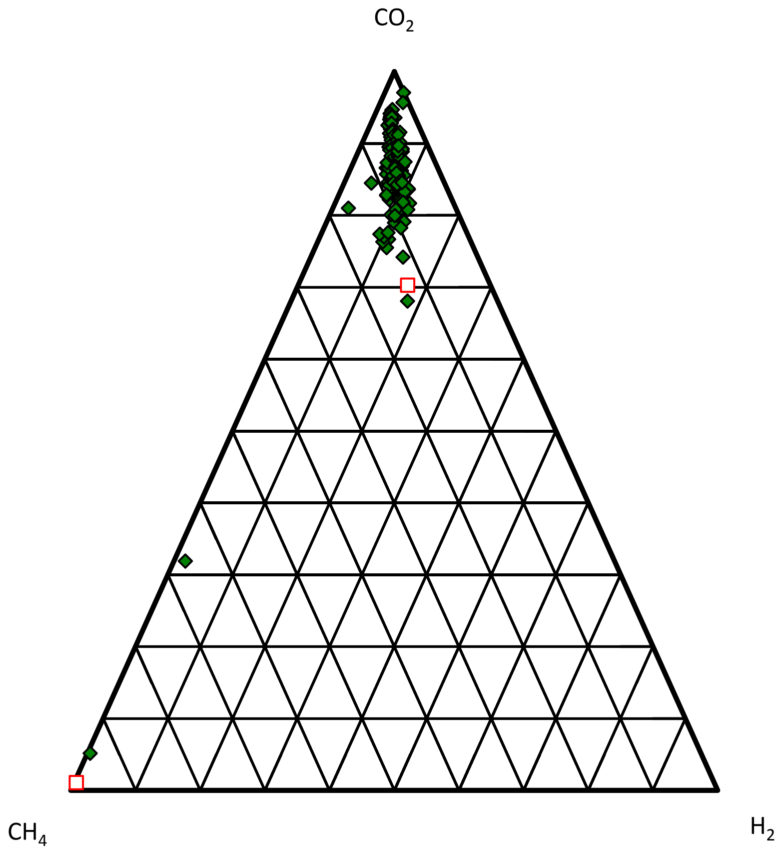
Figure D21

Salton Sea Well River Ranch 4



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Ternary Diagrams for Salton Sea Well Ranch River 4
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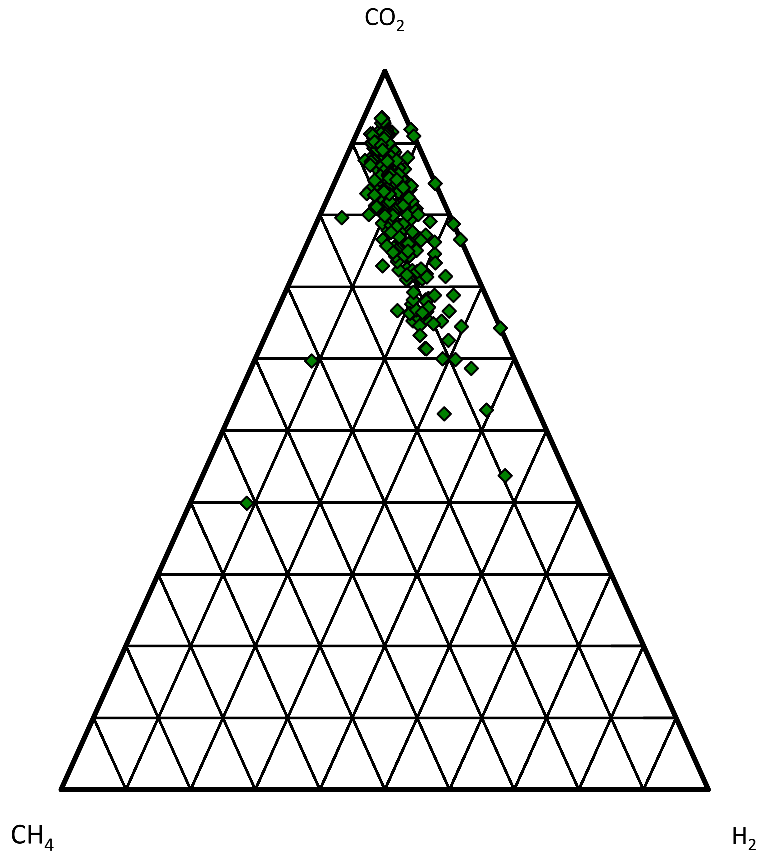
Figure D22

Salton Sea Well River Ranch 5



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Ternary Diagrams for Salton Sea Well Ranch River 5

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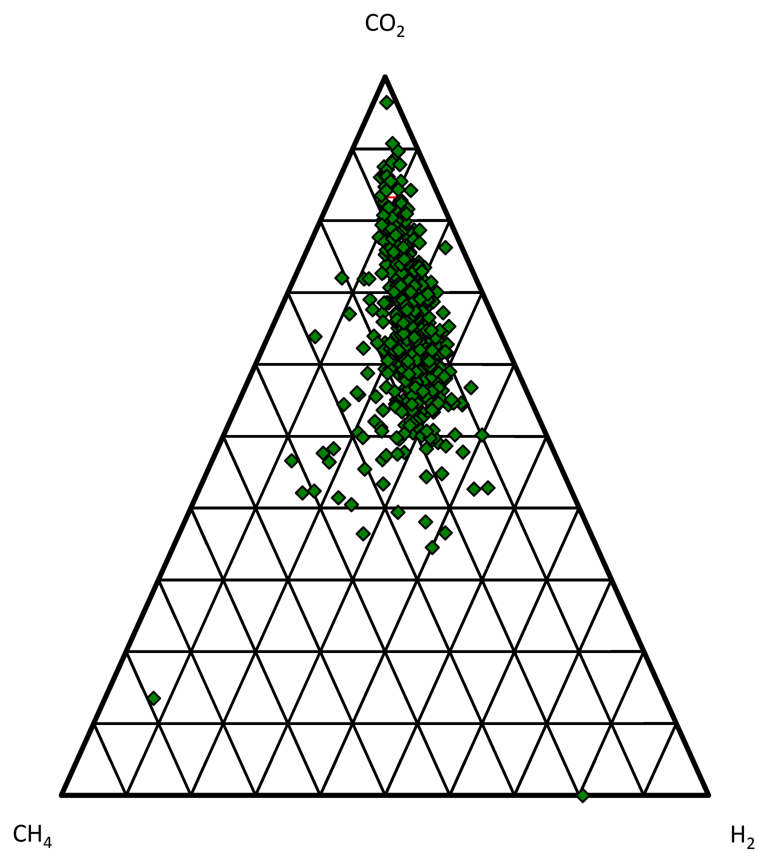
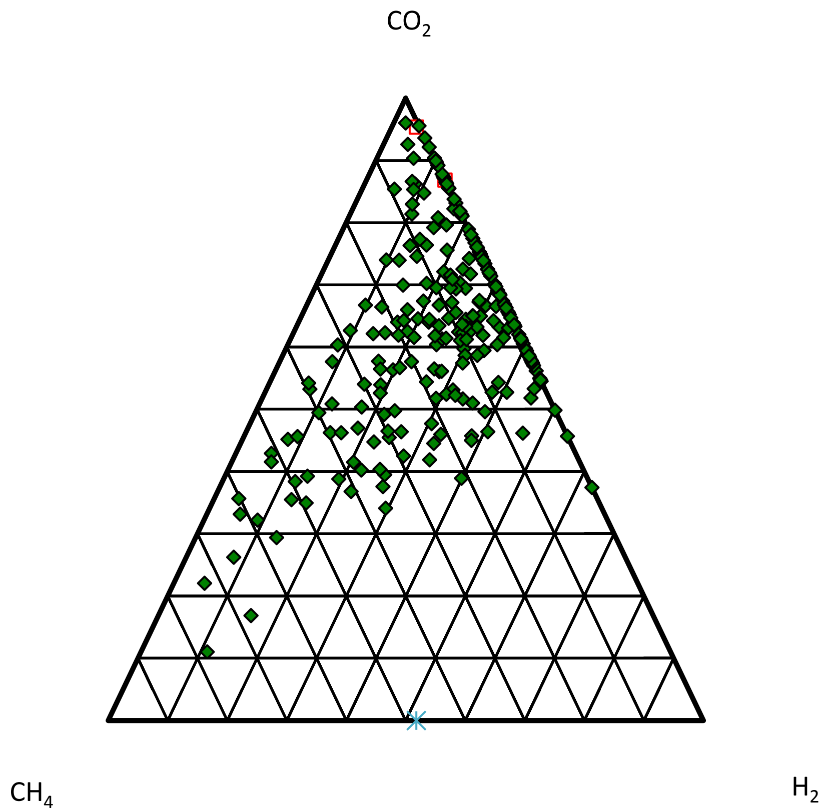
Figure D23

Kahara Tela Bodegas Well K33



Kahara Tela Bodegas Well T2



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Ternary Diagrams for Kahara Telga Bodegas Well T2
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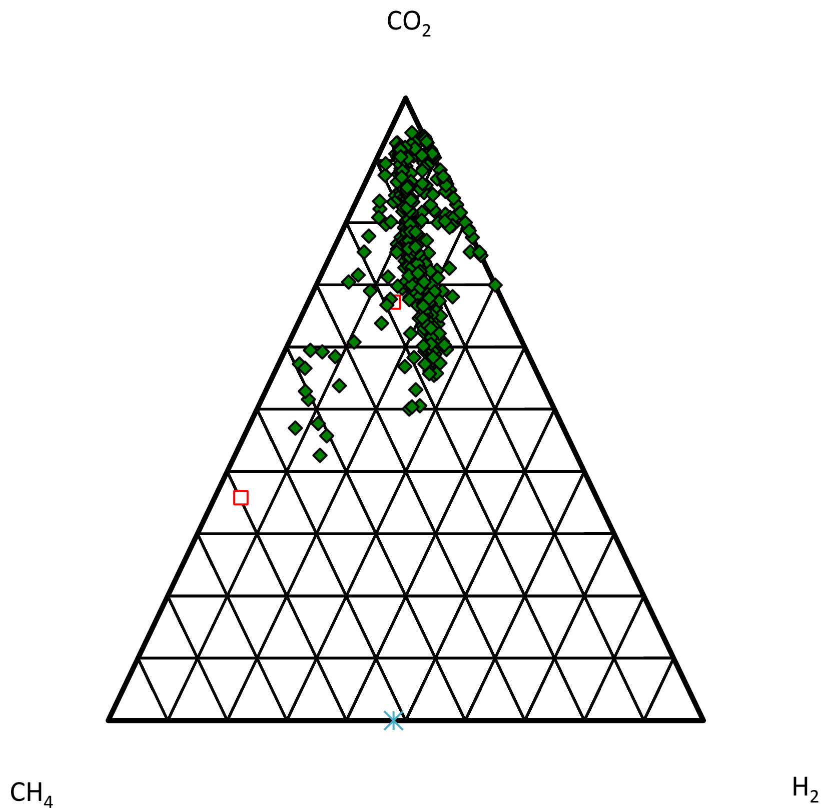
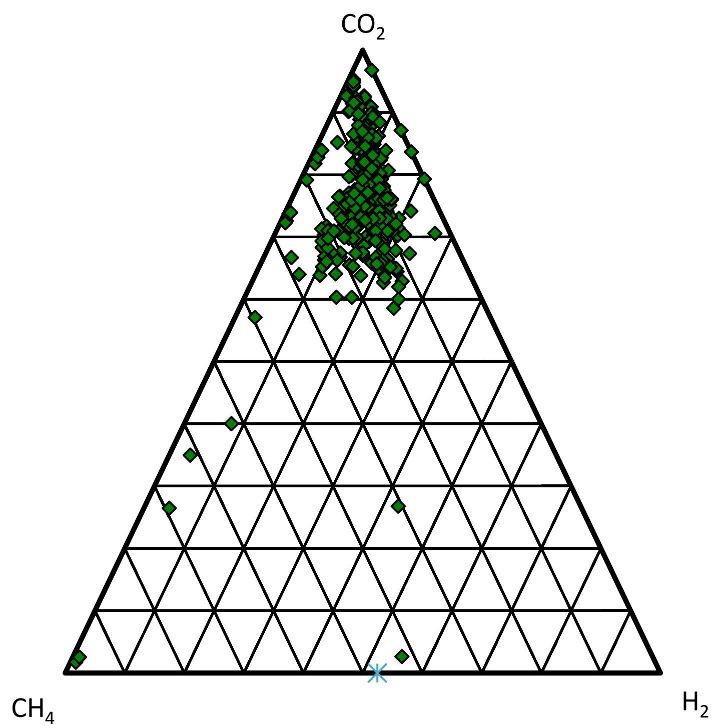
Figure D26

COSO Well 15A-17



COSO Well 23A-17



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Ternary Diagrams for COSO Well 23A-17
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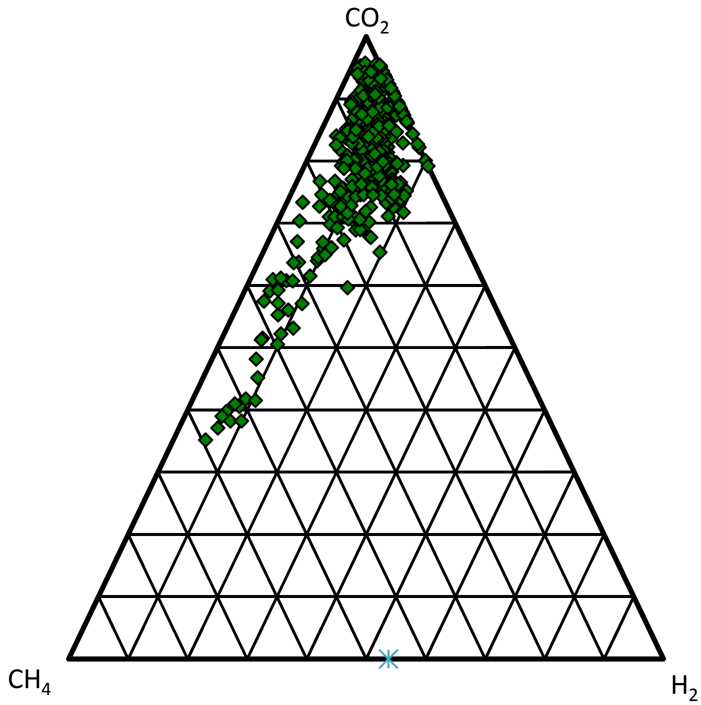
Figure D28

COSO Well 23A-19



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Ternary Diagrams for COSO Well 23A-19

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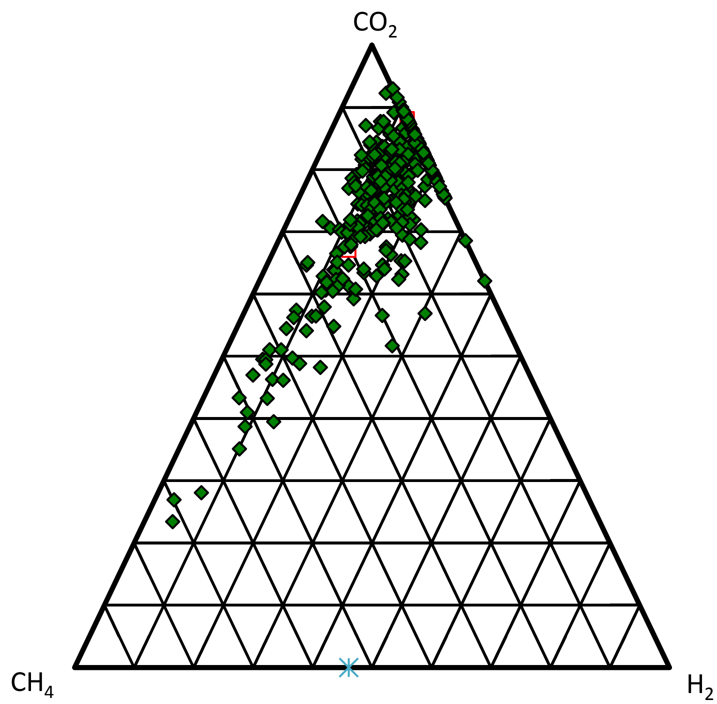
Figure D29

COSO Well 24A-8



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Ternary Diagrams for COSO Well 24A-8

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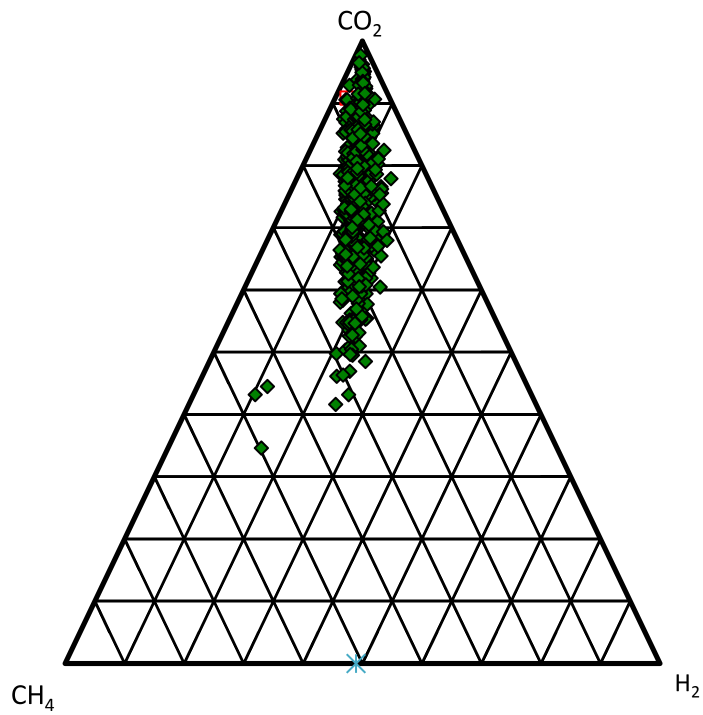
Figure D30

COSO Well 33-7



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Ternary Diagrams for COSO Well 33-7
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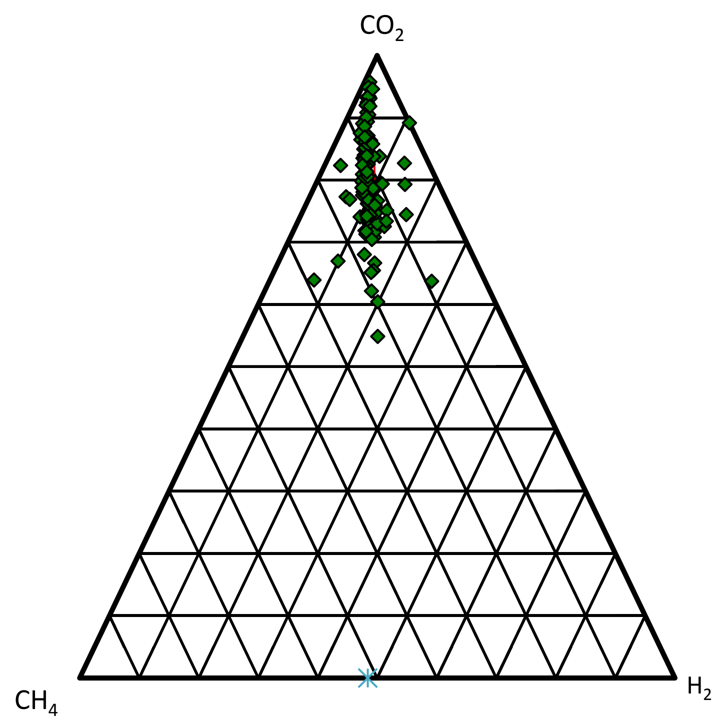
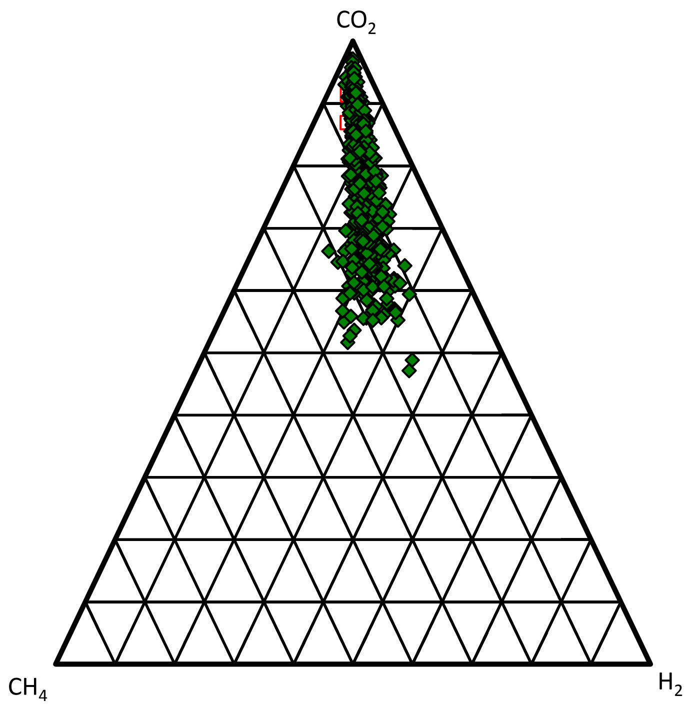
Figure D31

COSO Well 349RD2



COSO Well 38C-9



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Ternary Diagrams for COSO Well 38C-9
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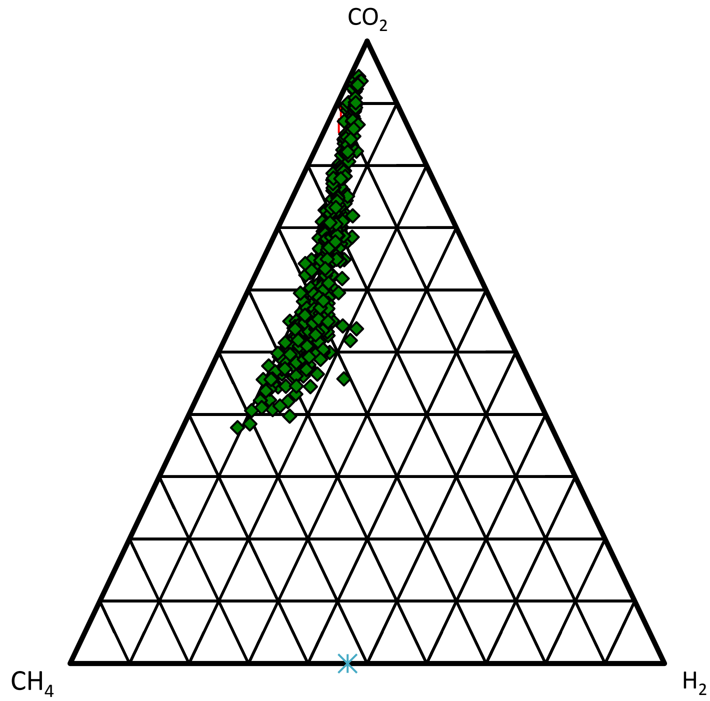
Figure D33

COSO Well 38D-9



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Ternary Diagrams for COSO Well 38D-9
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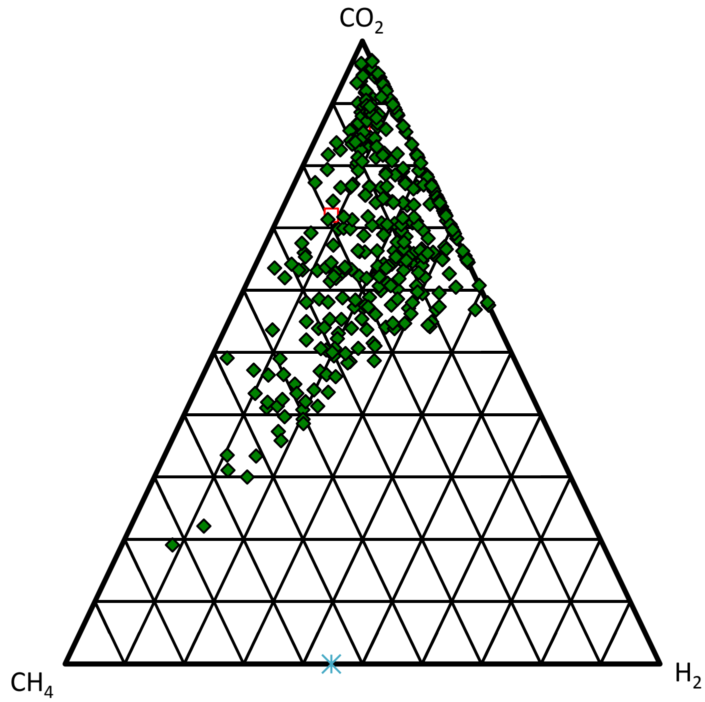
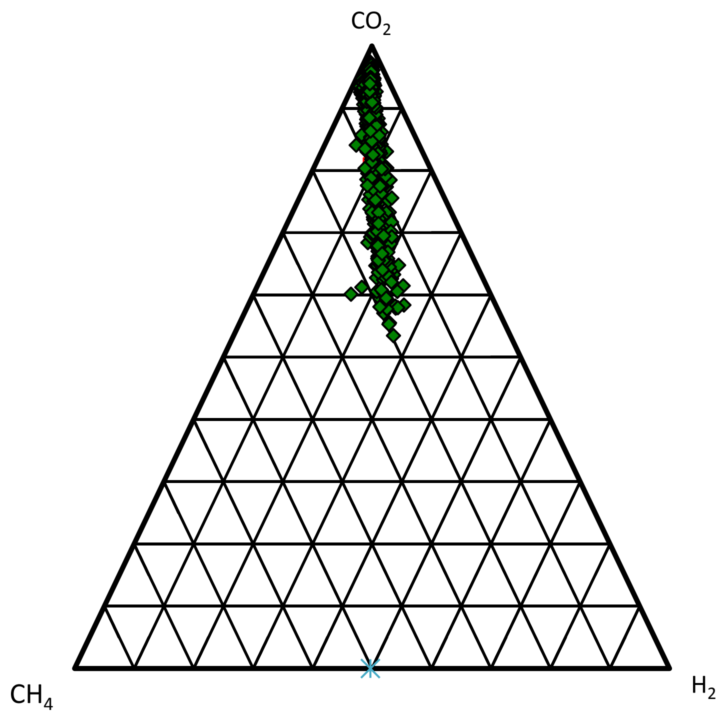
Figure D34

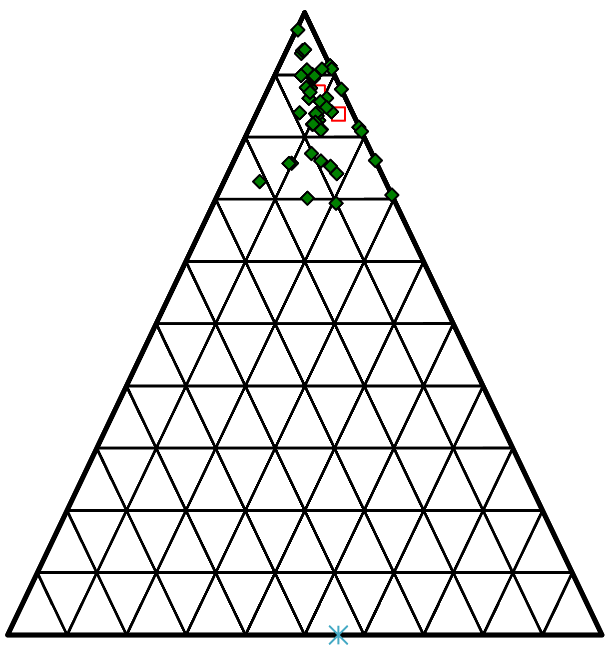
COSO Well 41B-8



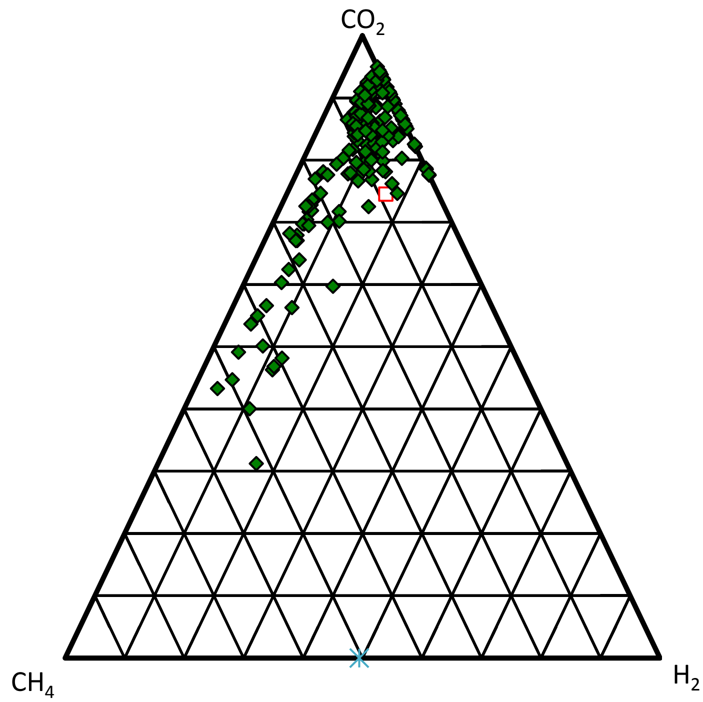
COSO Well 46A-19RD



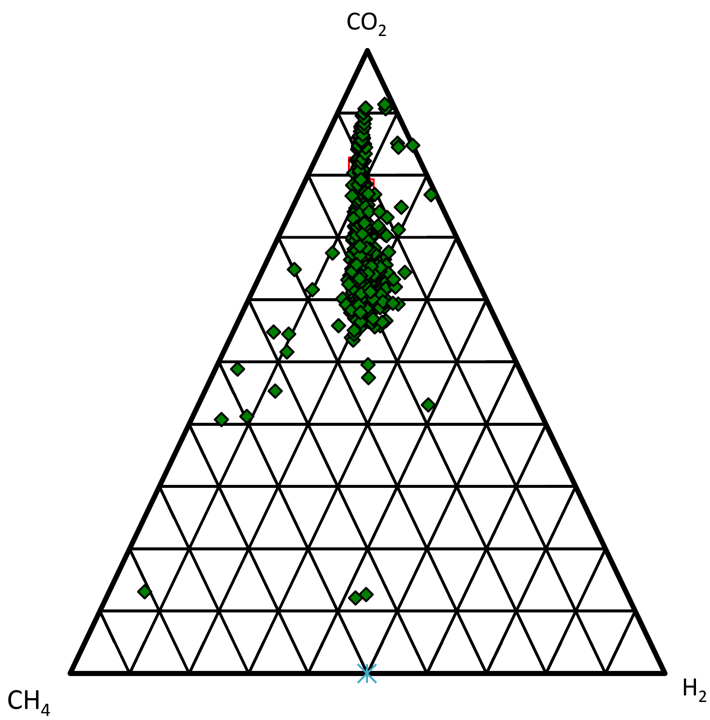
COSO Well 47A-8



COSO Well 47A-8RD



COSO Well 51B-16



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Ternary Diagrams for COSO Well 51B-16

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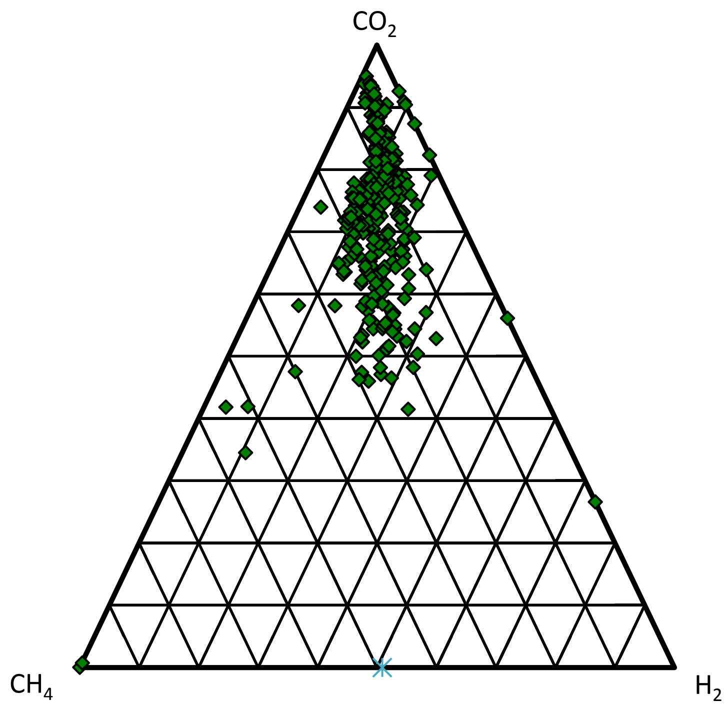
Figure D39

COSO Well 52-20



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Ternary Diagrams for COSO Well 52-20
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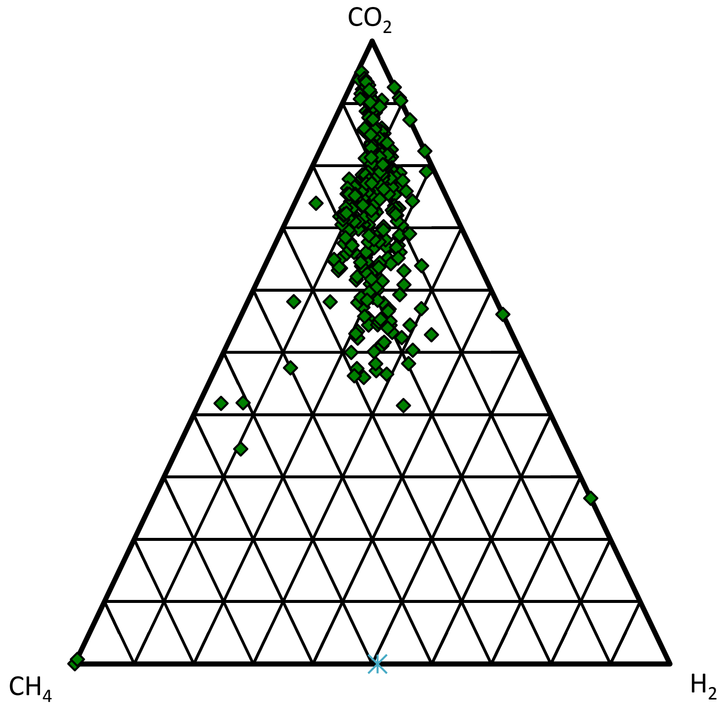
Figure D40

COSO Well 54-7



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Ternary Diagrams for COSO Well 54-7
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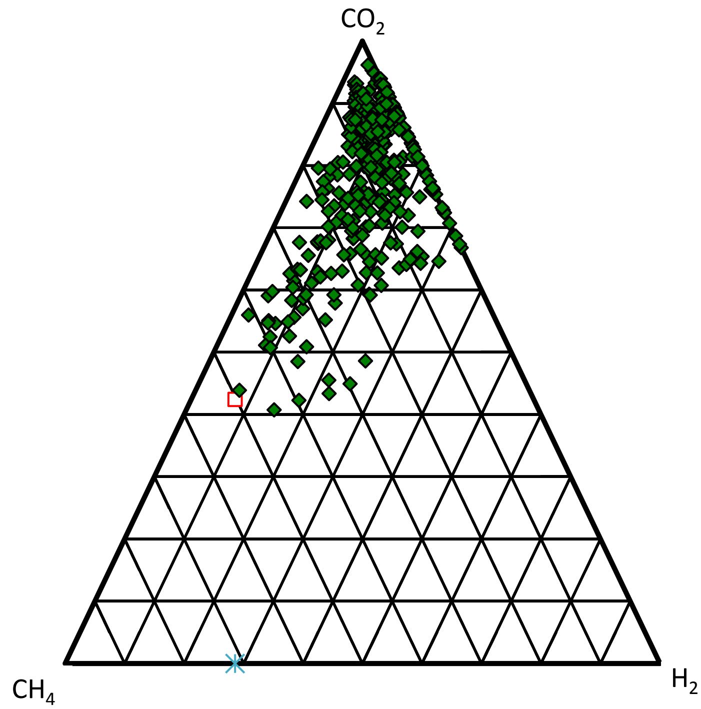
Figure D41

COSO Well 54-7RD



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Ternary Diagrams for COSO Well 54-7RD
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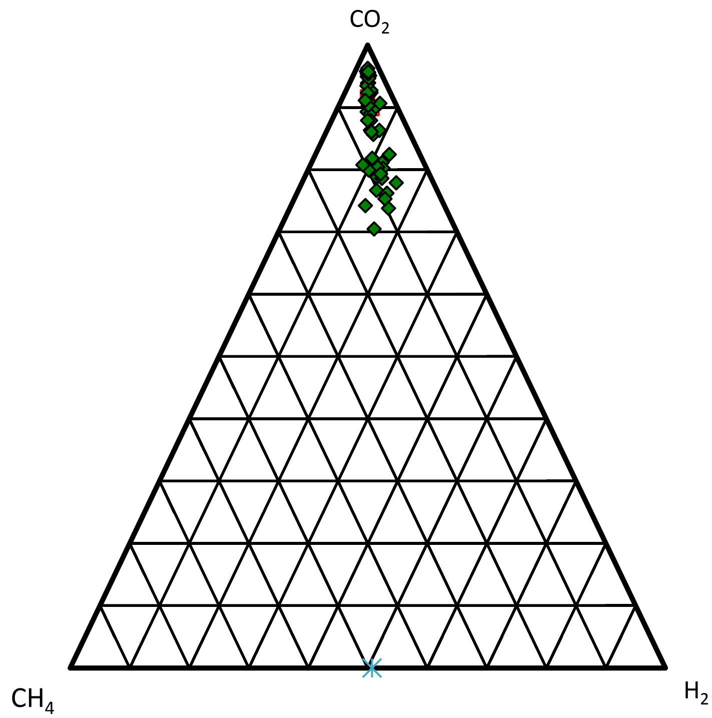
Figure D42

COSO Well 58A-10



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Ternary Diagrams for COSO Well 58A-10

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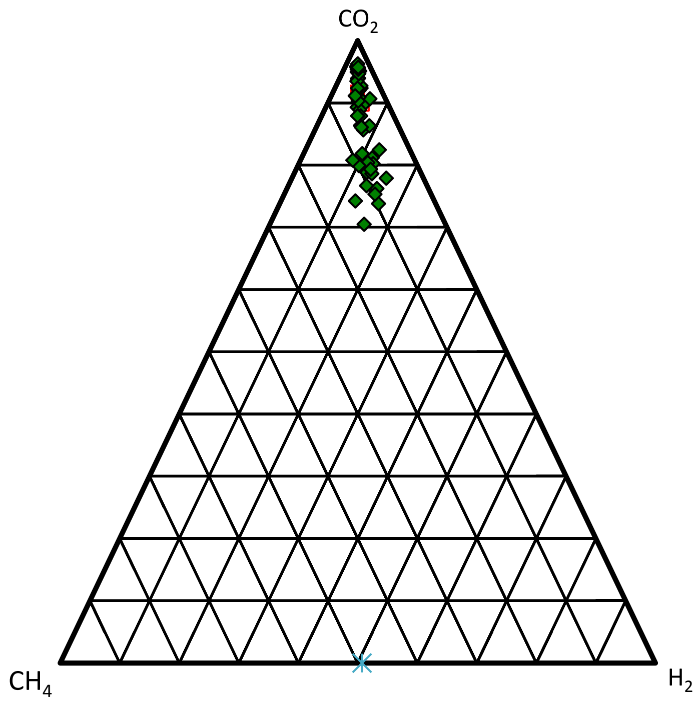
Figure D43

COSO Well 58A-18



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Ternary Diagrams for COSO Well 58A-18

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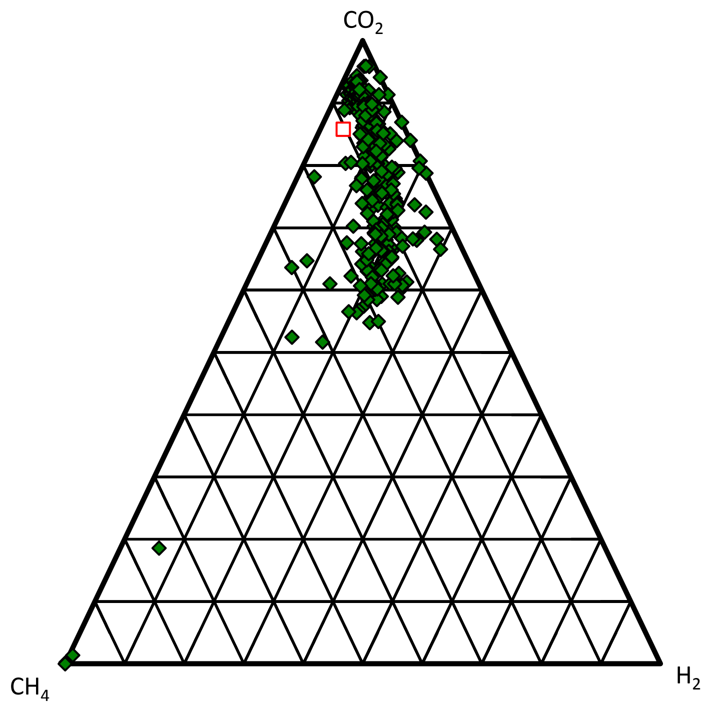
Figure D44

COSO Well 67-17



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Ternary Diagrams for COSO Well 67-17
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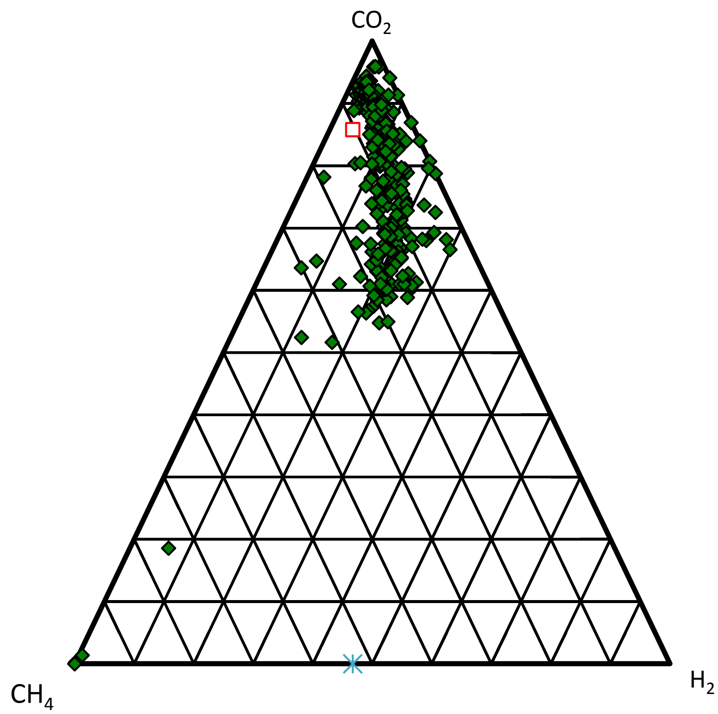
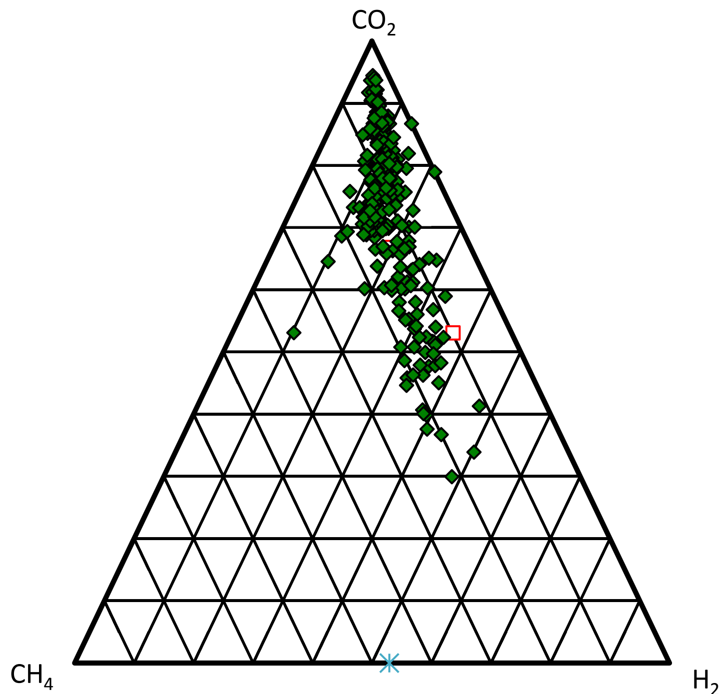
Figure D45

COSO Well 67C-17



COSO Well 68-20



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Ternary Diagrams for COSO Well 68-20
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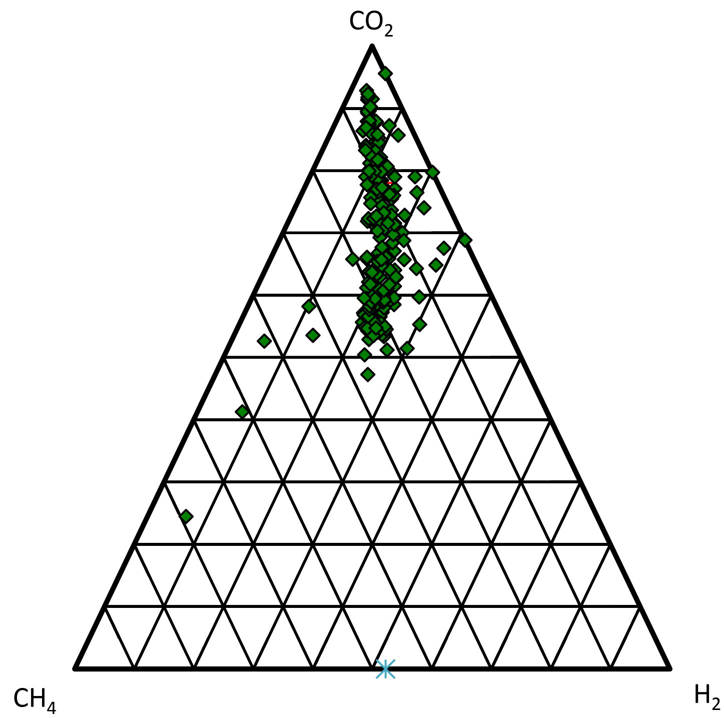
Figure D48

COSO Well 68-20RD



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Ternary Diagrams for COSO Well 68-20RD
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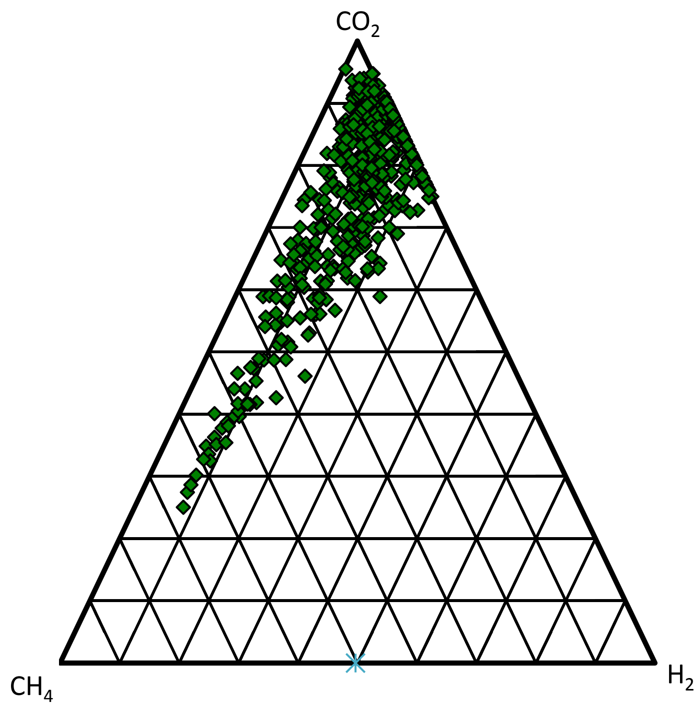
Figure D49

COSO Well 68-6



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Ternary Diagrams for COSO Well 68-6
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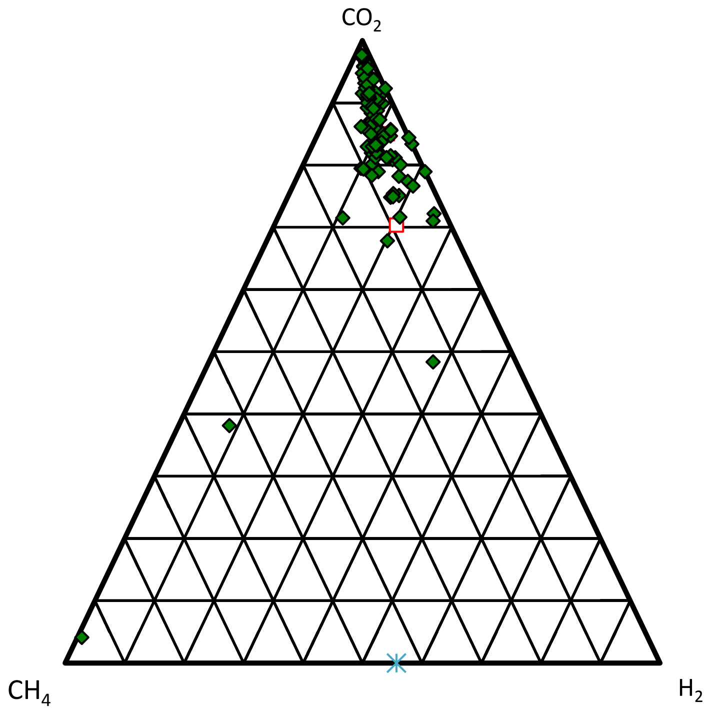
Figure D47

COSO Well 73-19



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Ternary Diagrams for COSO Well 73-19

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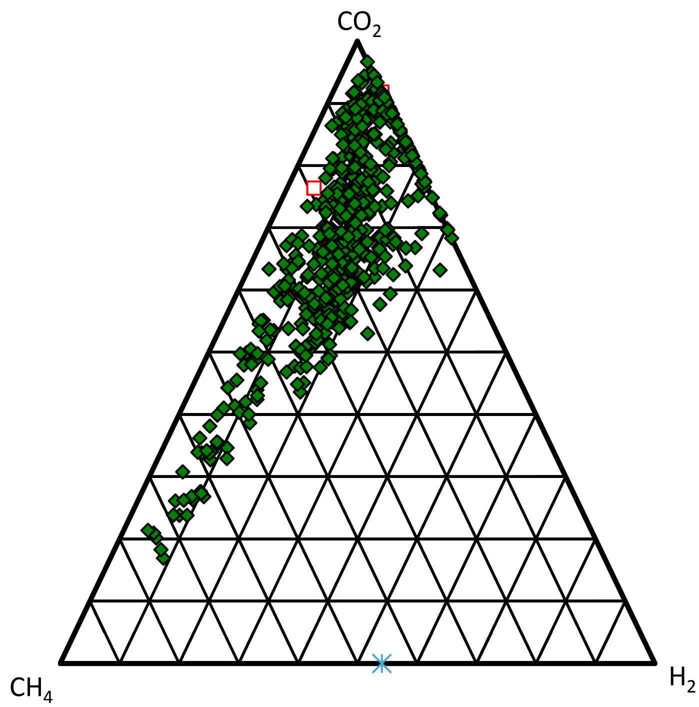
Figure D50

COSO Well 83B-16



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Ternary Diagrams for COSO Well 83B-16

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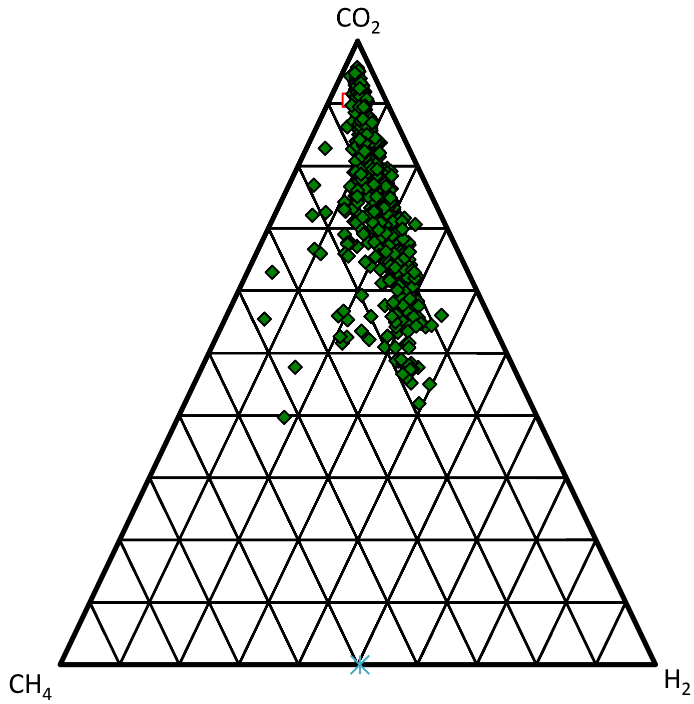
Figure D51

COSO Well 84-30



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Ternary Diagrams for COSO Well 84-30
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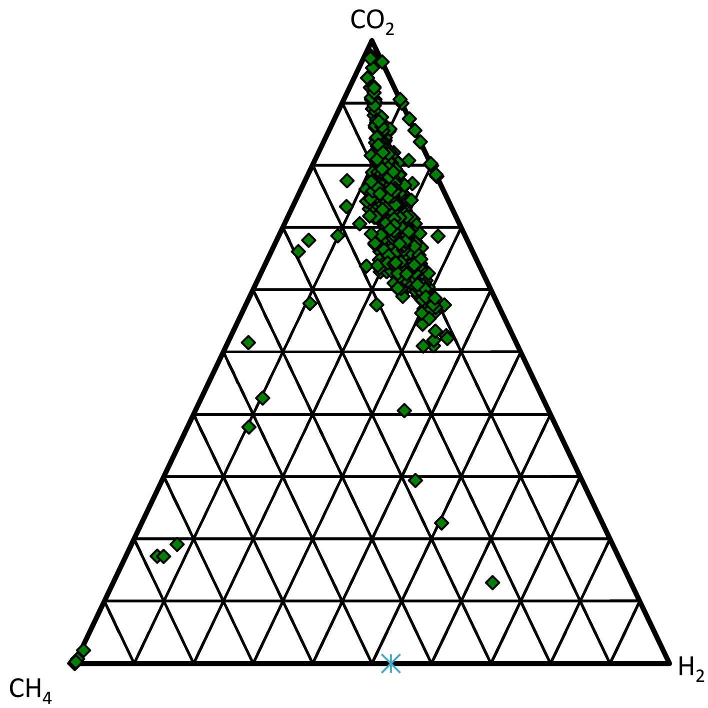
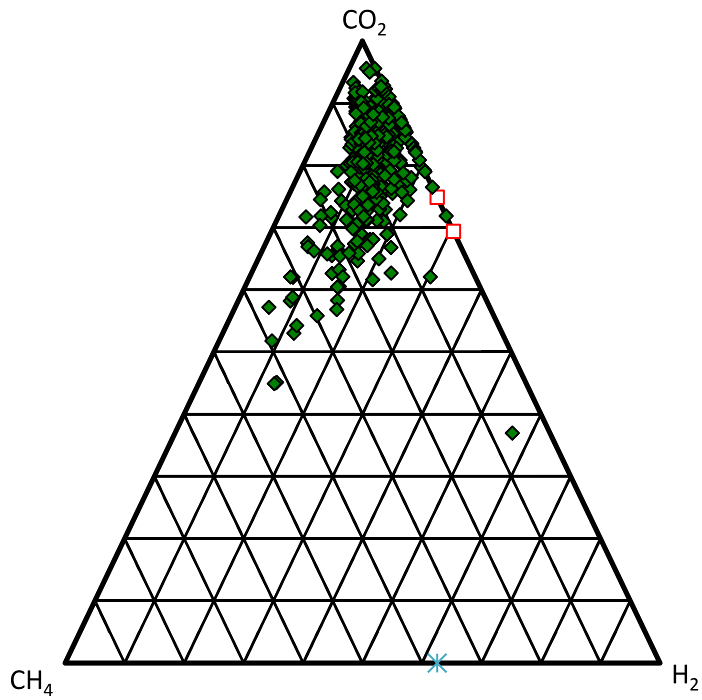
Figure D52

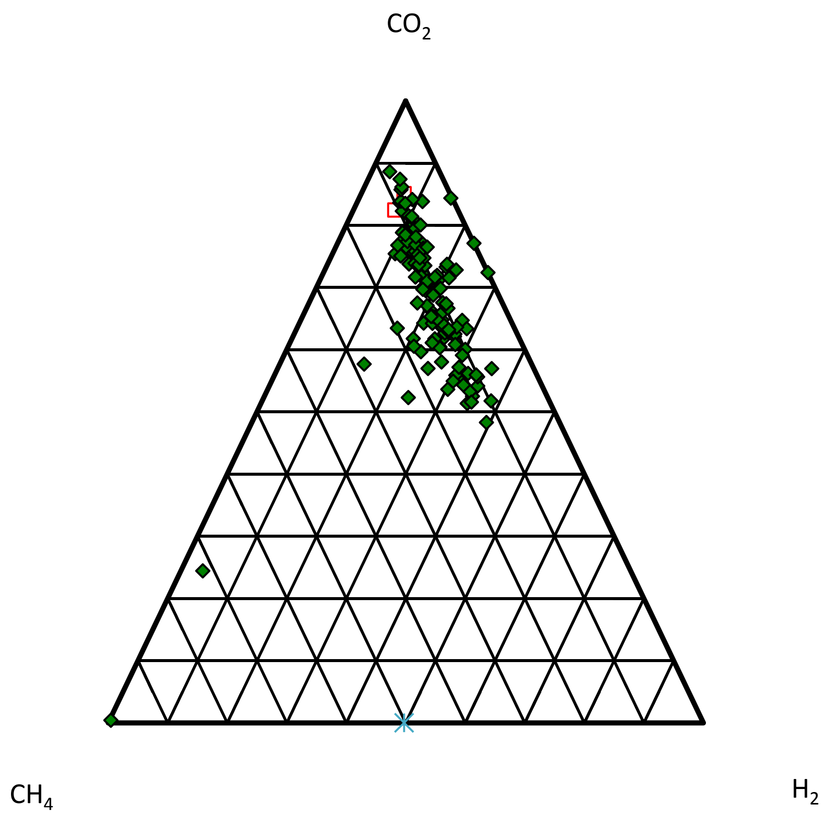
COSO Well 86-17



COSO Well 88-20



Hawaii Well SOH1



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Ternary Diagrams for Hawaii Well SOH1
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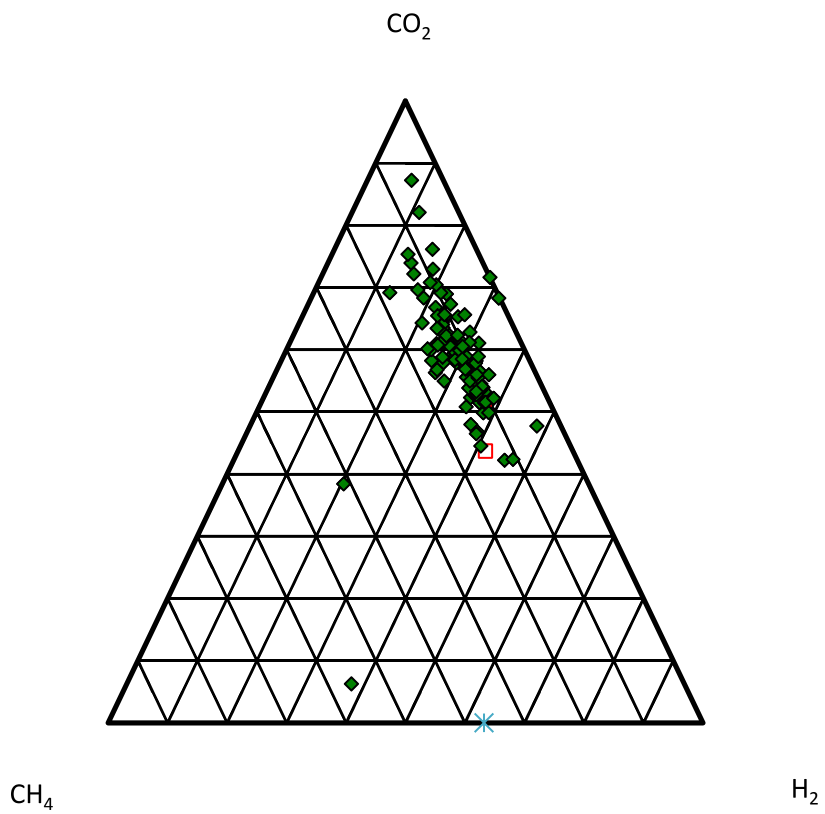
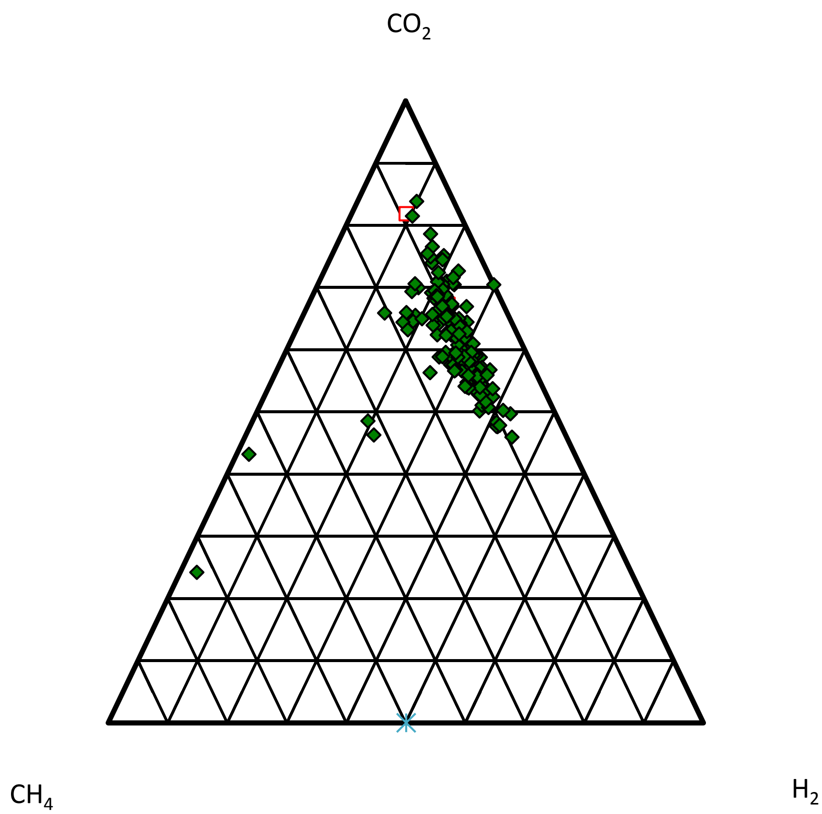
Figure D55

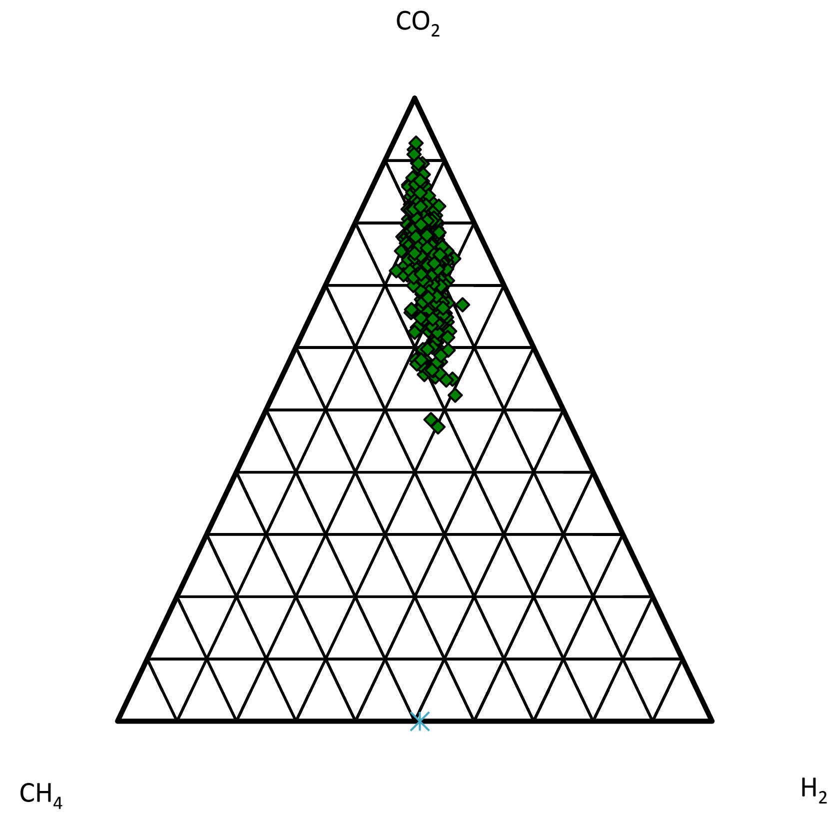
Hawaii Well SOH2



Hawaii Well SOH4



Glass Mountain Well 17A-6



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Ternary Diagrams for Glass Mountain Well 17A-6
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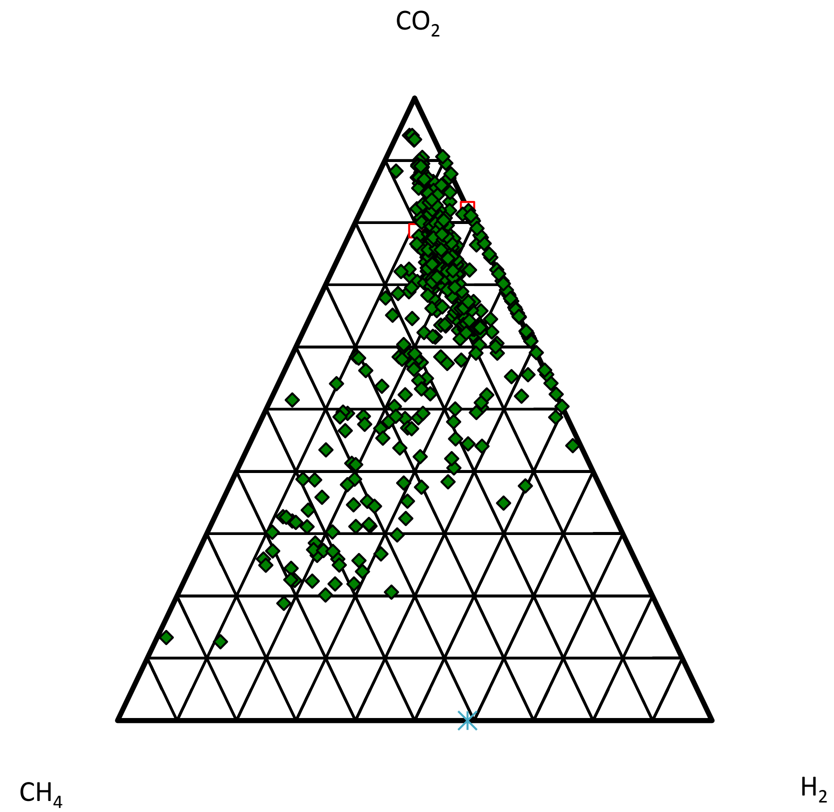
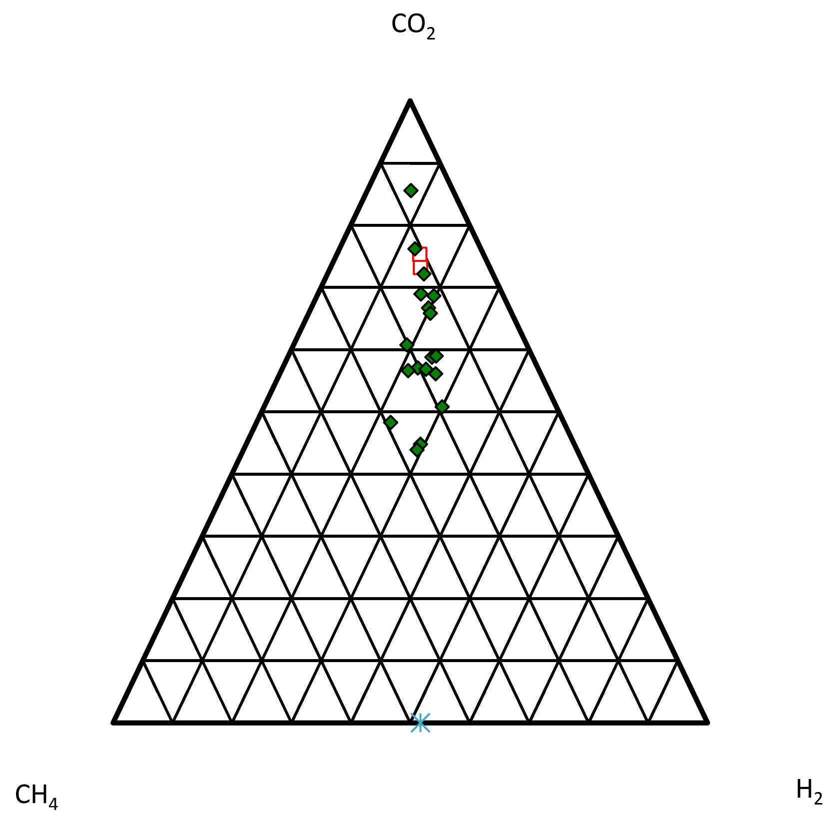
Figure D58

Glass Mountain Well 88-28



Iceland Well NG07



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Ternary Diagrams for Iceland Well NG07

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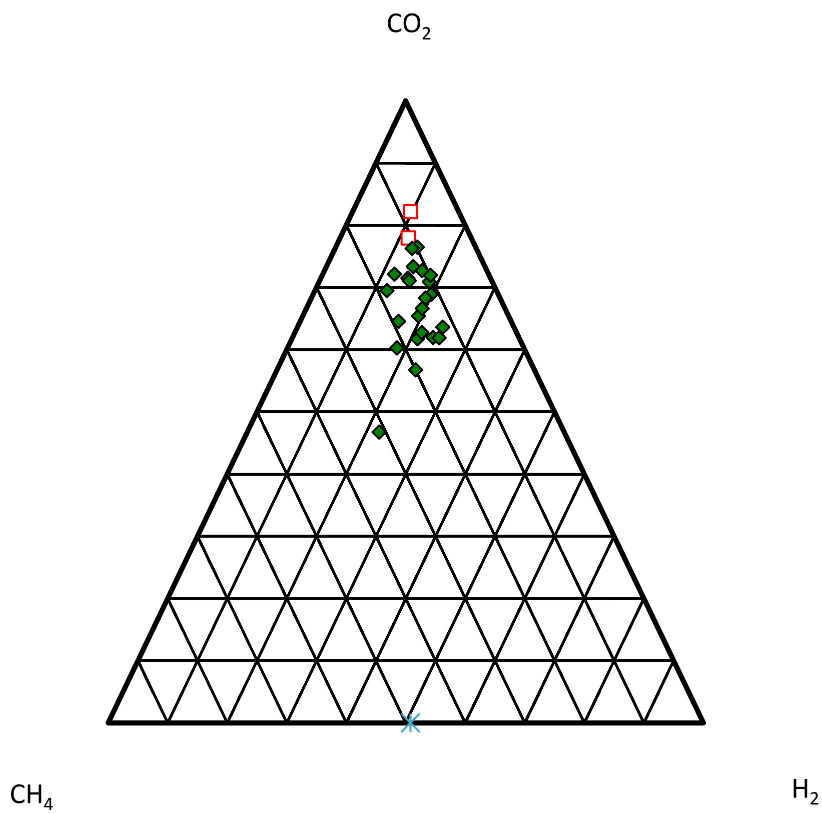
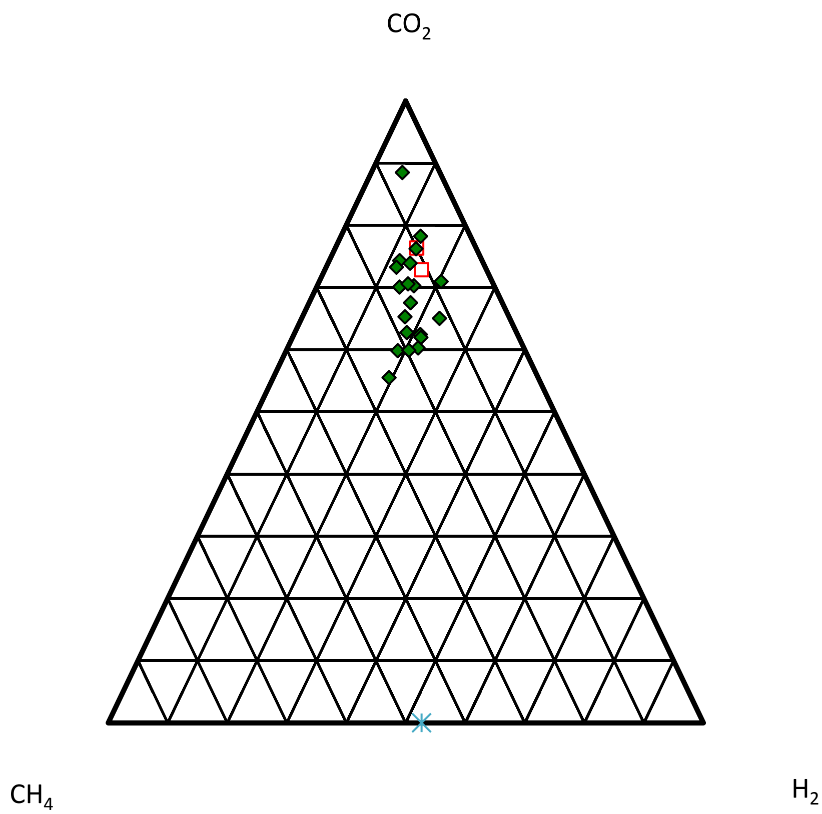
Figure D60

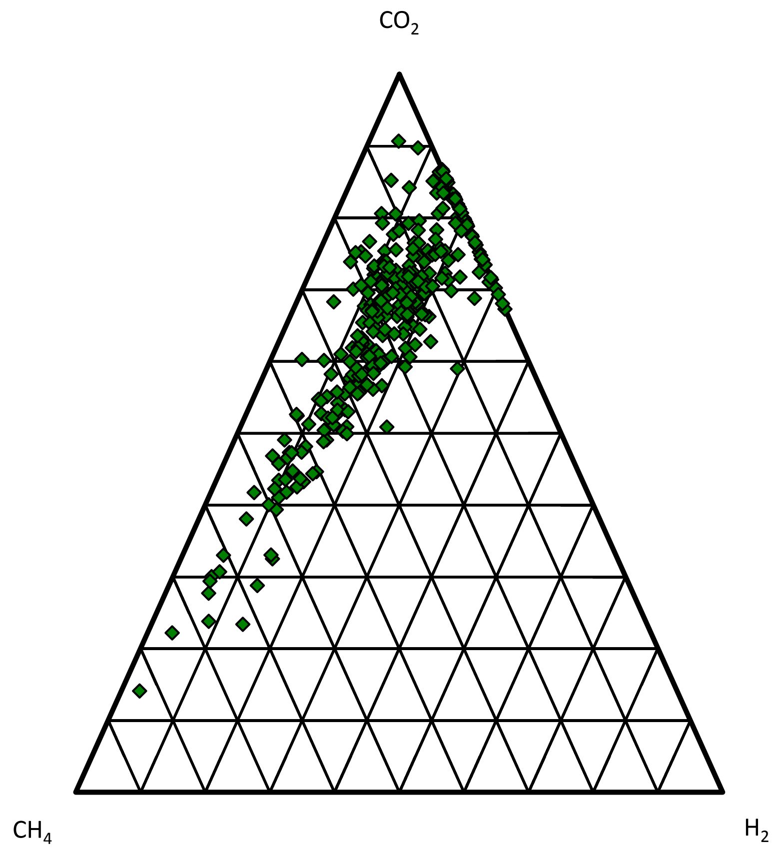
Iceland Well NJ11



Iceland Well RN10



Steamboat Springs Well 87-29



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Ternary Diagrams for Steamboat Springs Well 87-29
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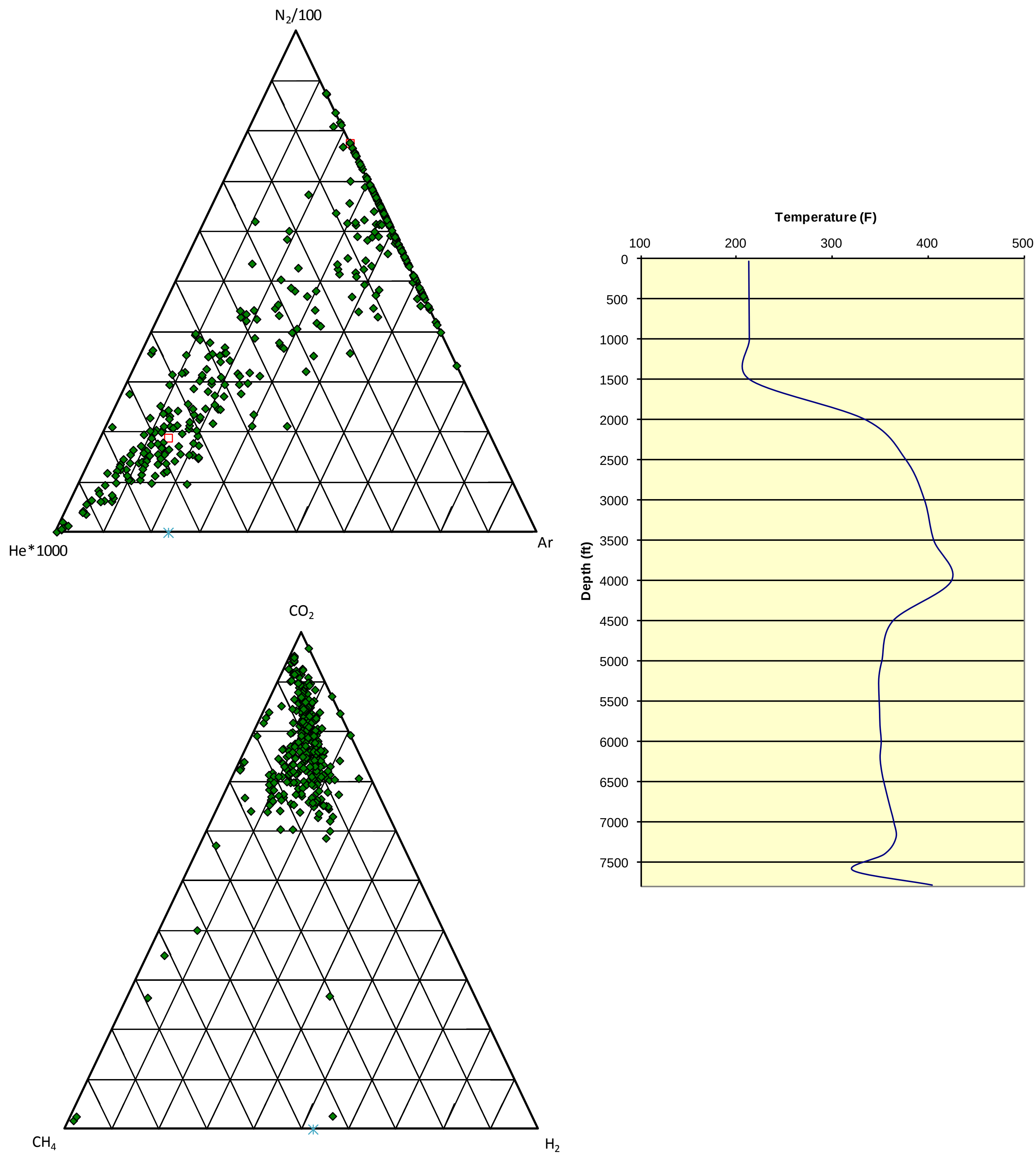
Figure D63

APPENDIX E
TERNARY PLOTS AND
TEMPERATURE GRAPH FOR COSO WELLS

COSO WELL 23A-17



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Ternary Diagrams for Coso Well 23A-17
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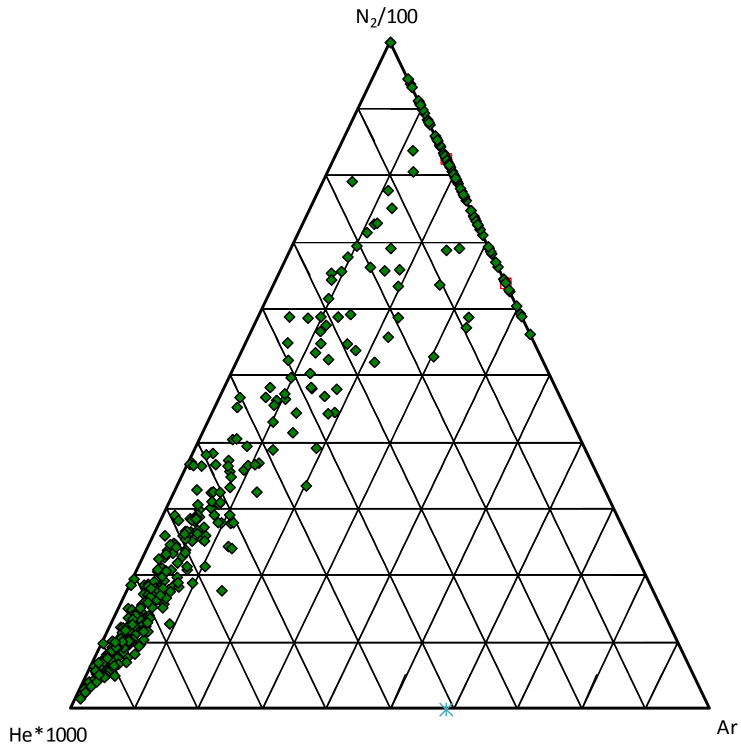
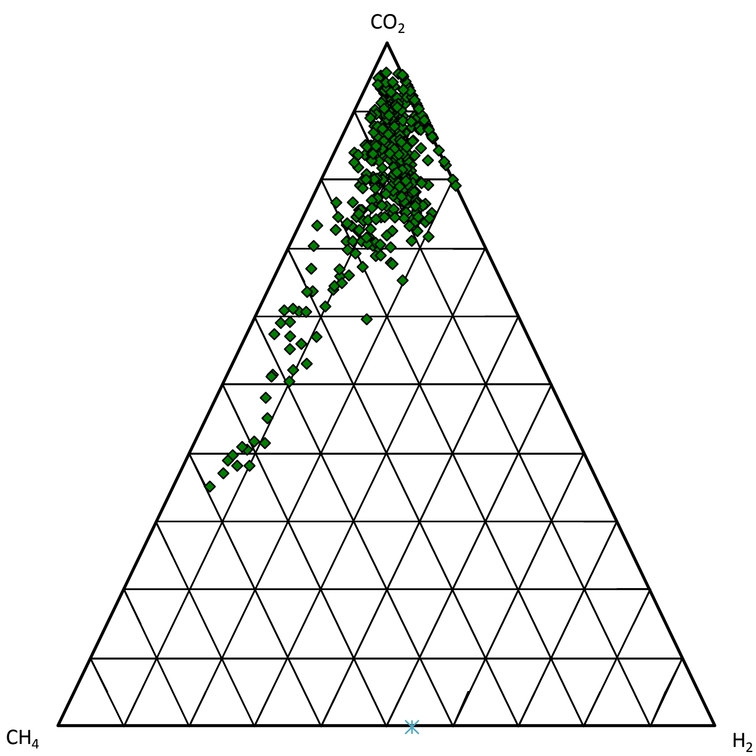
Figure E1

COSO WELL 23A-19





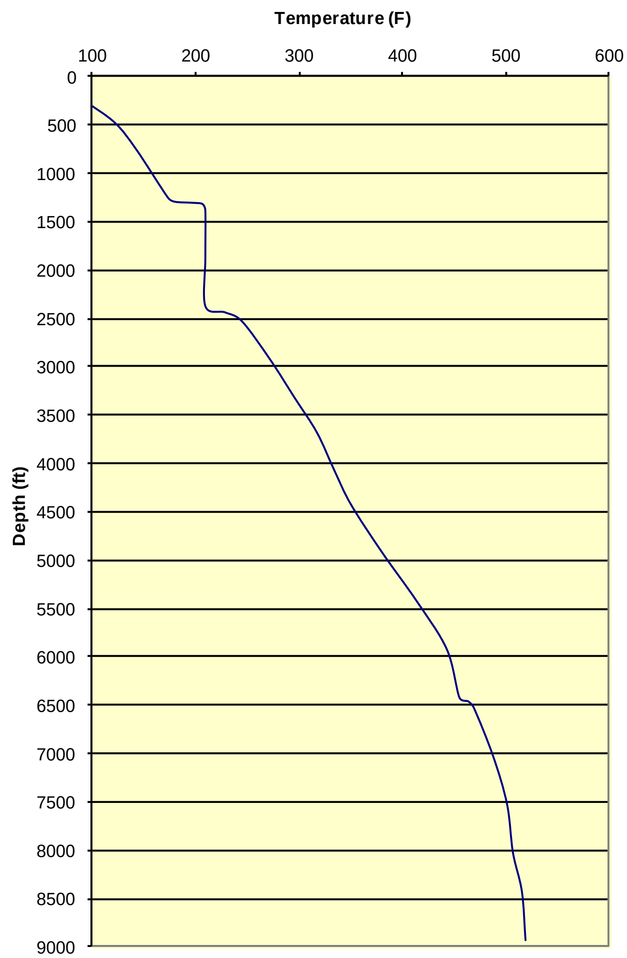


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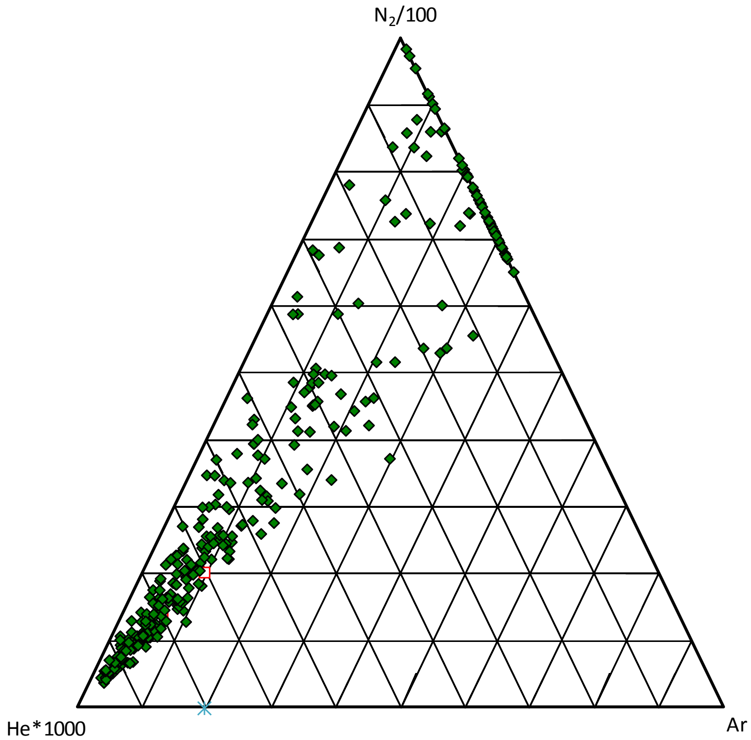
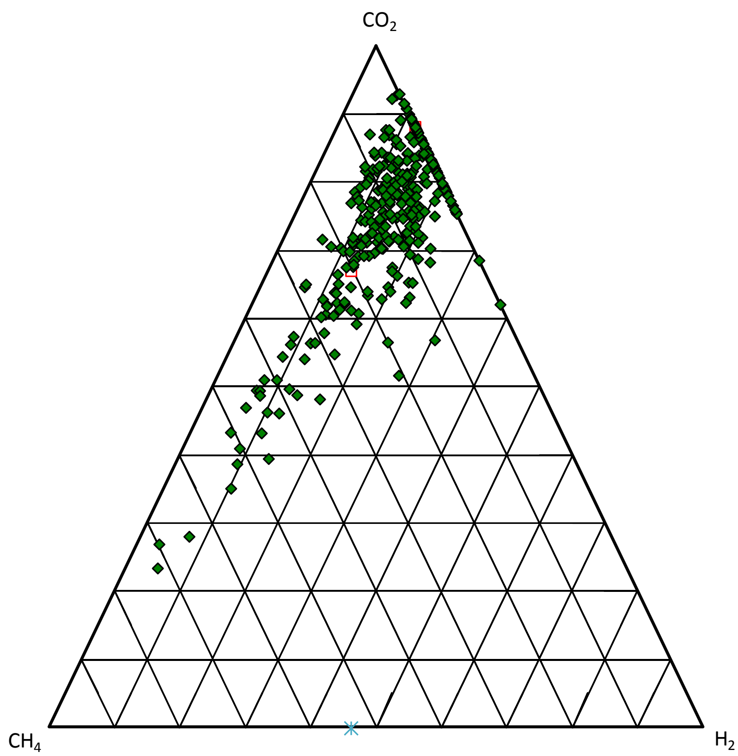
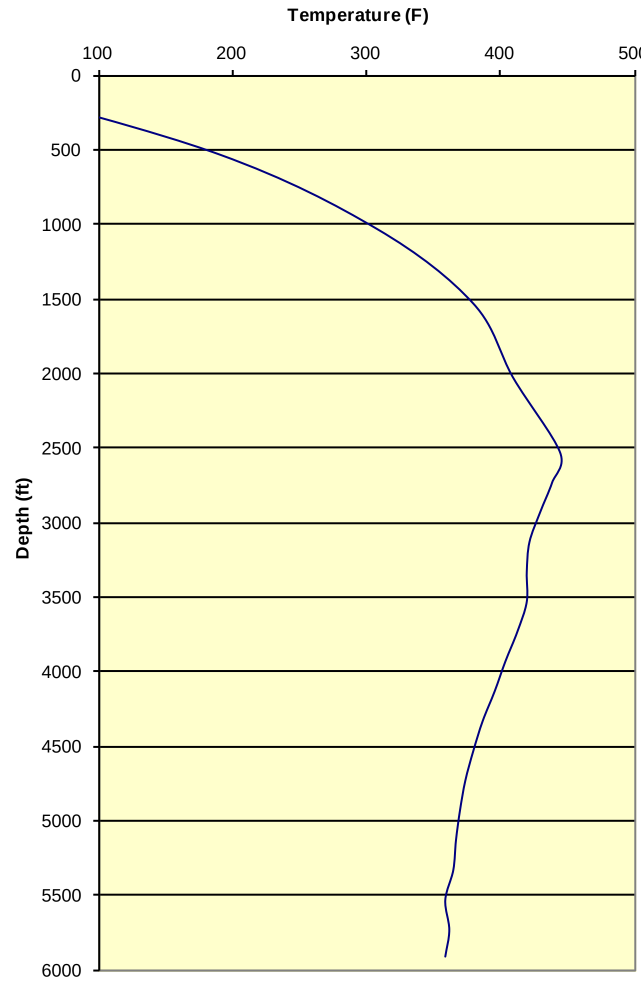
Figure E2

COSO WELL 24A-8







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Ternary Diagrams for Coso Well 24A-8
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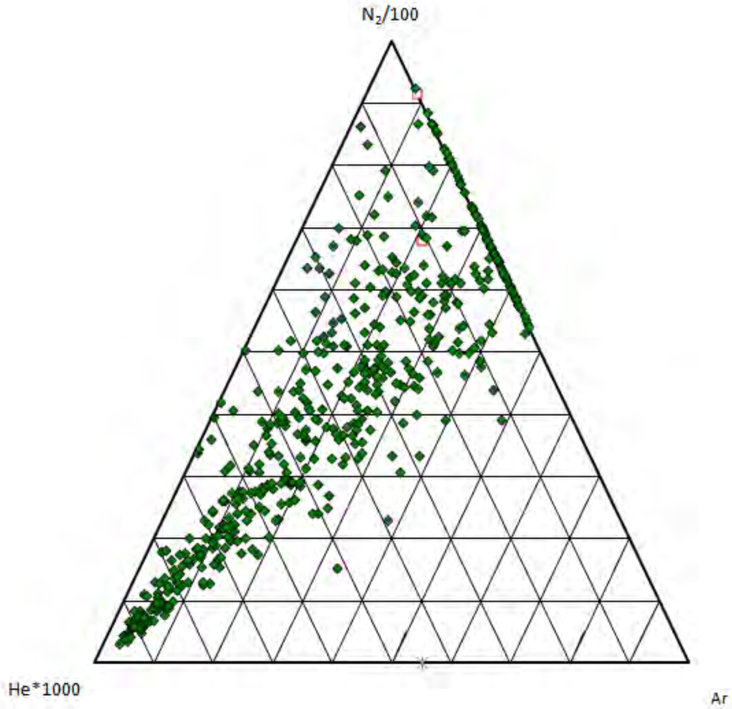
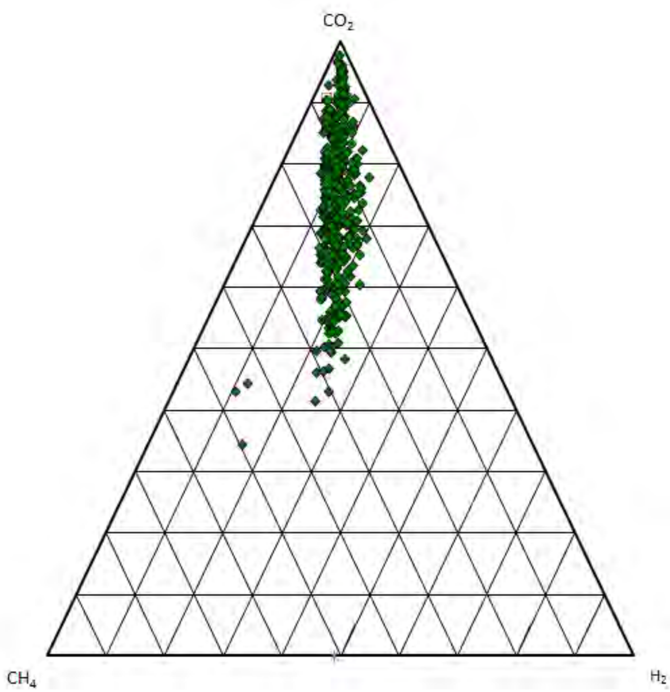
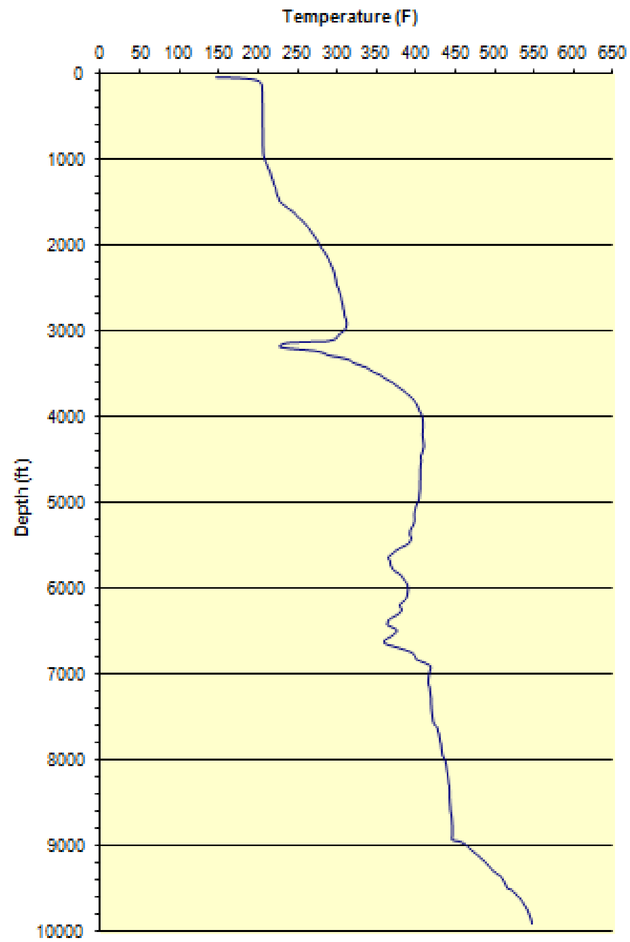
Figure E3

COSO WELL 33-7







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Ternary Diagrams for Coso Well 33-7
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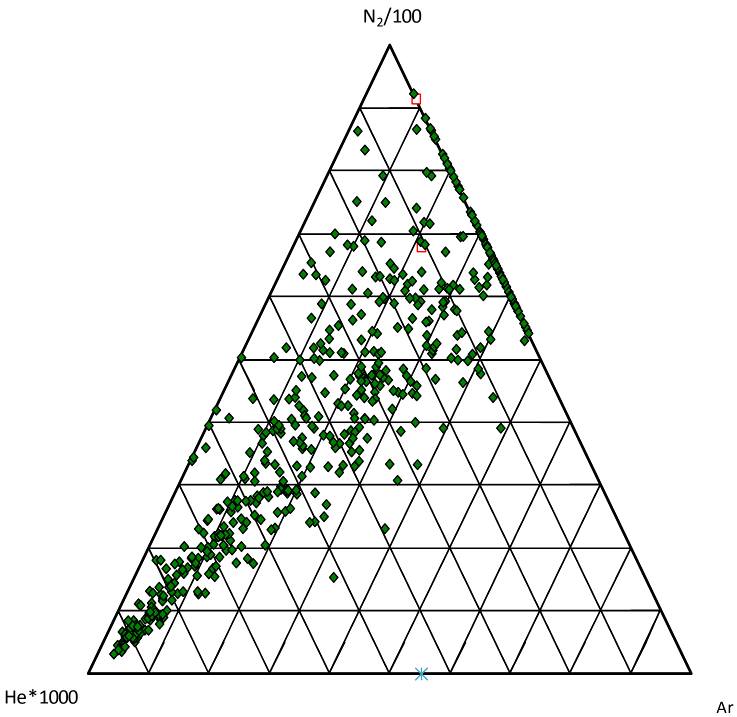
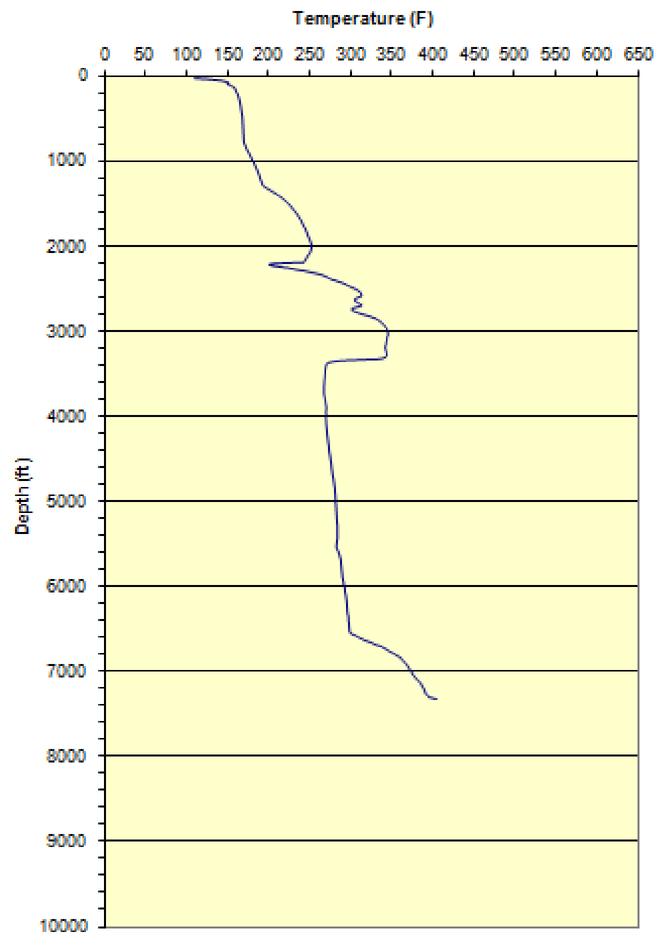
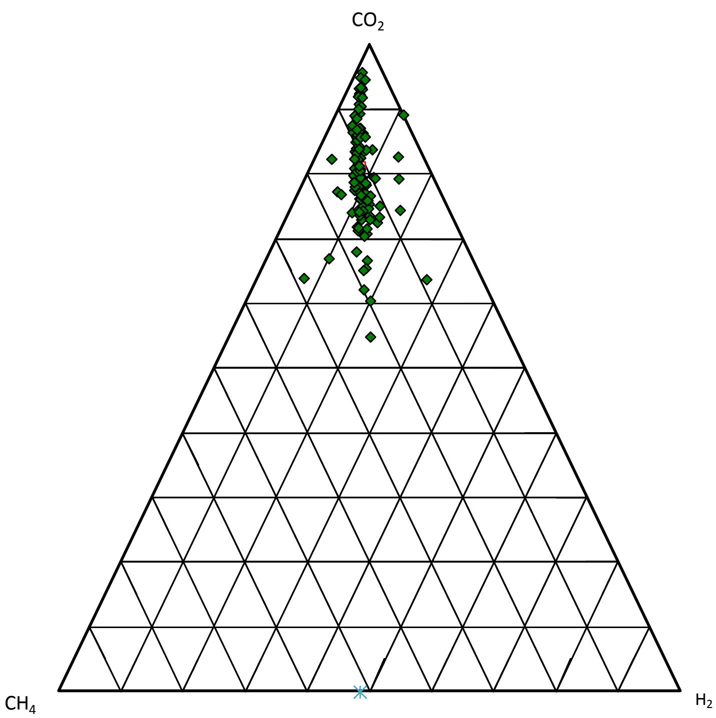
Figure E4

COSO WELL 34-9RD2







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Ternary Diagrams for Coso Well 34-9RD2

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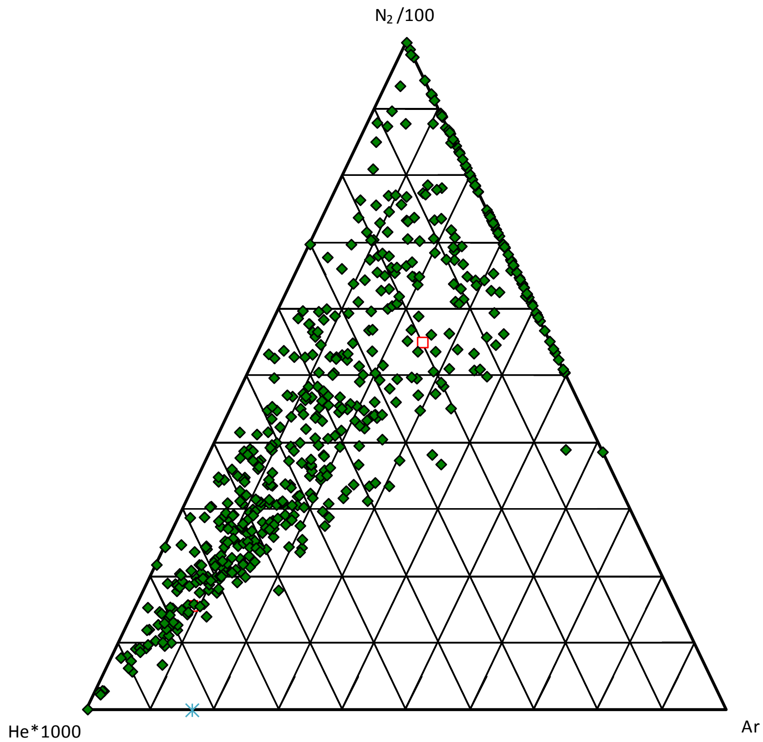
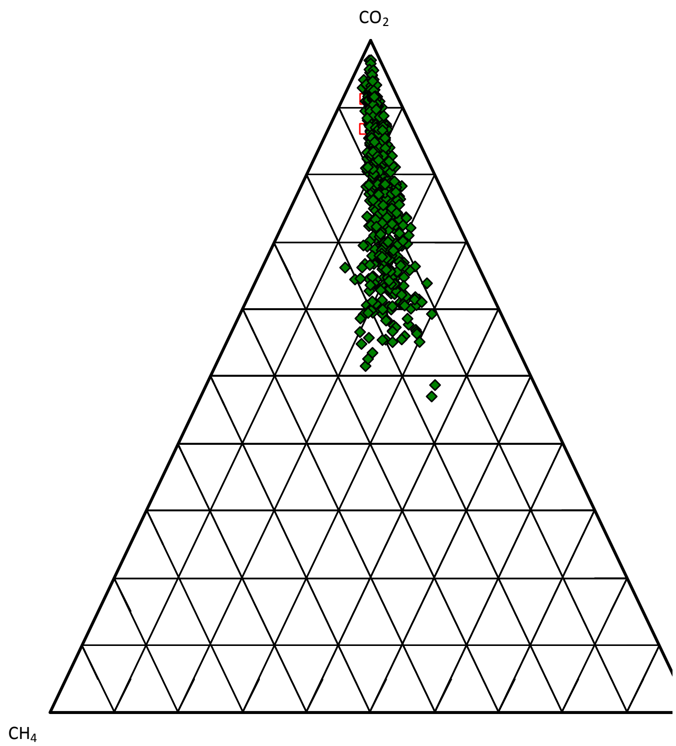
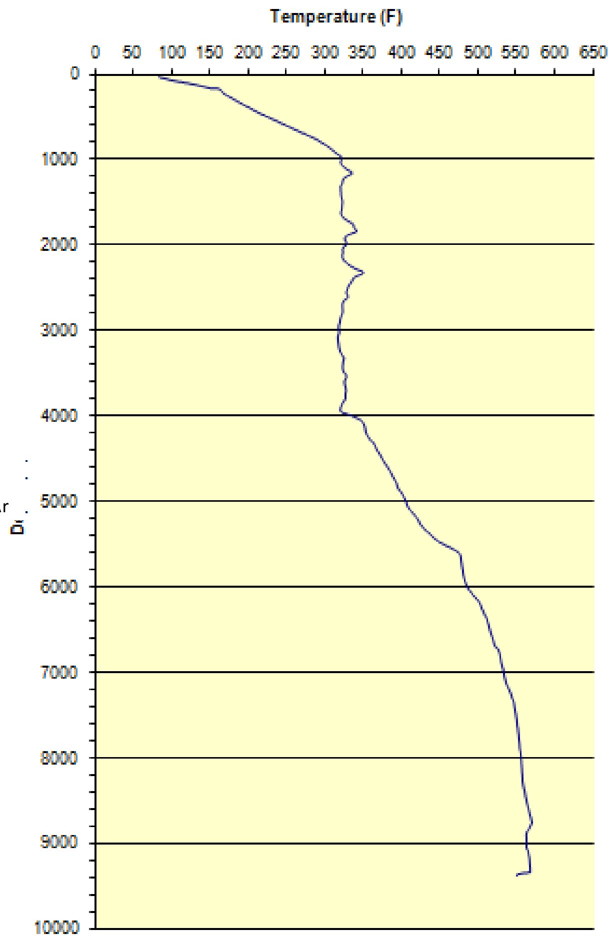
Figure E5

COSO WELL 38C-9







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Ternary Diagrams for Coso Well 38C-9

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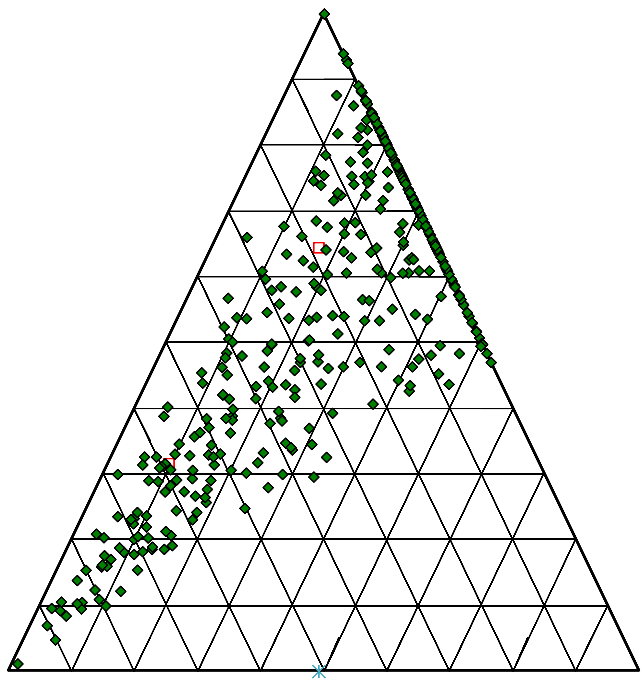
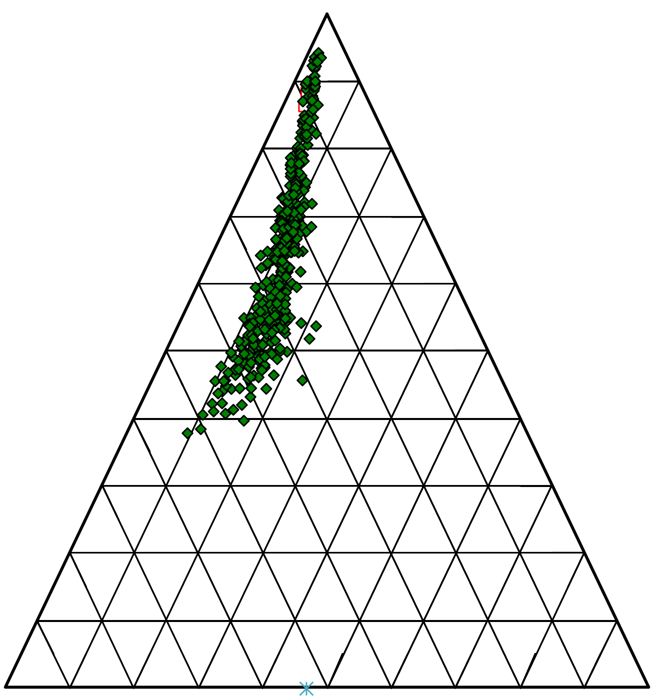
Figure E6

COSO WELL 38D-9





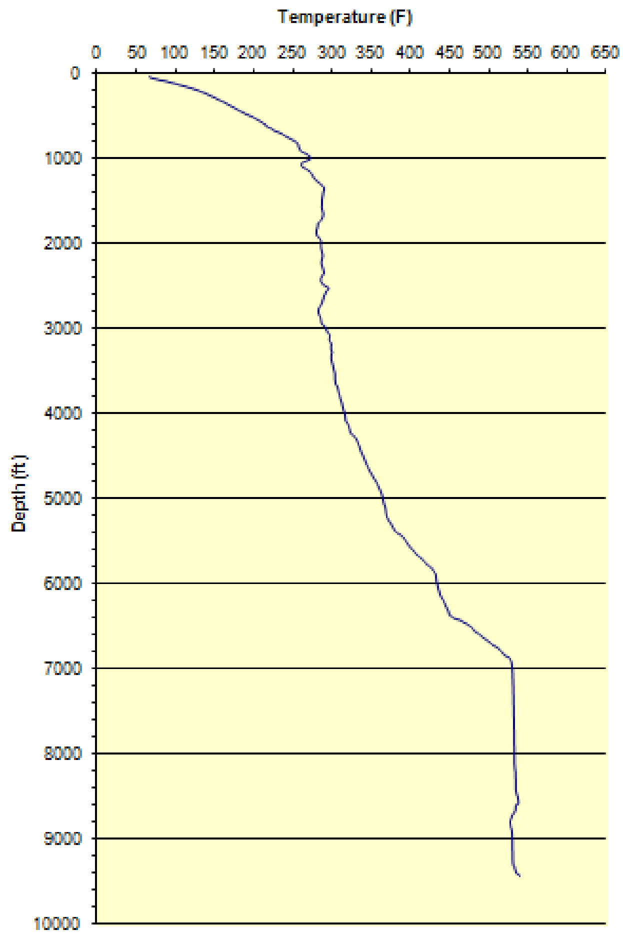


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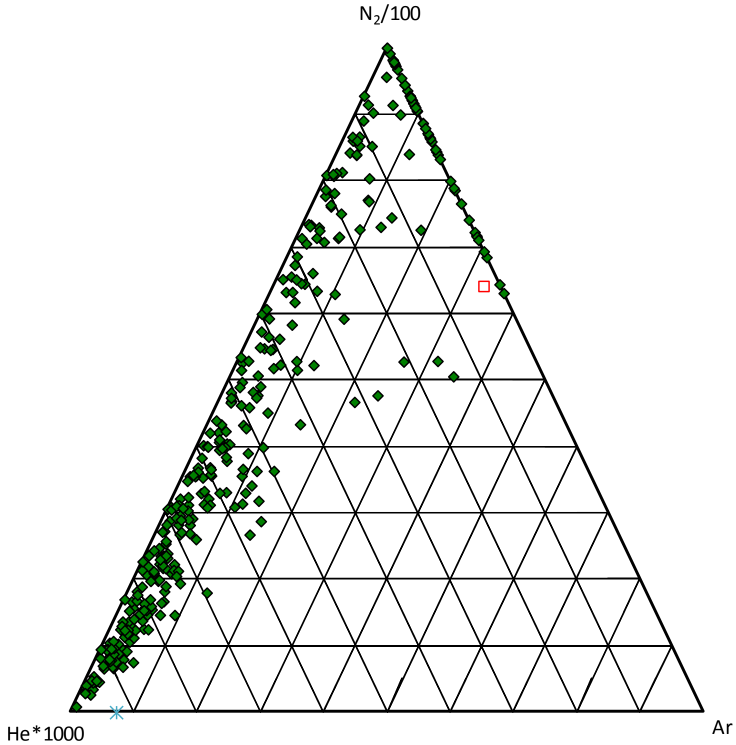
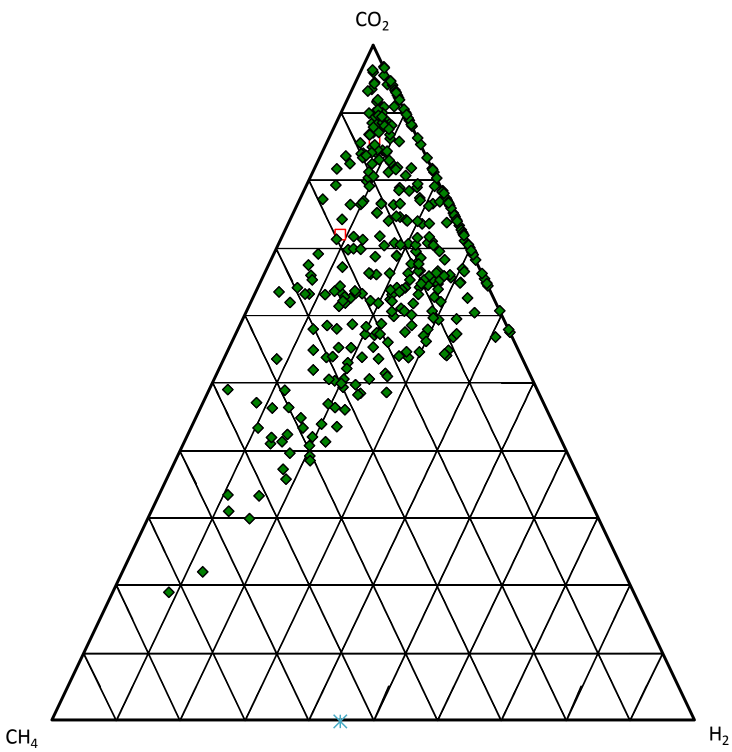
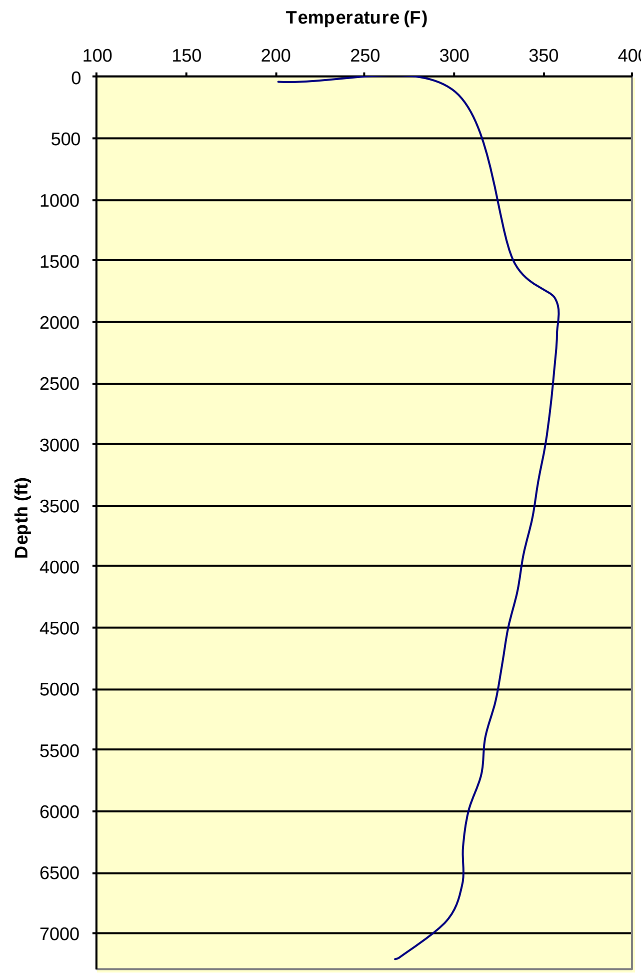
Figure E7

COSO WELL 41B-8







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Ternary Diagrams for Coso Well 41B-8

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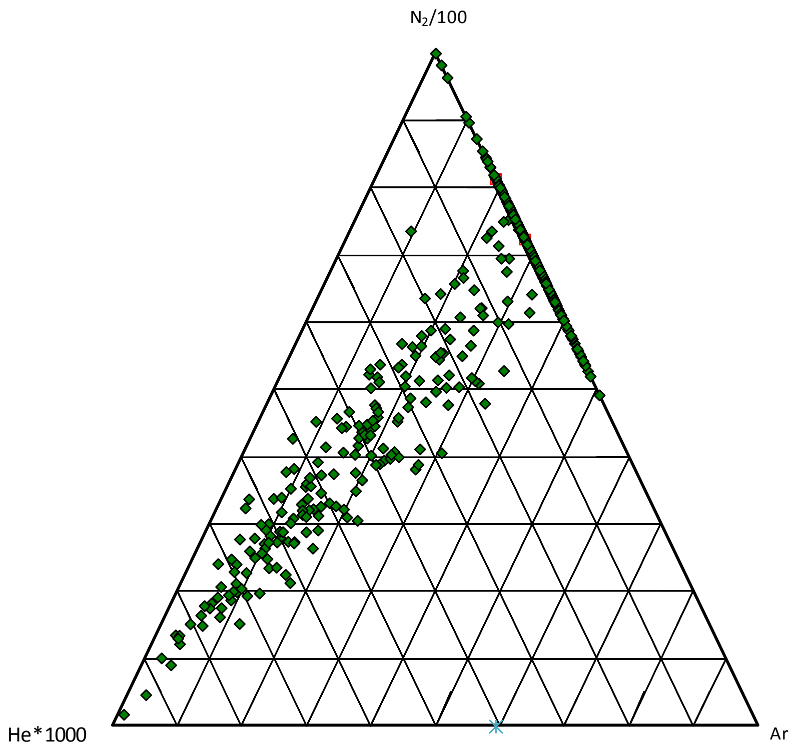
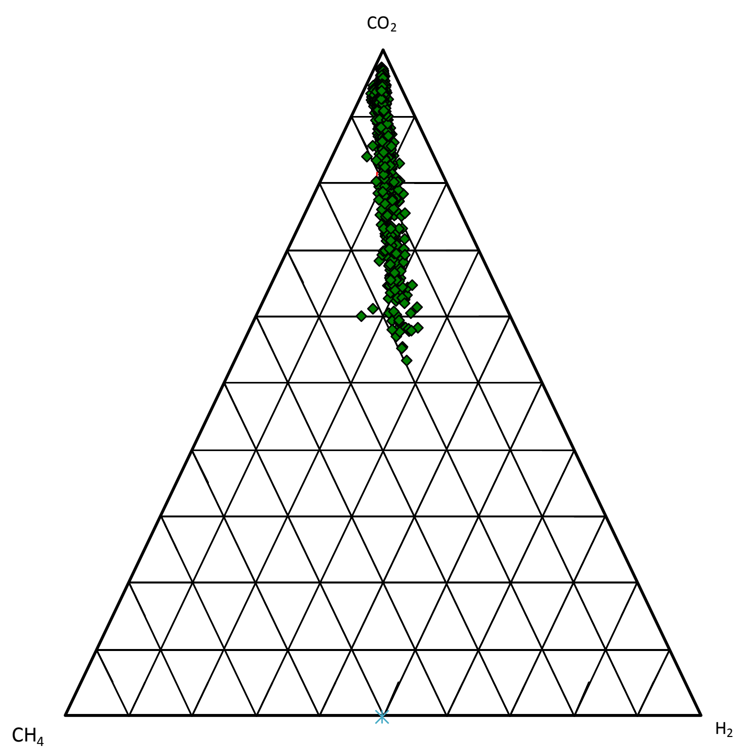
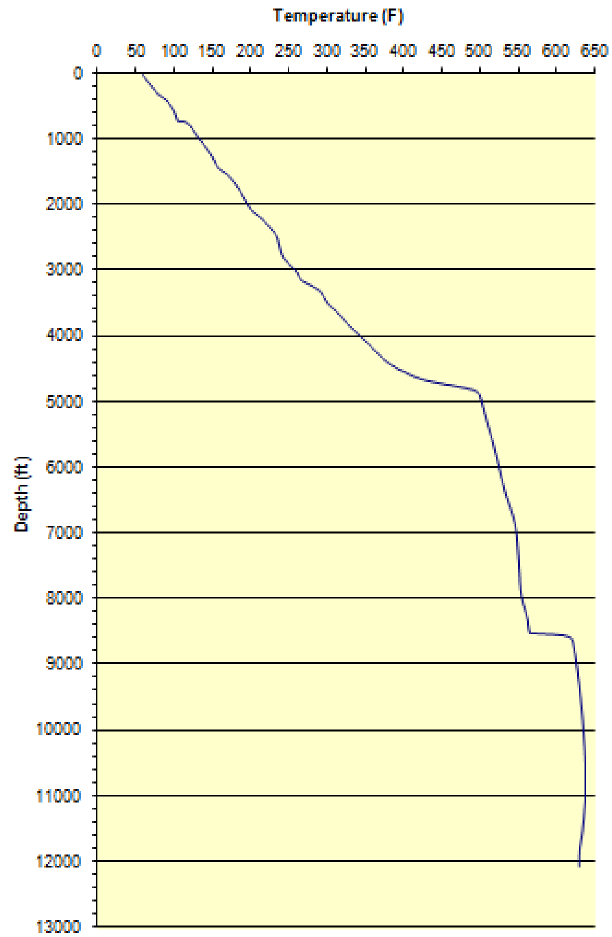
Figure E8

COSO WELL 46A-19RD







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Ternary Diagrams for Coso Well 46A-19RD

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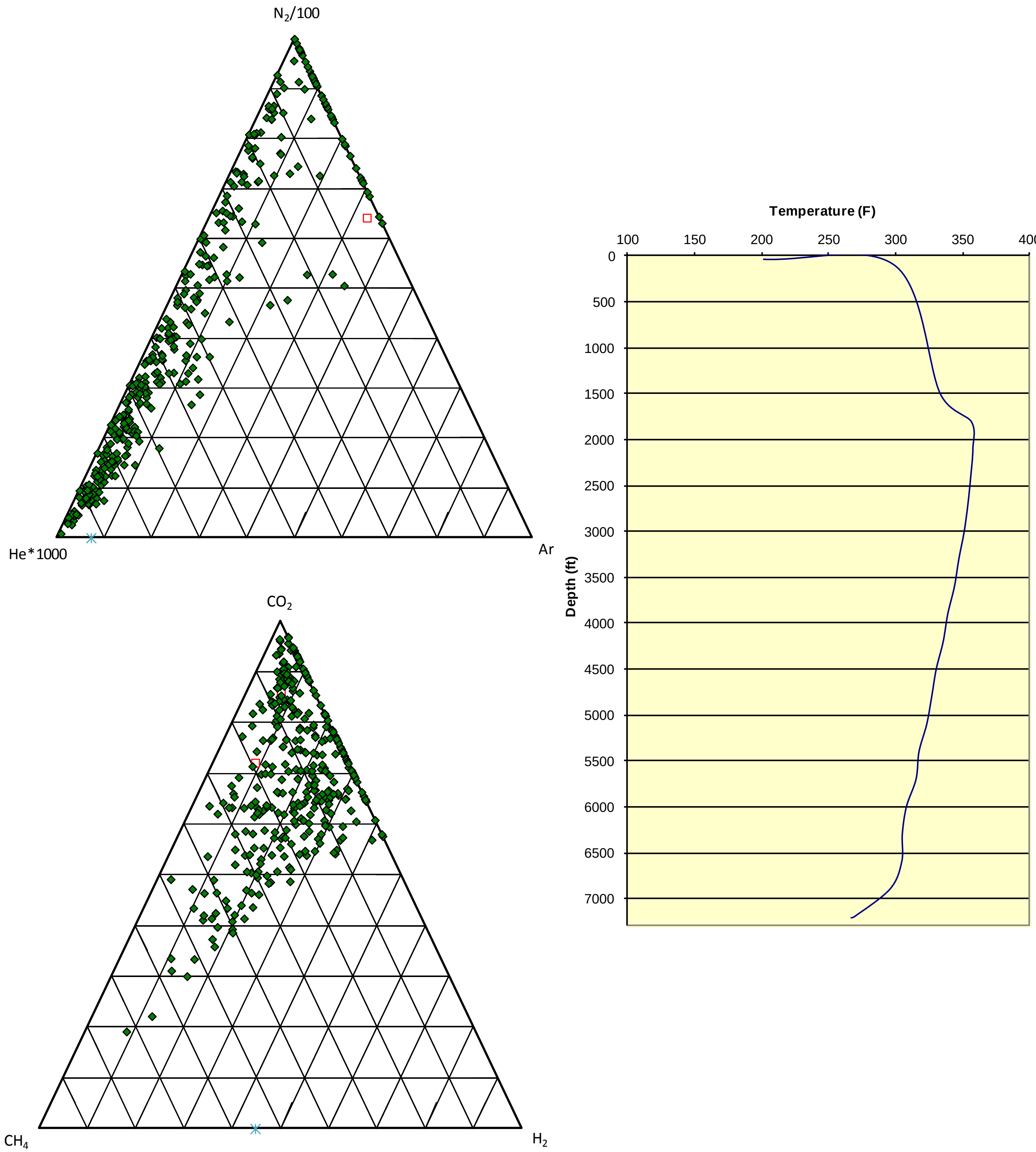
Figure E9

COSO WELL 47A-8



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Ternary Diagrams for Coso Well 47A-8

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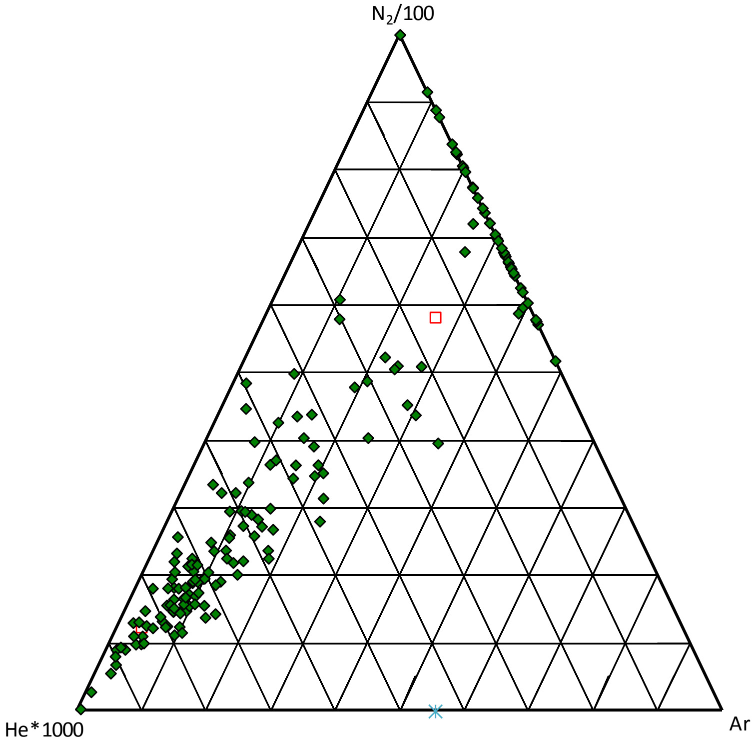
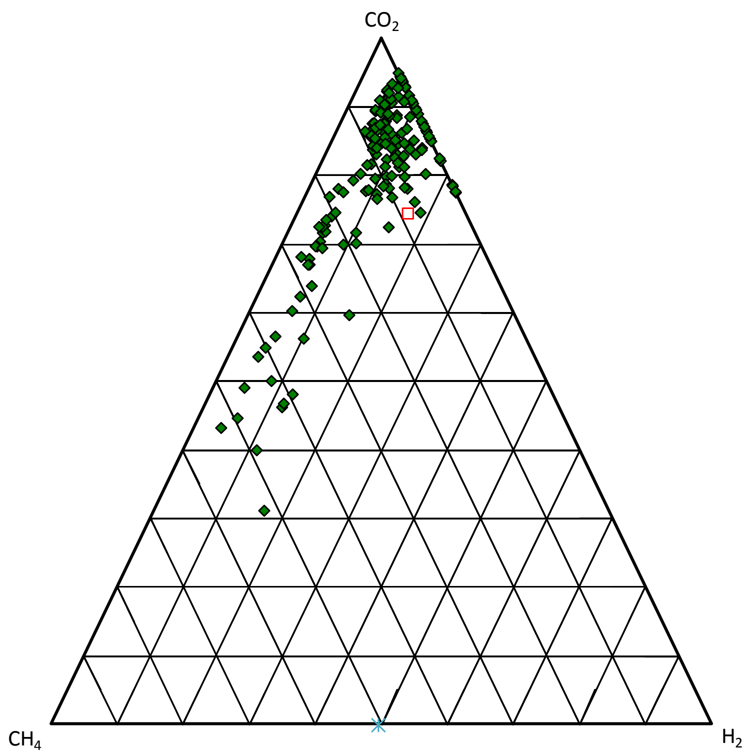
Figure E10

COSO WELL 47A-8RD





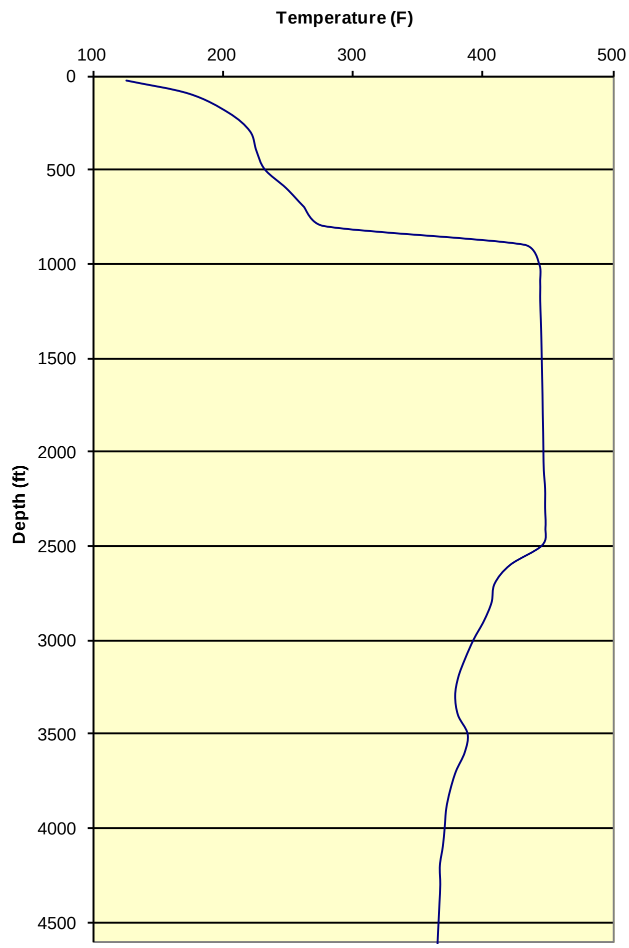


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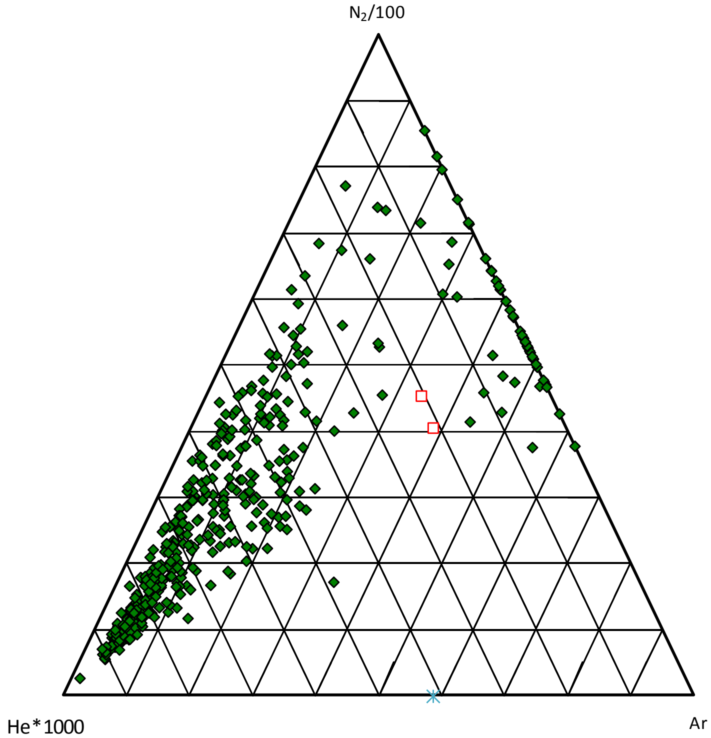
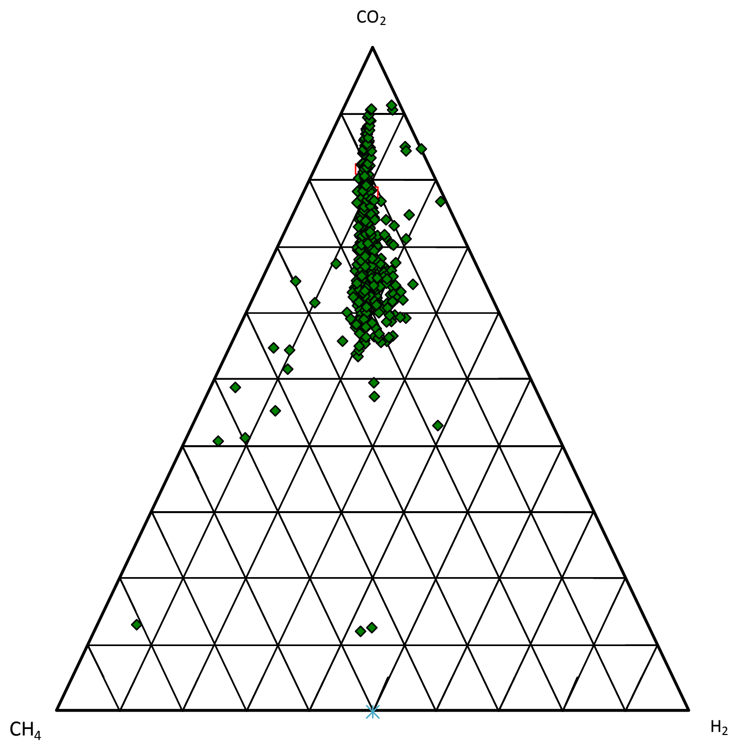
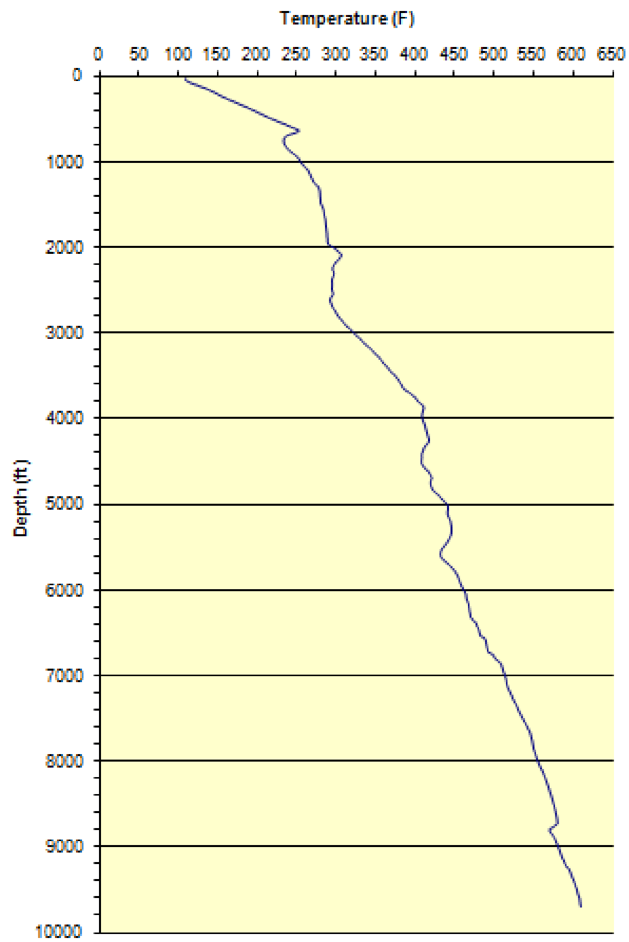
Figure E11

COSO WELL 51B-16







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Ternary Diagrams for Coso Well 51B-16
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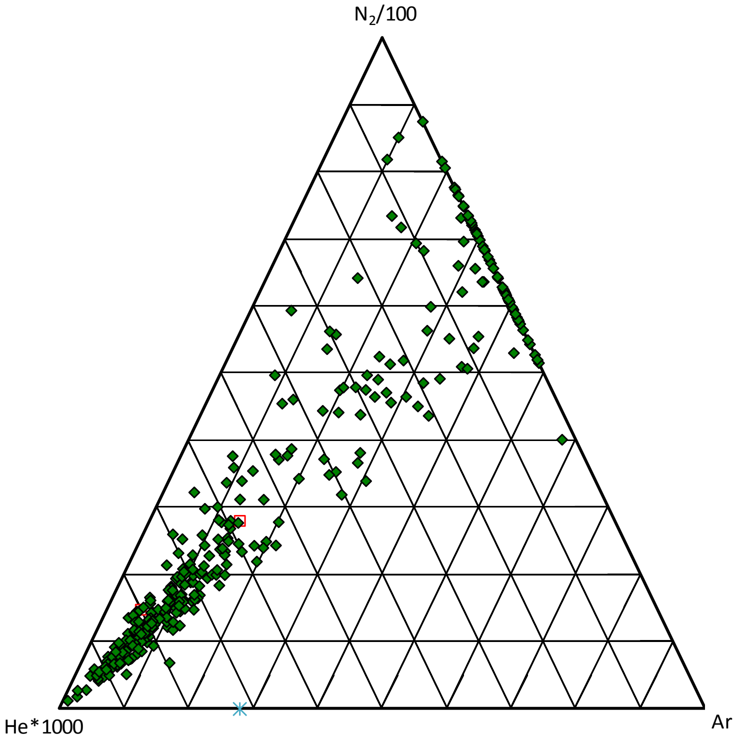
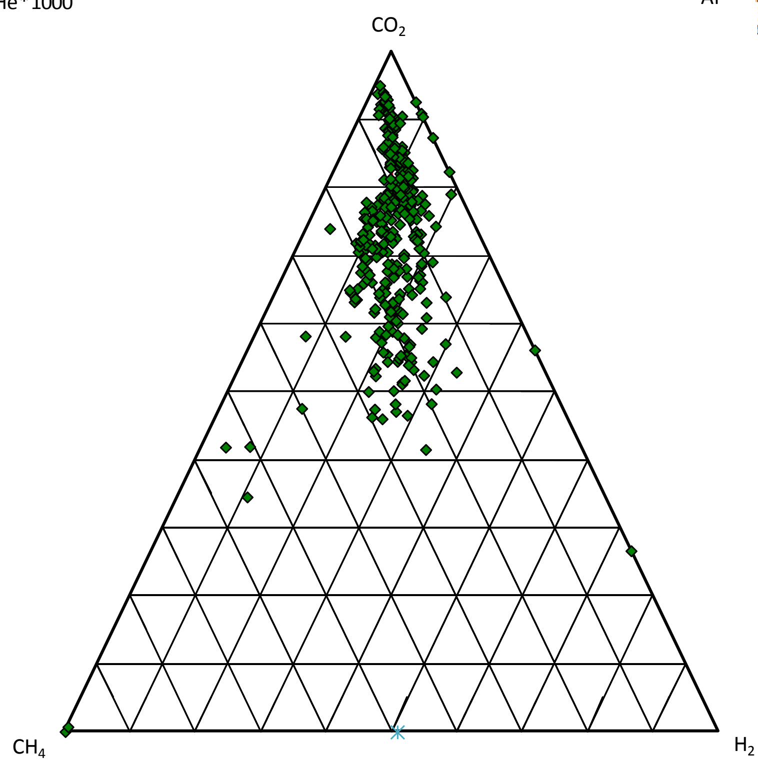
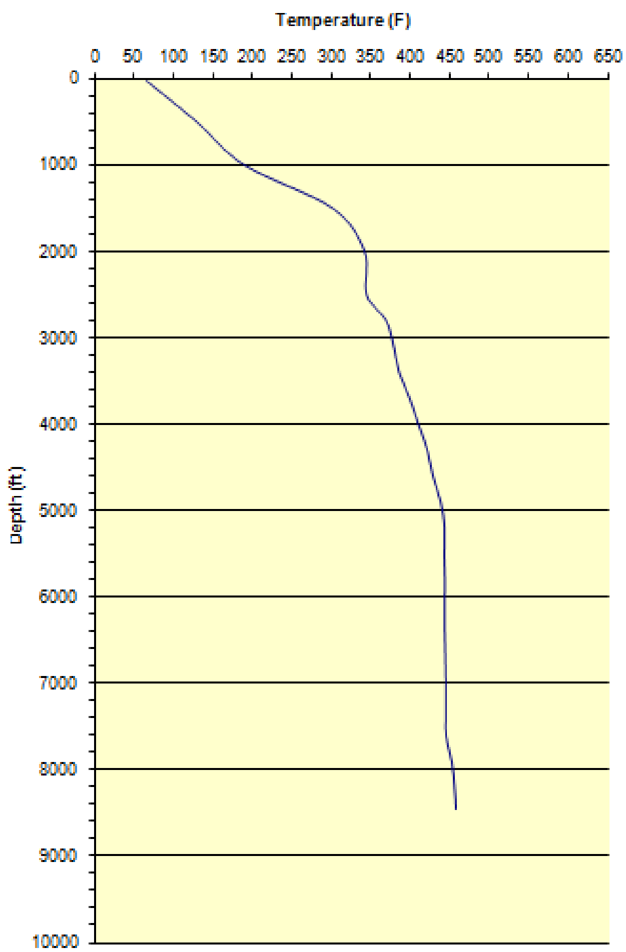
Figure E12

COSO WELL 52-20







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Ternary Diagrams for Coso Well 52-20

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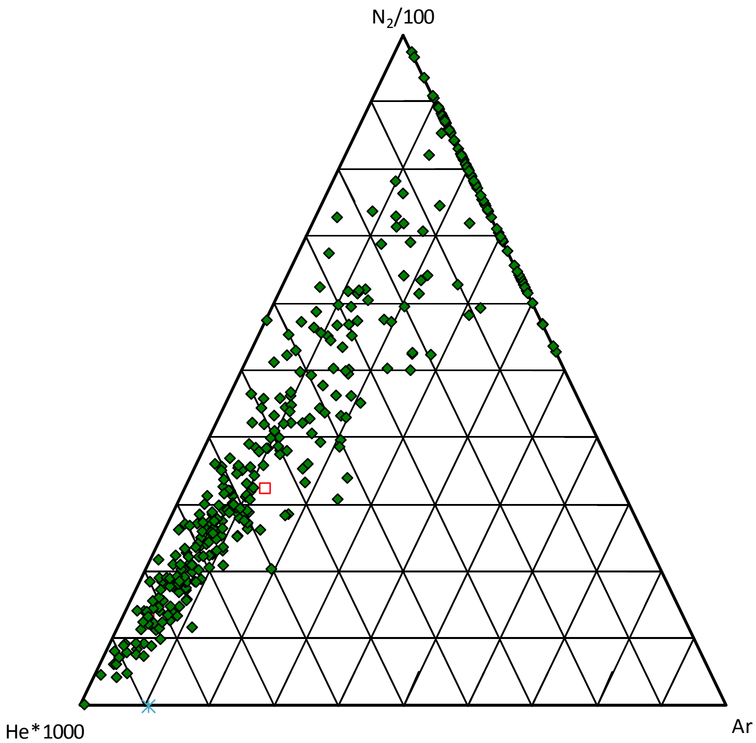
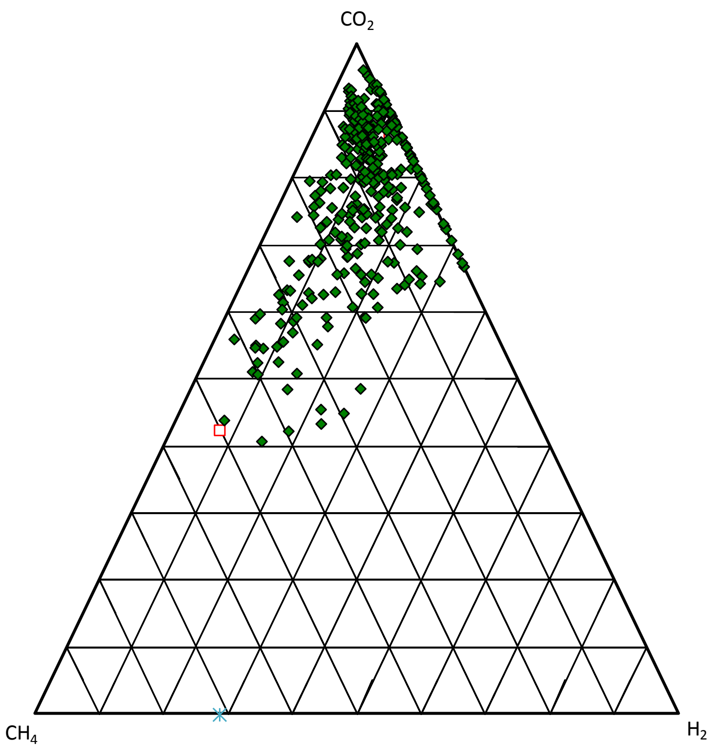
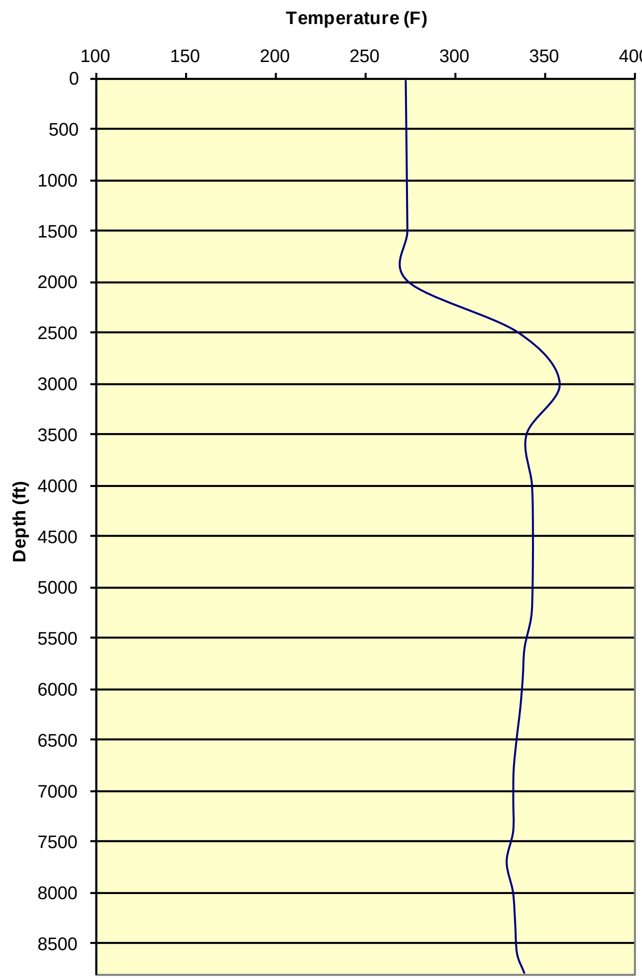
Figure E13

COSO WELL 54-7RD







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Ternary Diagrams for Coso Well 54-7RD
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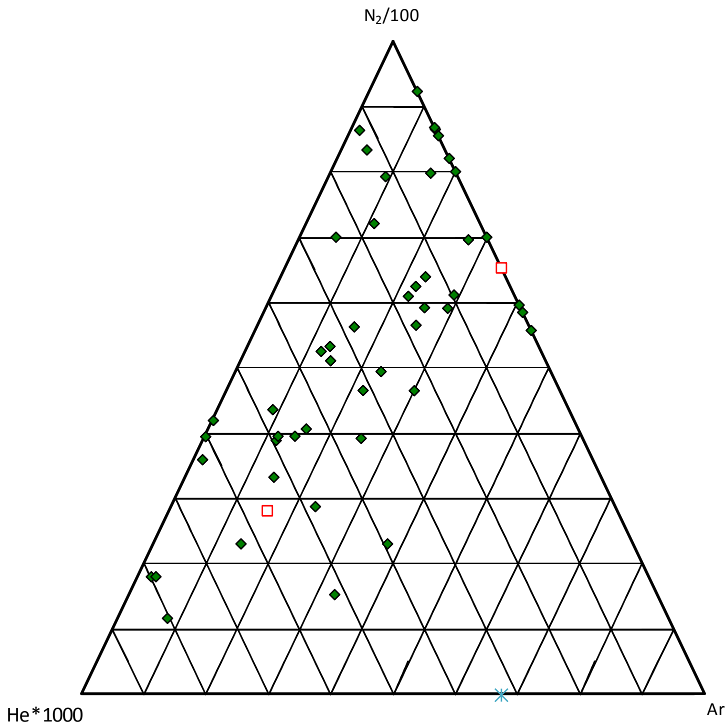
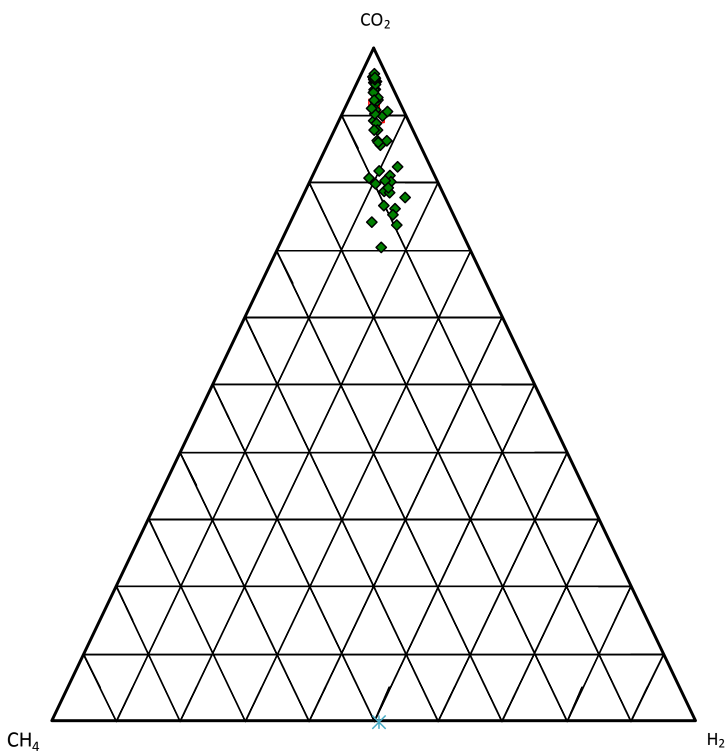
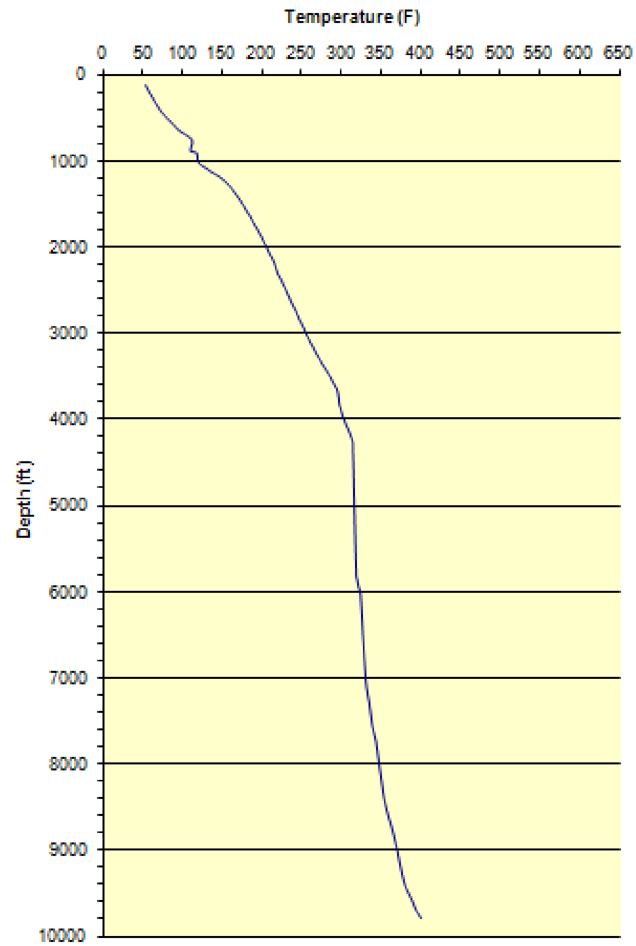
Figure E14

COSO WELL 58A-10







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Ternary Diagrams for Coso Well 58A-10

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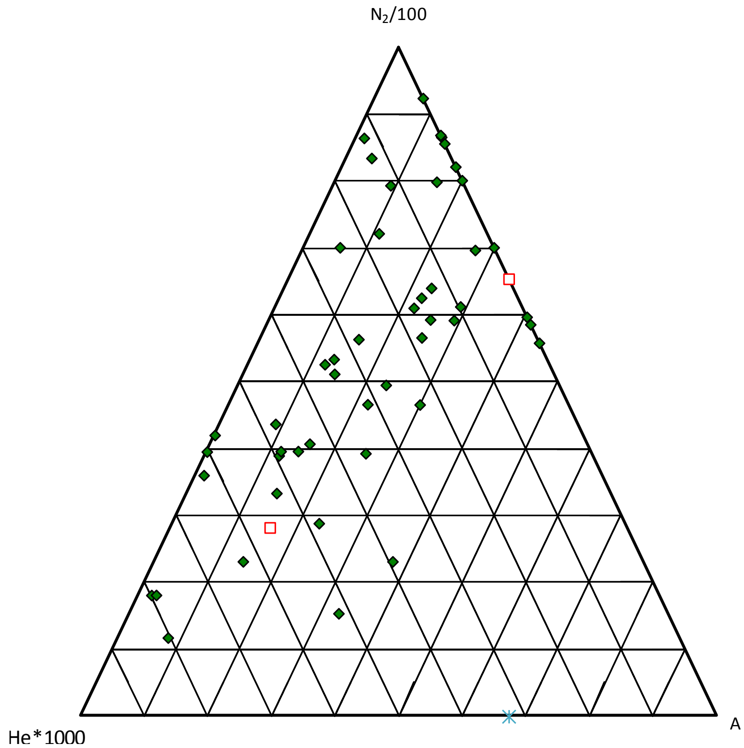
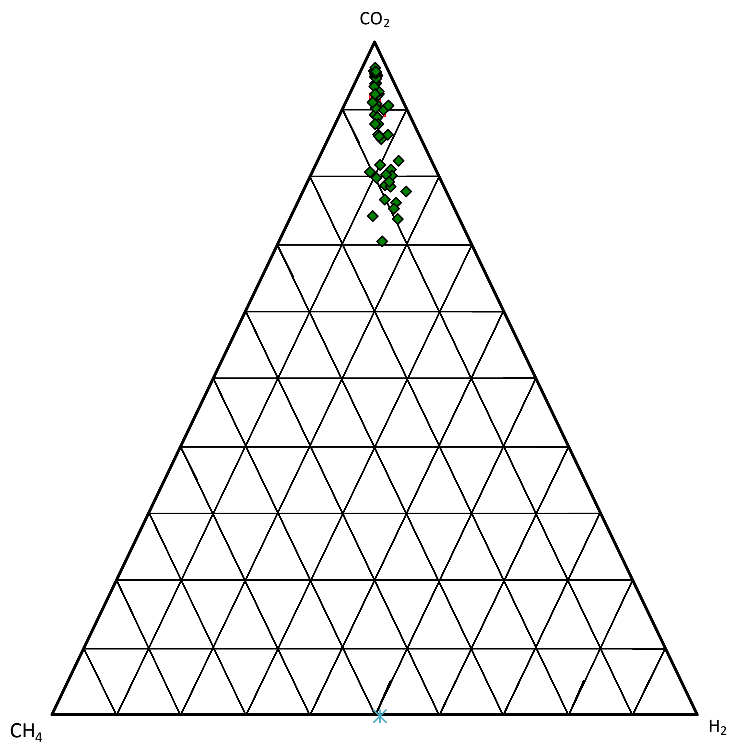
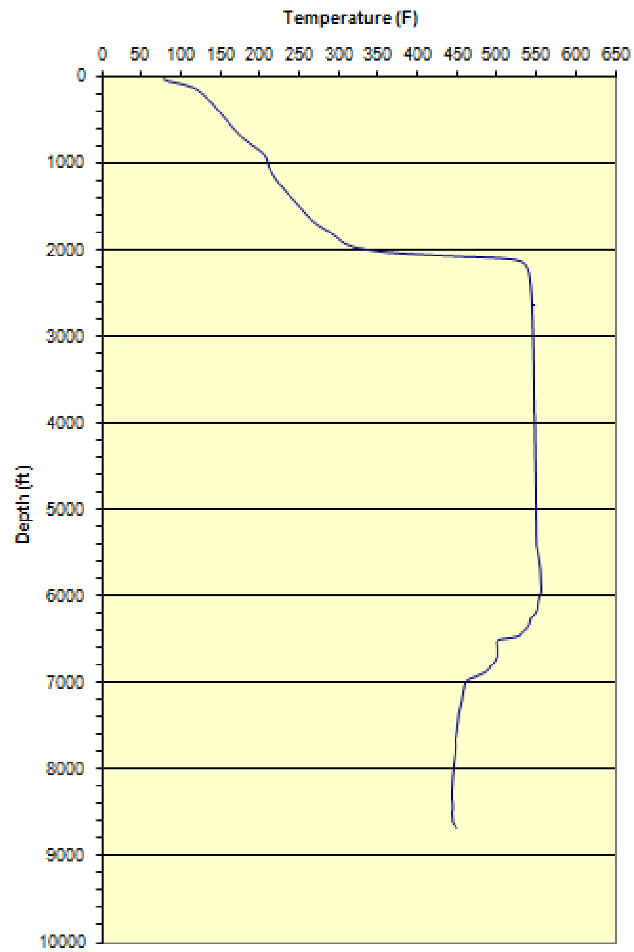
Figure E15

COSO WELL 58A-18







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Ternary Diagrams for Coso Well 58A-18
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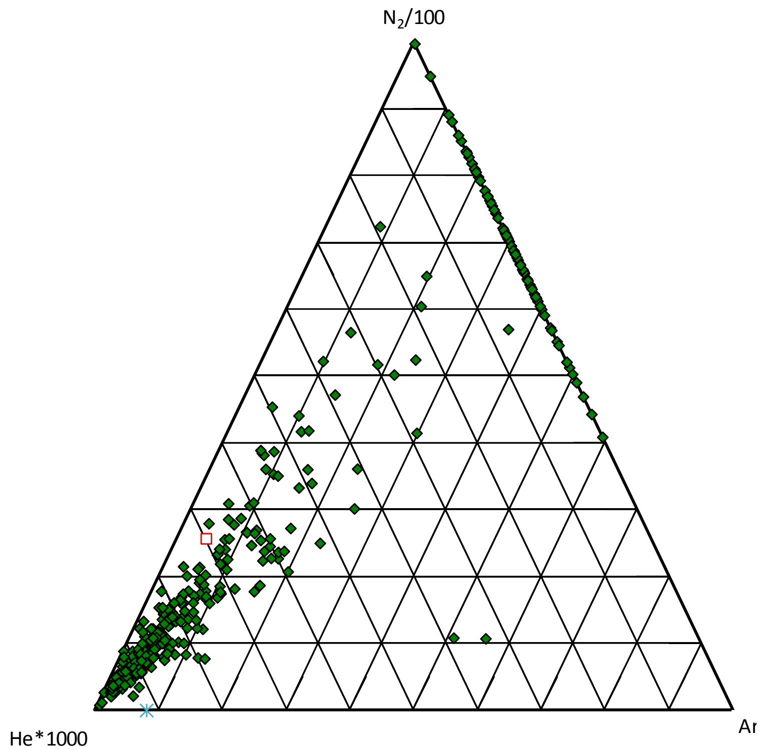
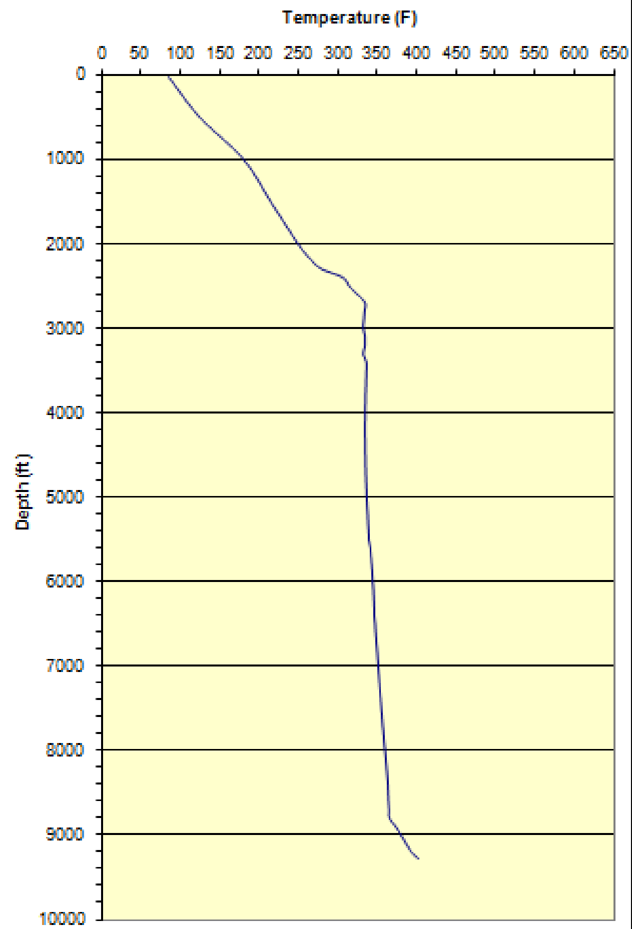
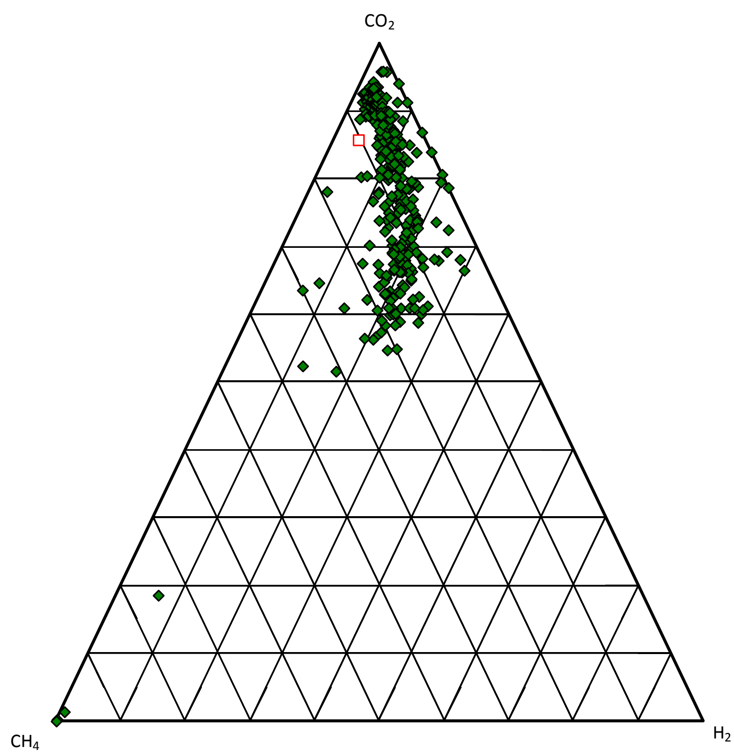
Figure E16

COSO WELL 67-17







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Ternary Diagrams for Coso Well 67-17

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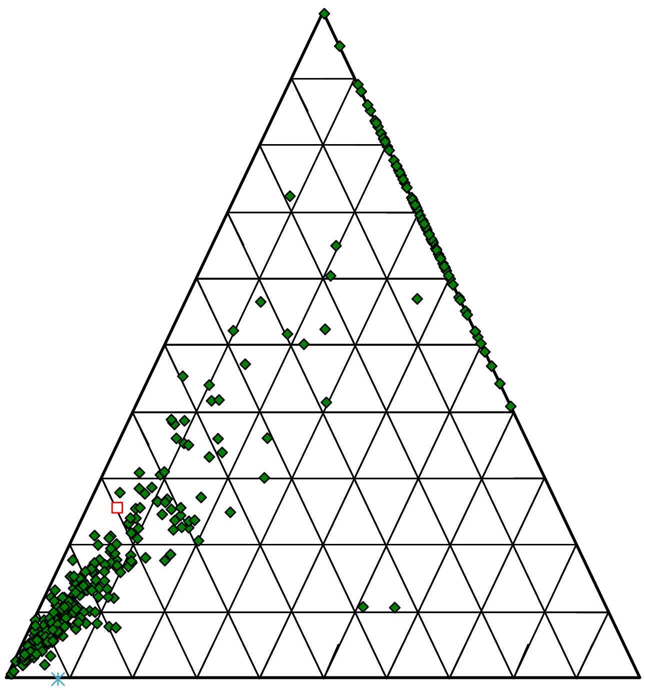
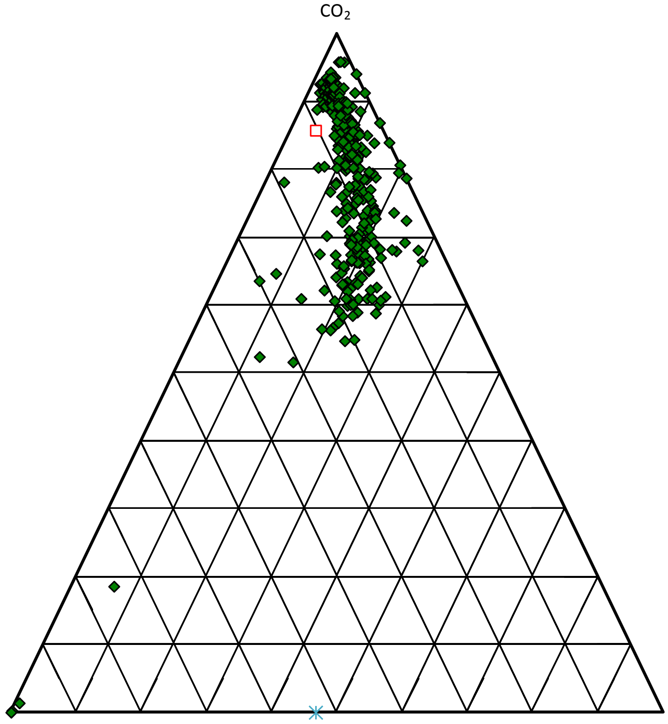
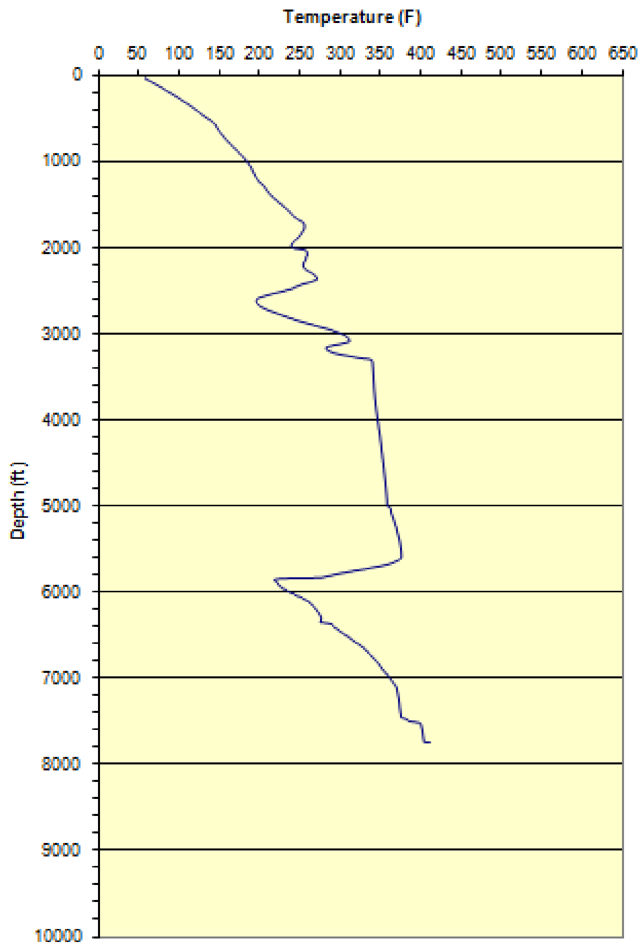
Figure E17

COSO WELL 67-17C







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Ternary Diagrams for Coso Well 67-17C

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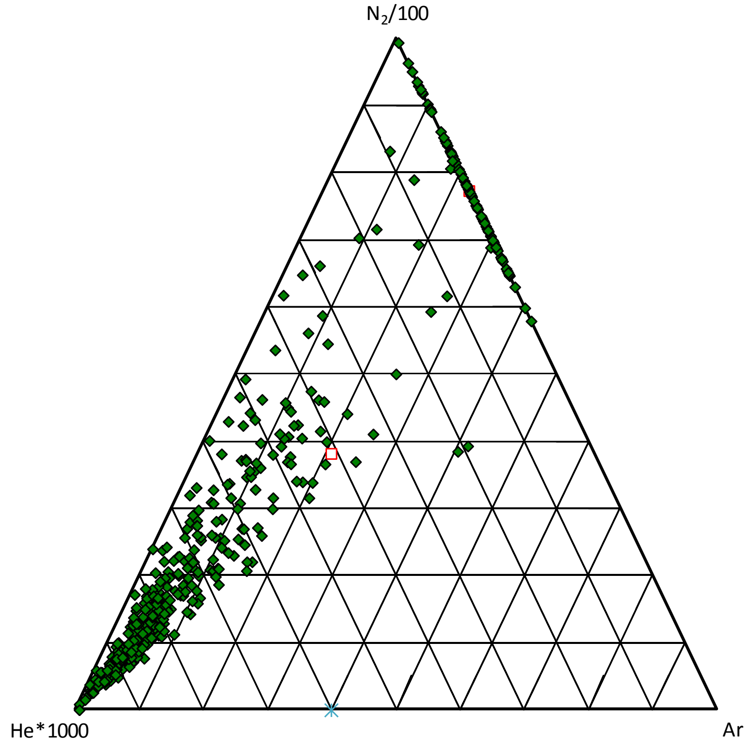
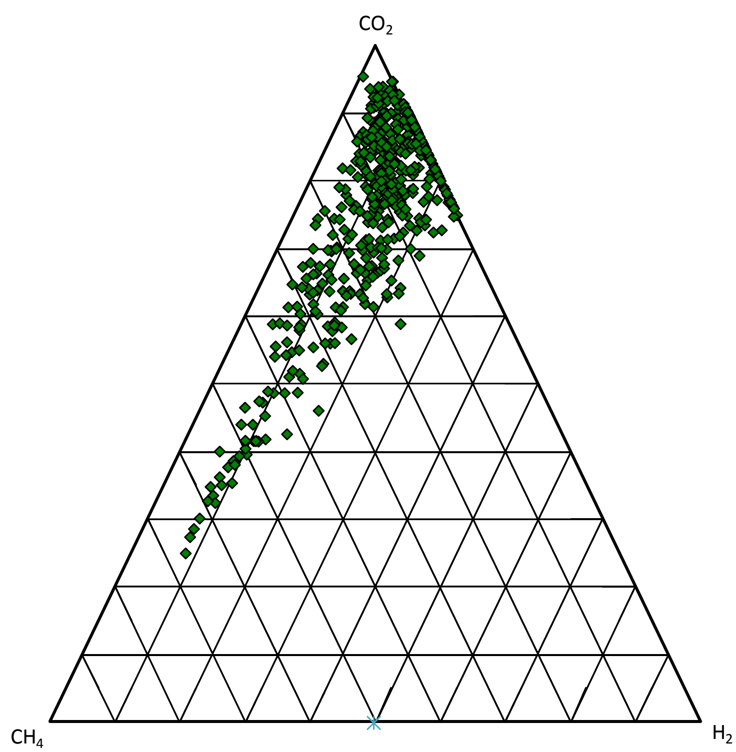
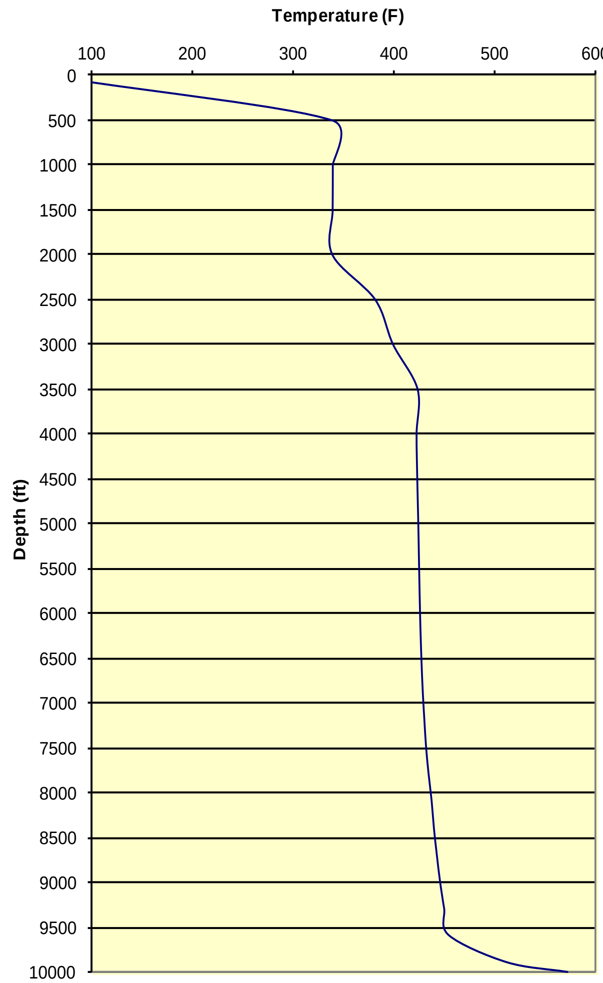
Figure E18

COSO WELL 68-6







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Ternary Diagrams for Coso Well 68-6

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Figure E19

COSO WELL 68-20

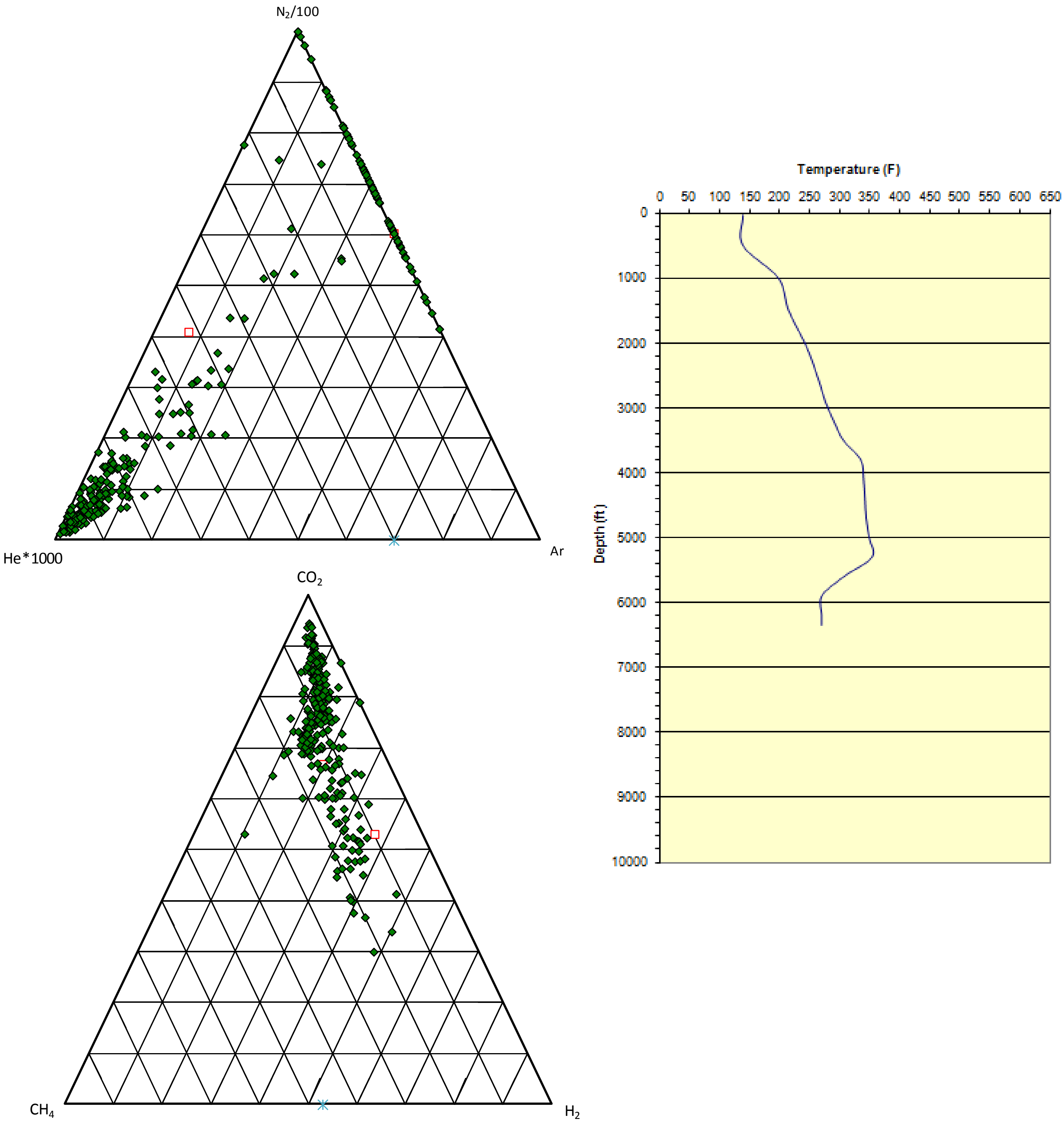

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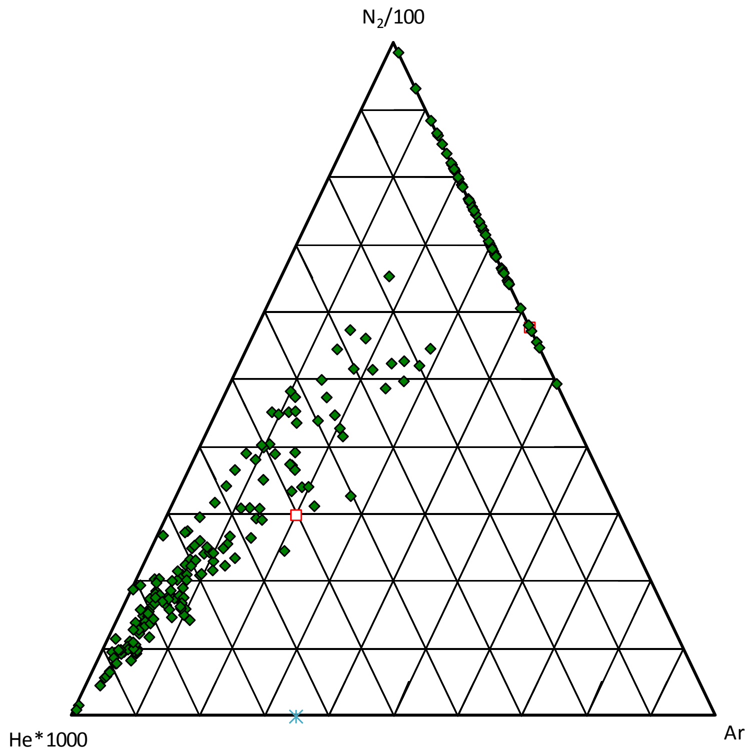
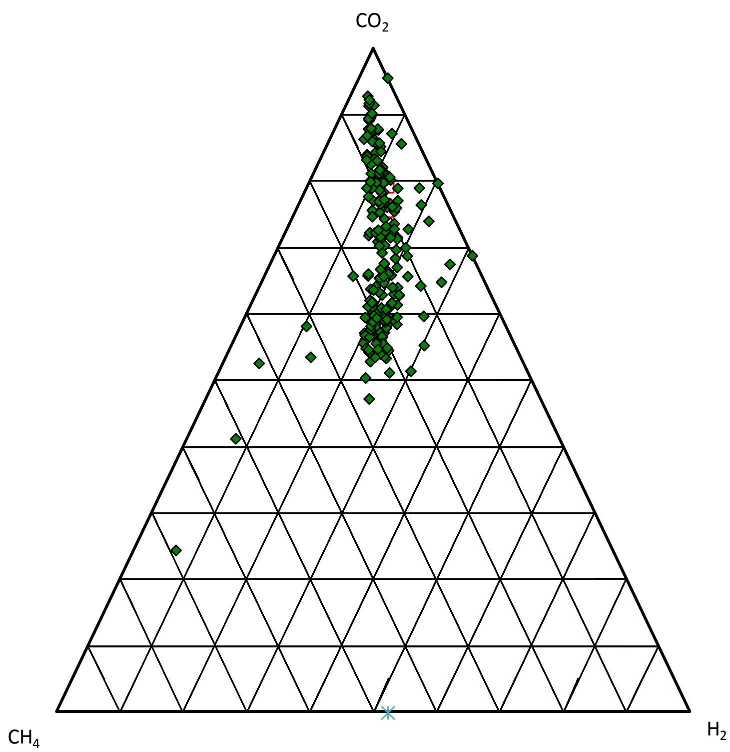
Figure E20

COSO WELL 68-20RD





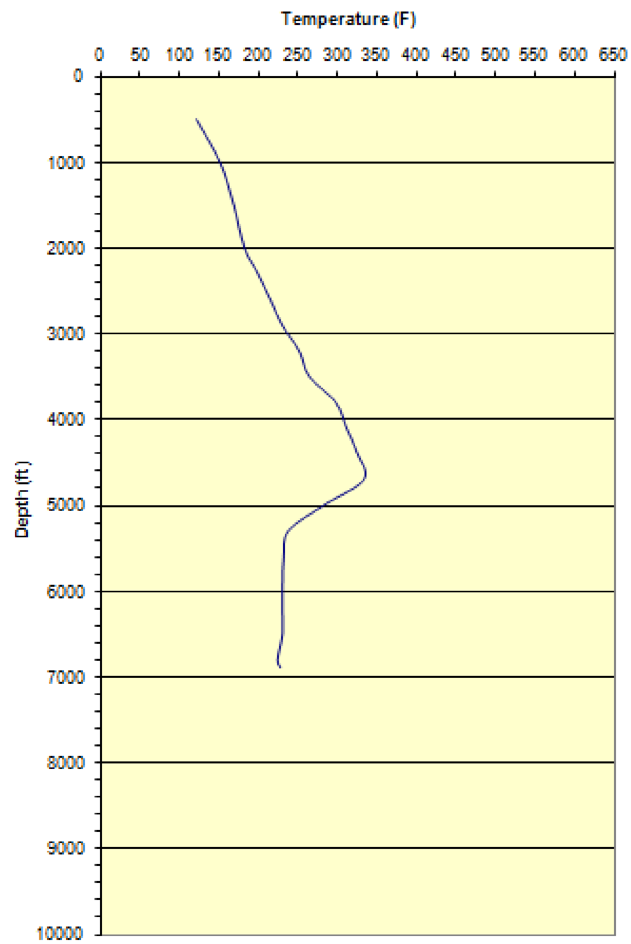


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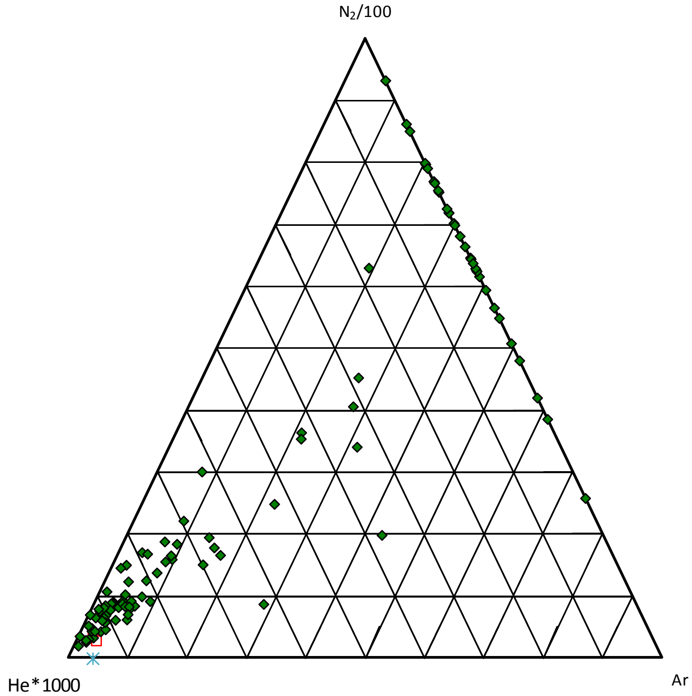
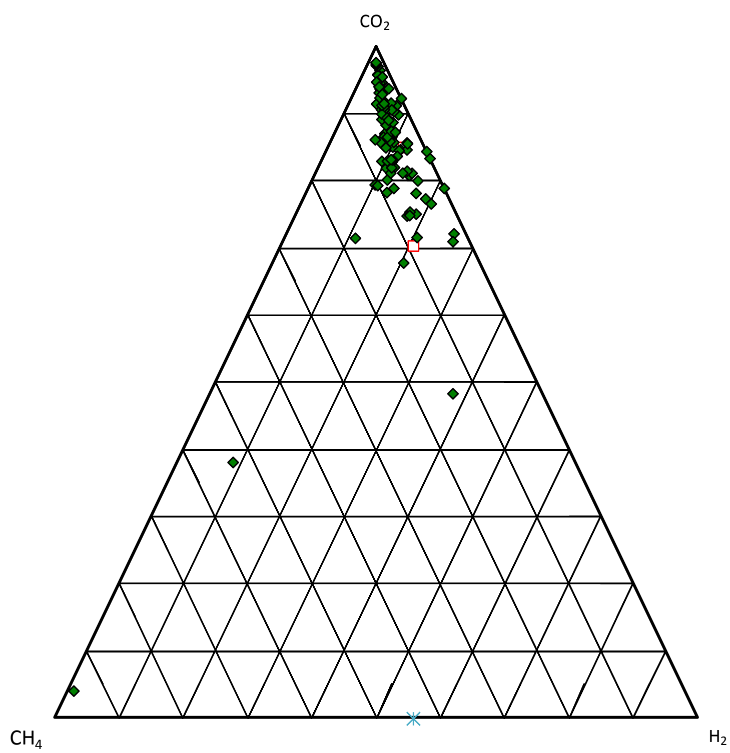
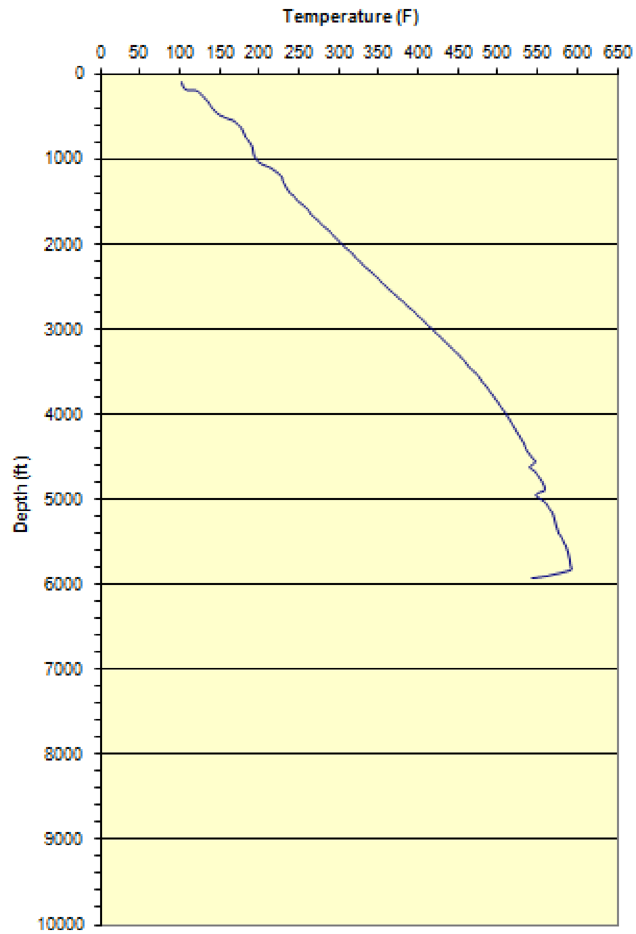
Figure E21

COSO WELL 73-19







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Ternary Diagrams for Coso Well 73-19
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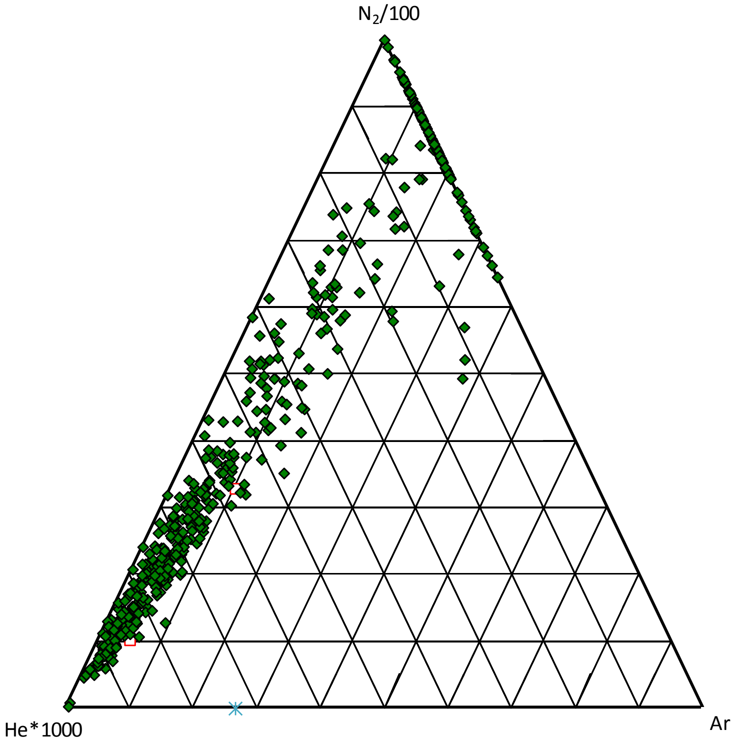
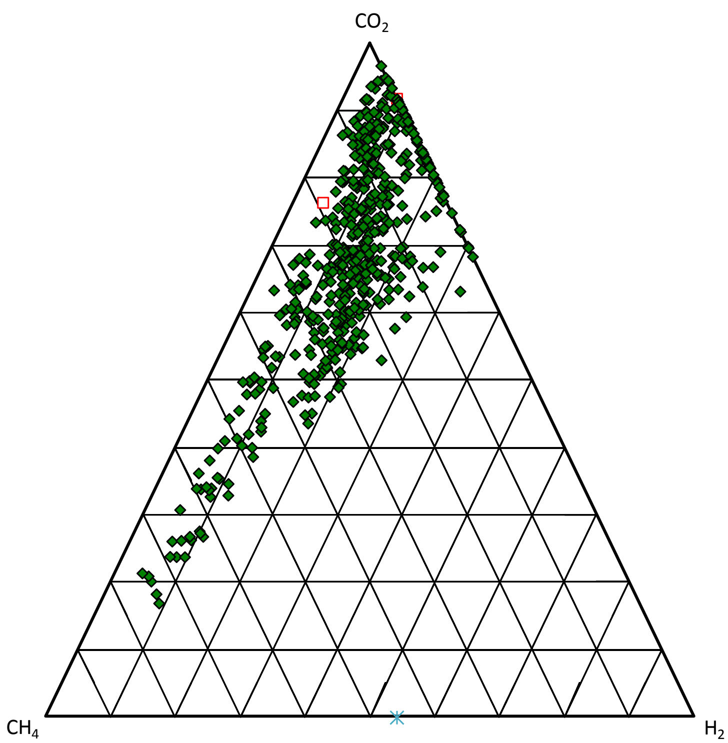
Figure E22

COSO WELL 83B-16





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Ternary Diagrams for Coso Well 83B-16
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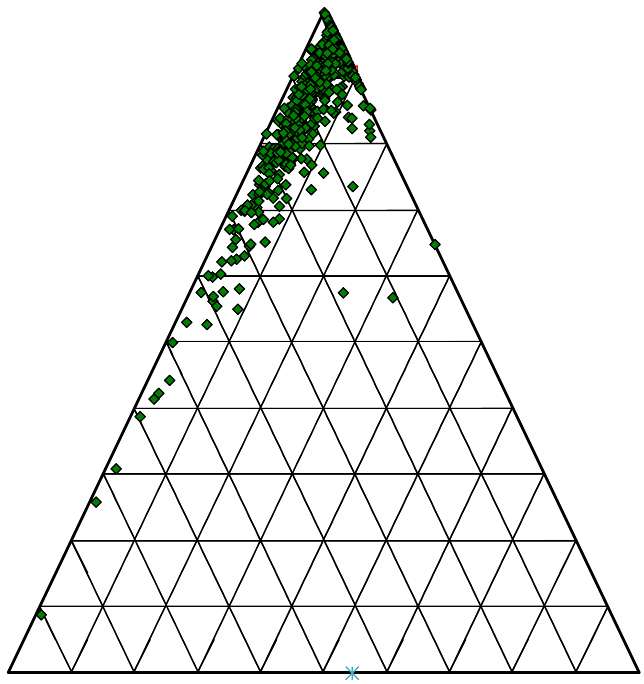
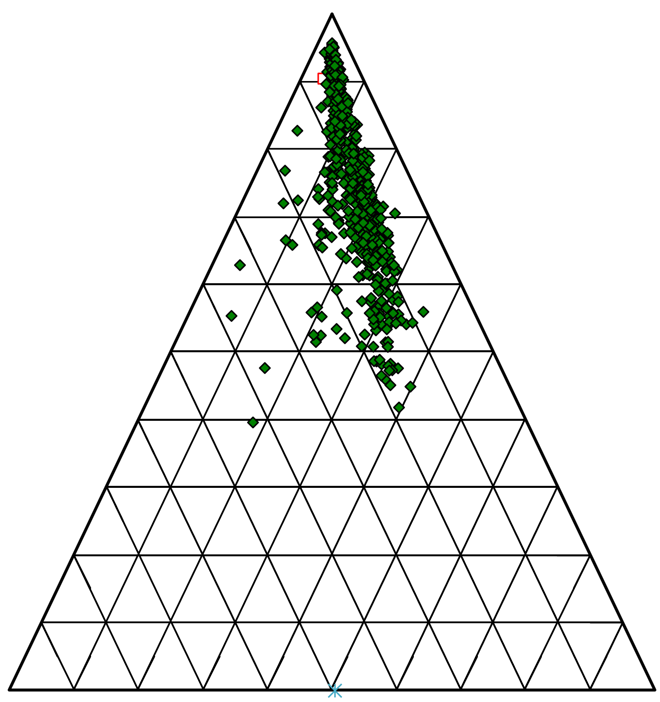
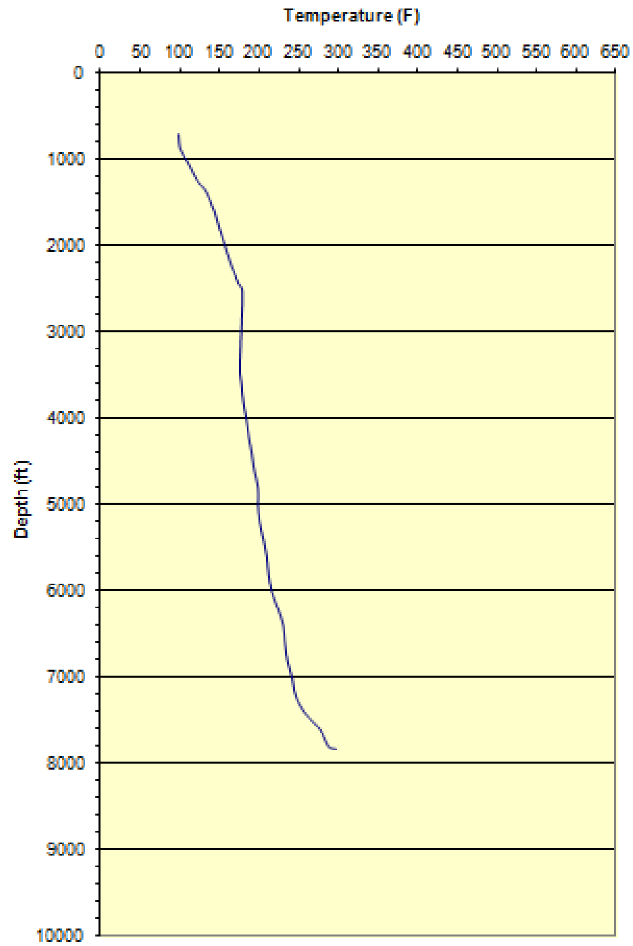
Figure E23

COSO WELL 84-30







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Ternary Diagrams for Coso Well 84-20
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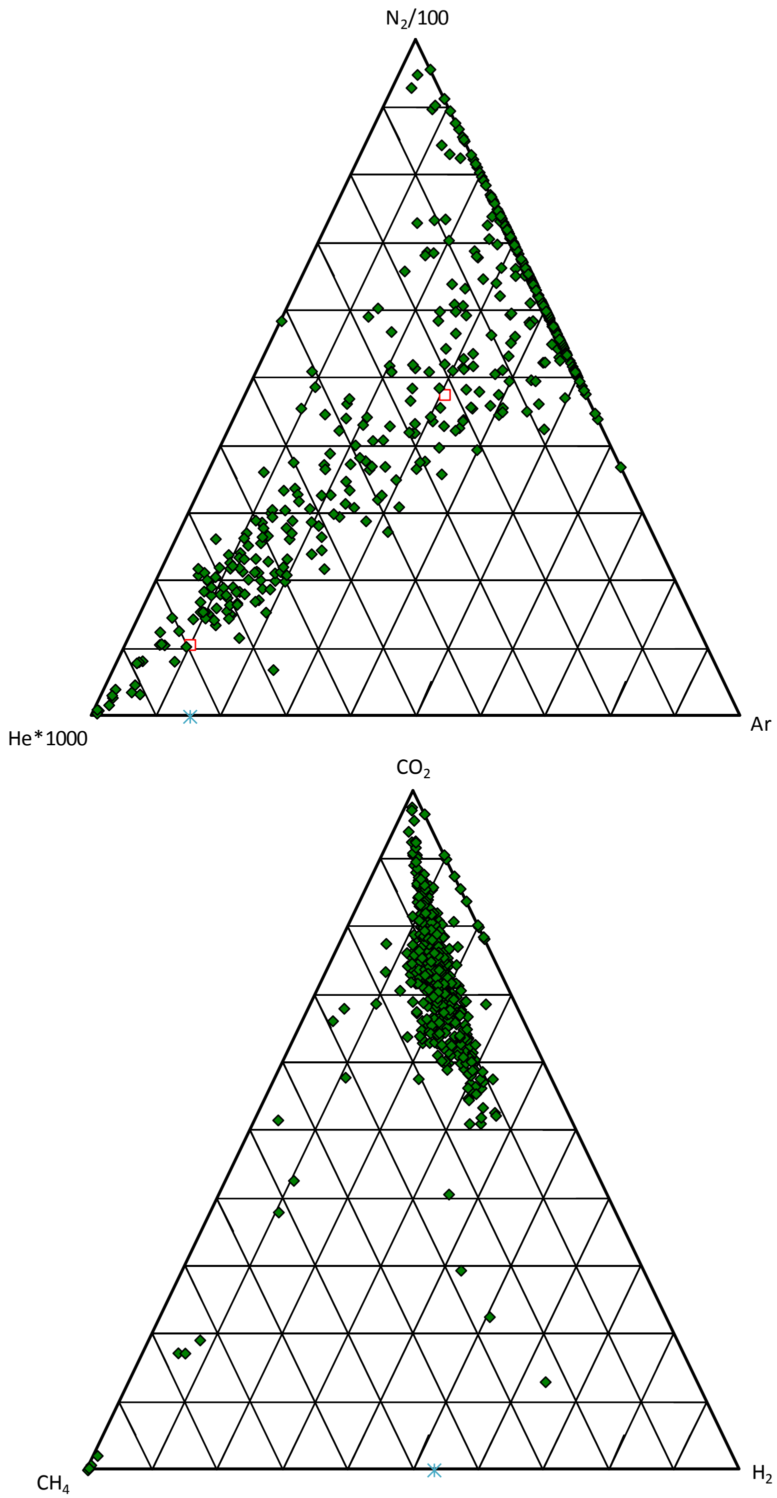
Figure E24

COSO WELL 86-17



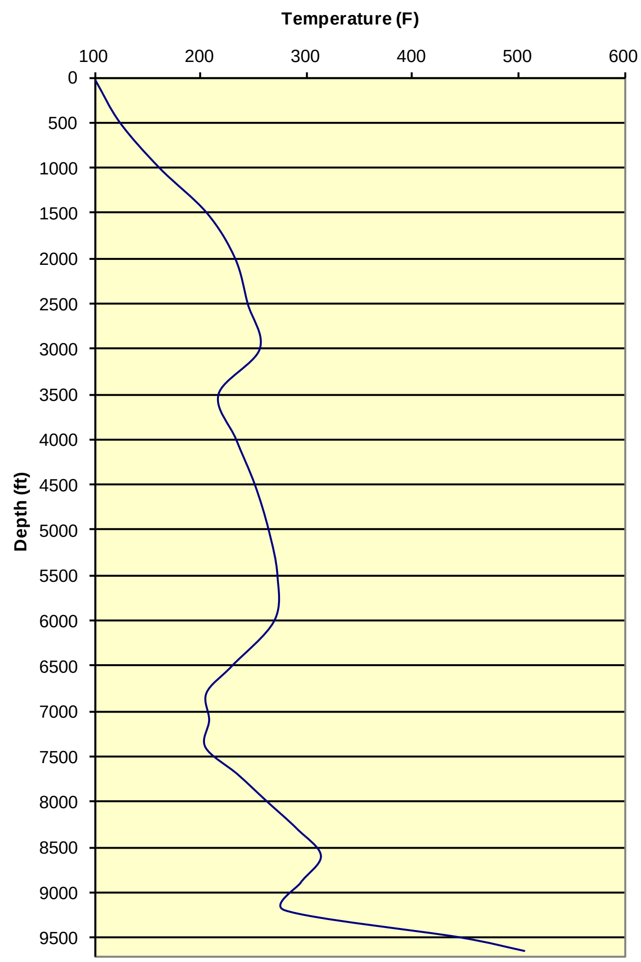


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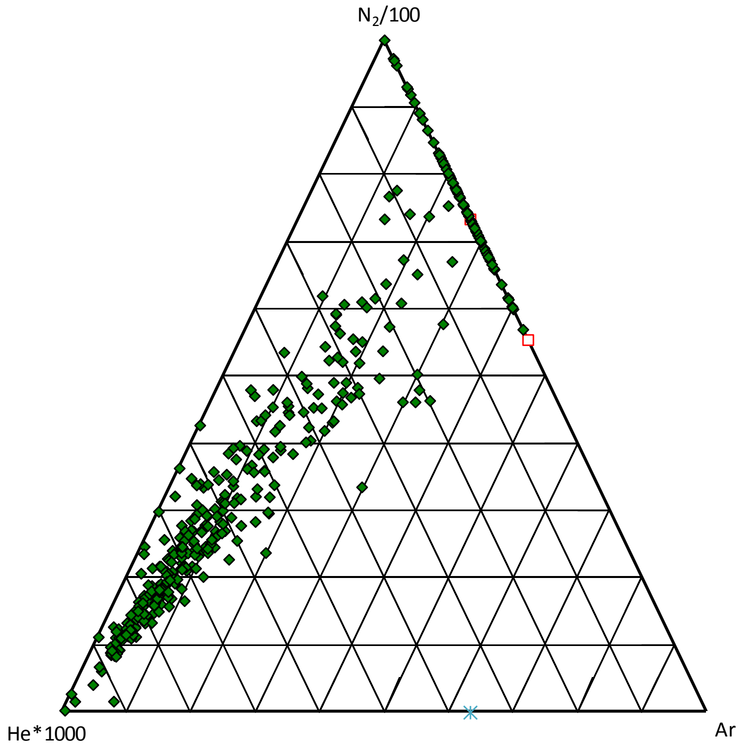
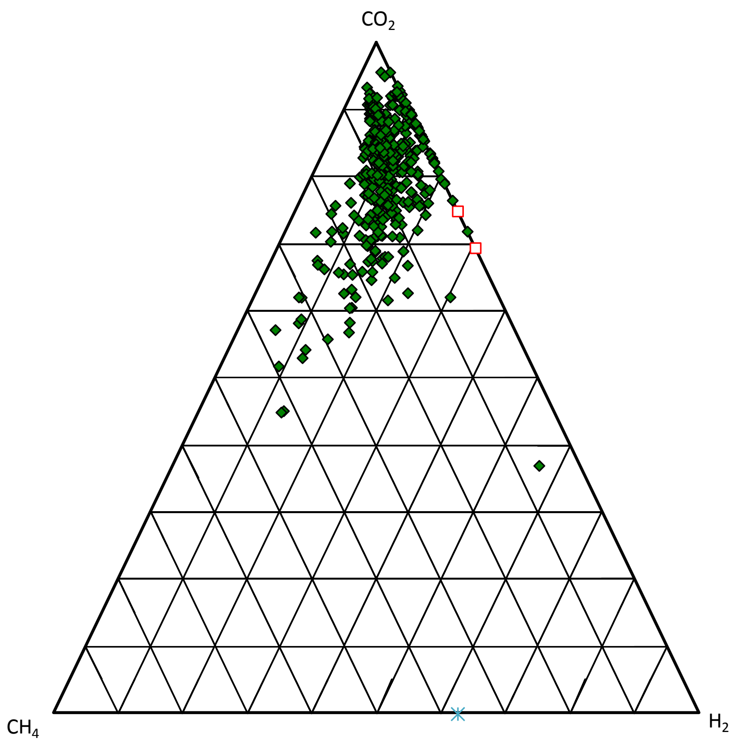
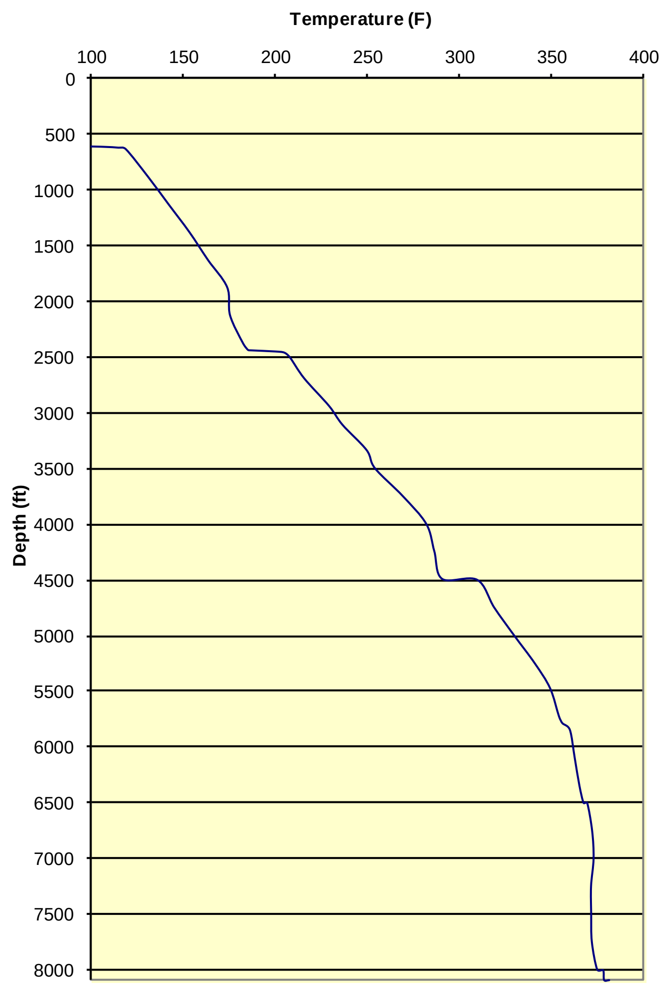
Figure E25

COSO WELL 88-20







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Ternary Diagrams for Coso Well 88-20

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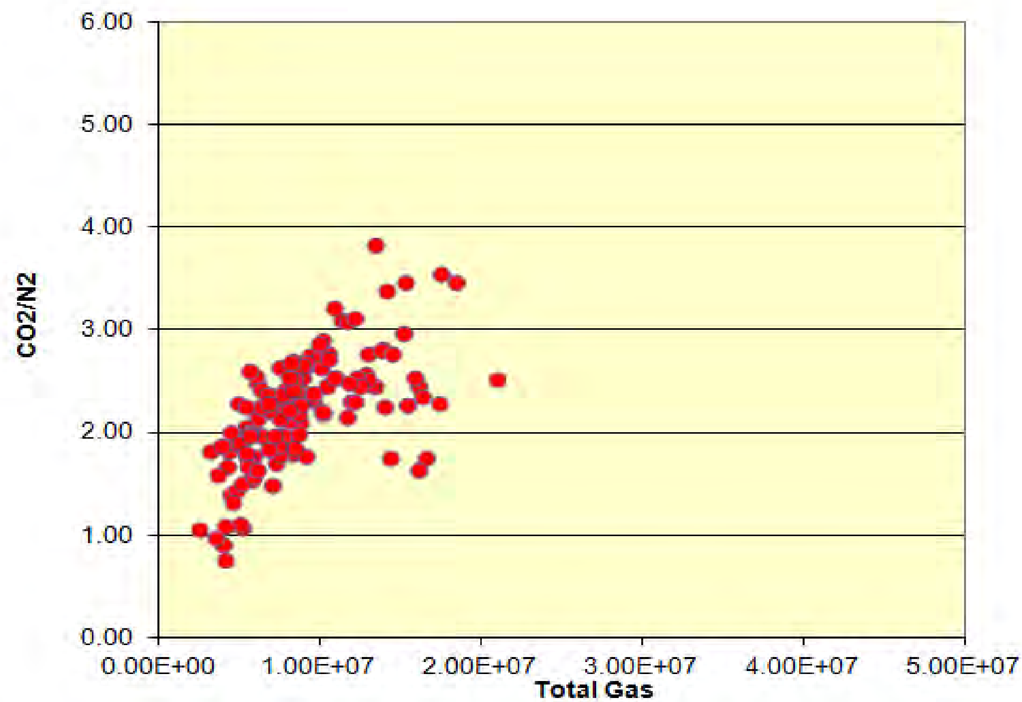
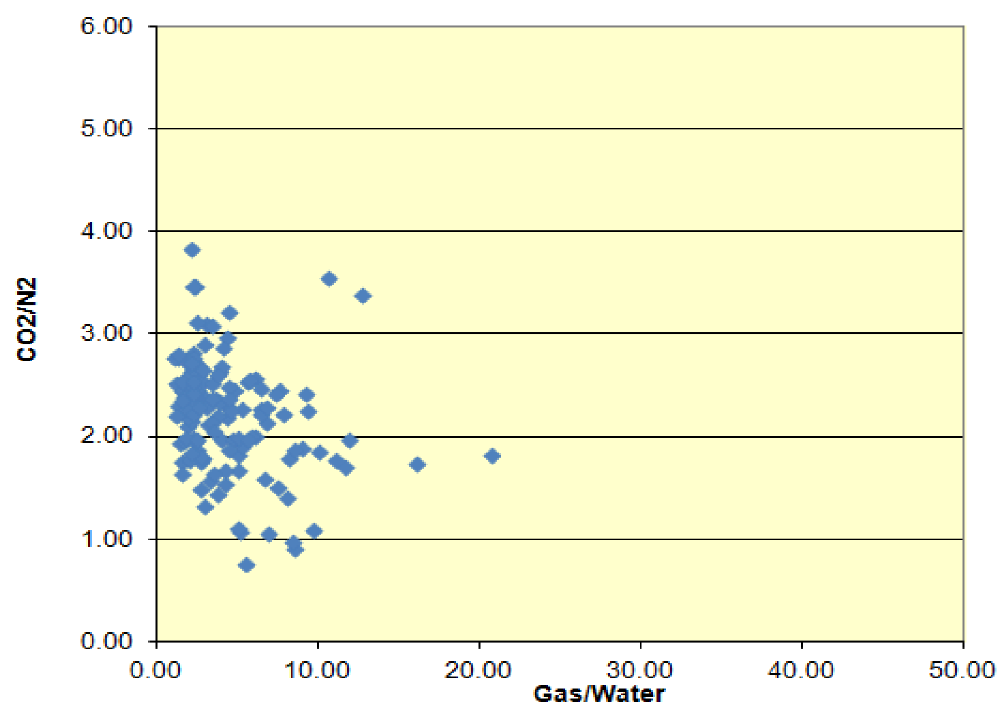
Figure E26

APPENDIX F
GAS/WATER RATIO VERSUS CO_2/N_2 GRAPHS

Chocolate Mountains Well 17-8





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Chocolate Mountains Well 17-8
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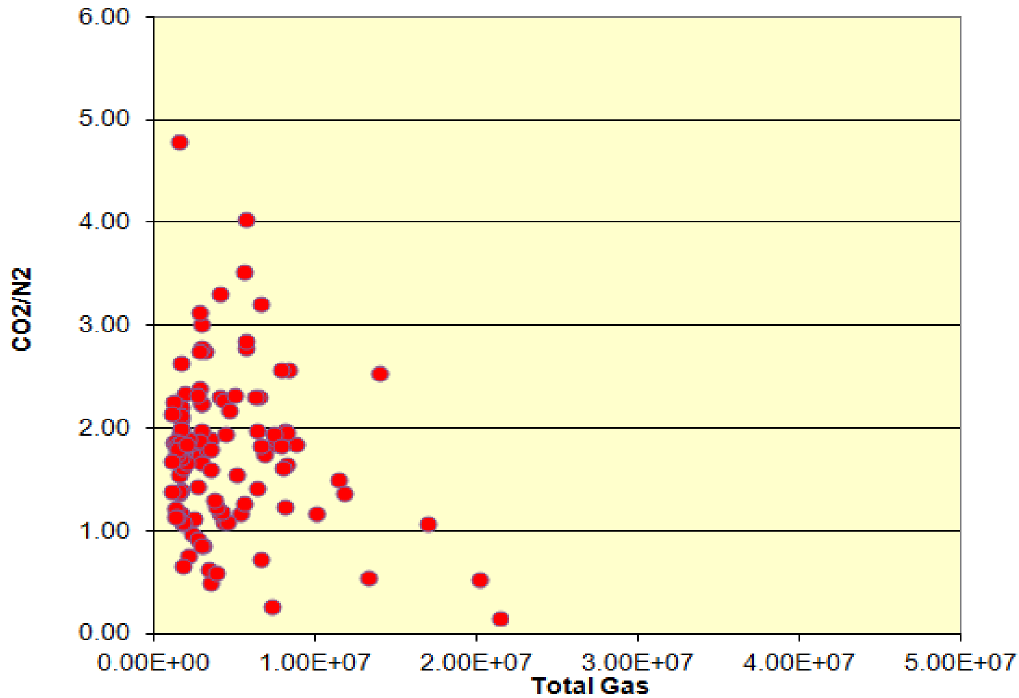
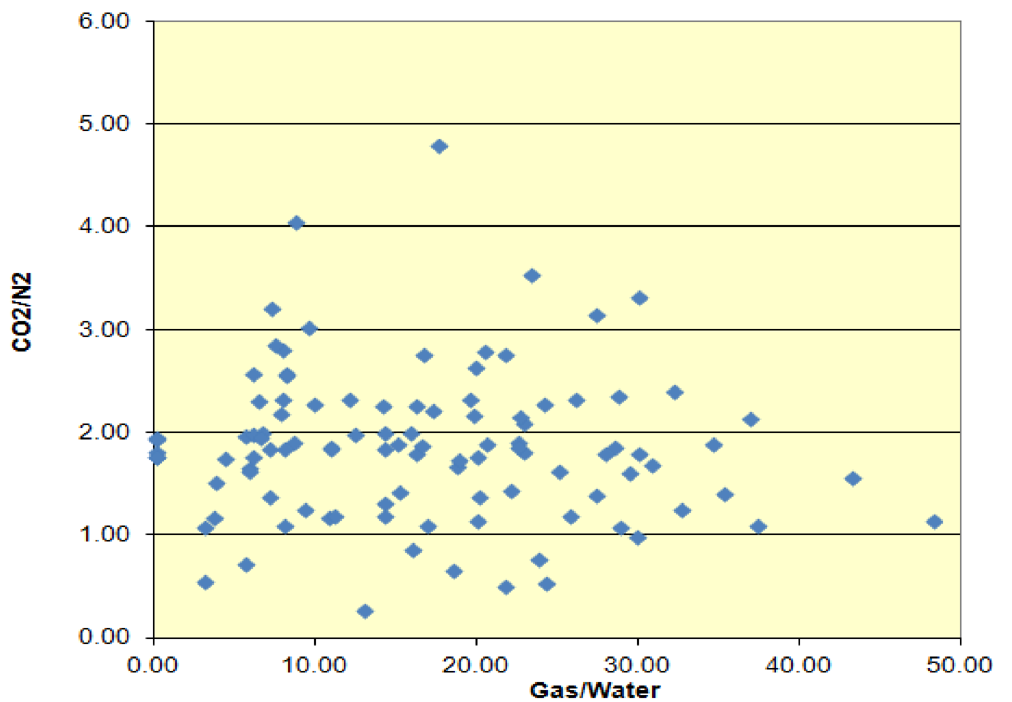
Figure F1

El Centro Well NAFEC-1





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El Centro NAFEC-1
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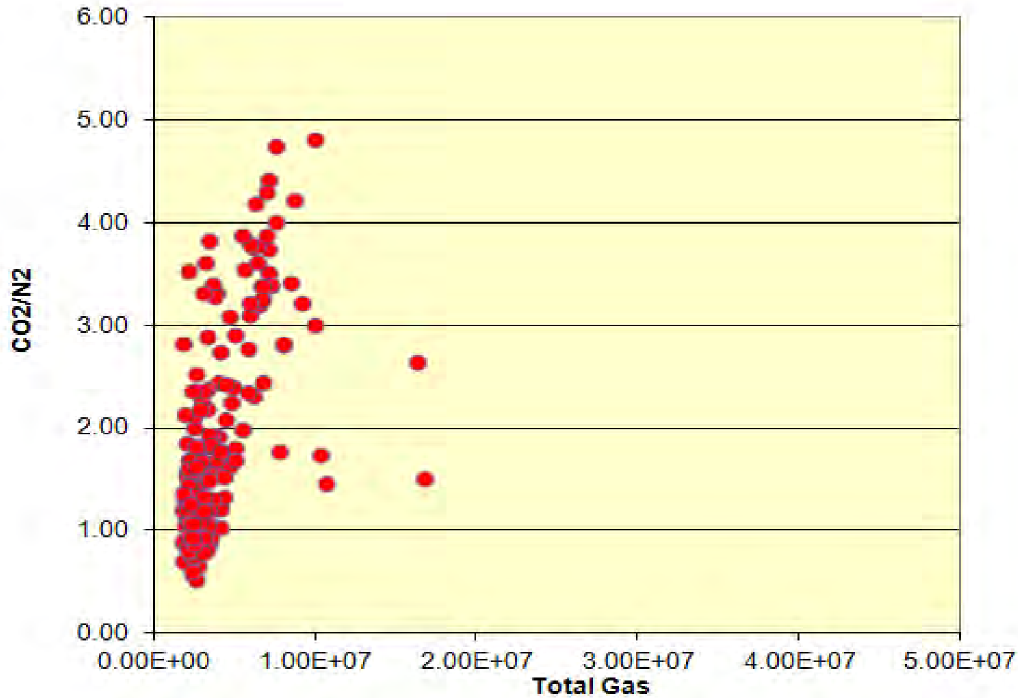
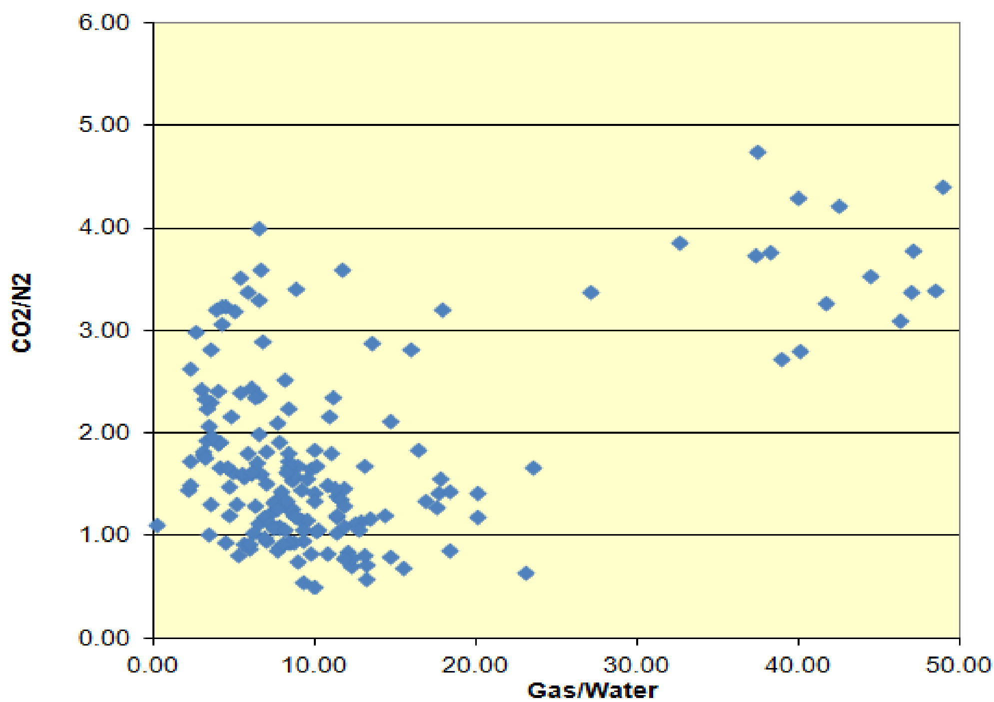
Figure F2

El Centro Well NAFEC-3





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El Centro NAFEC-3

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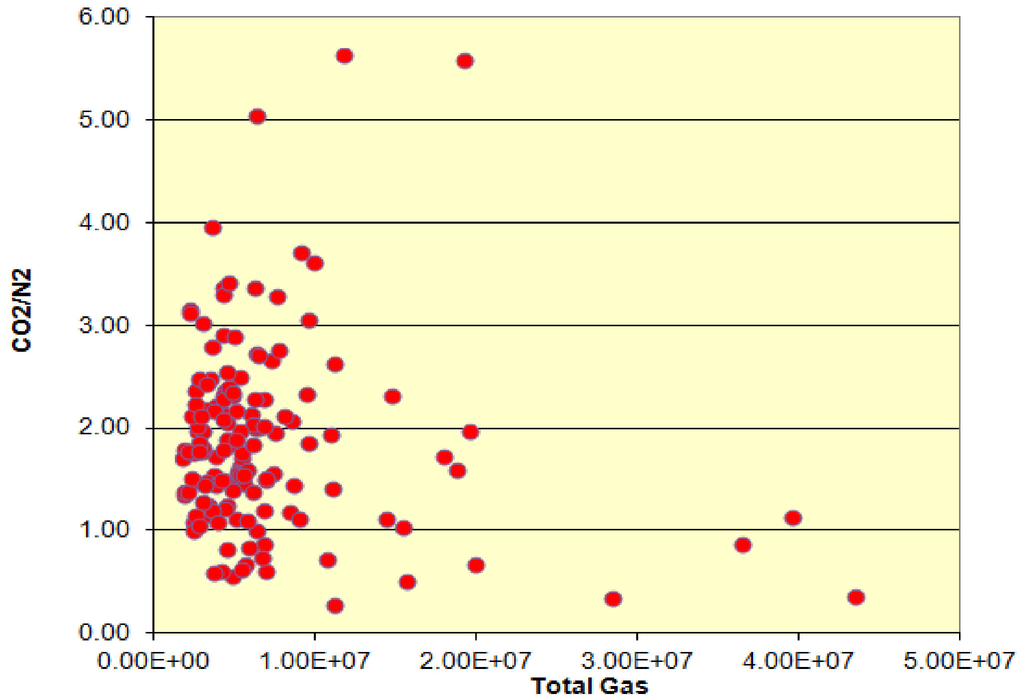
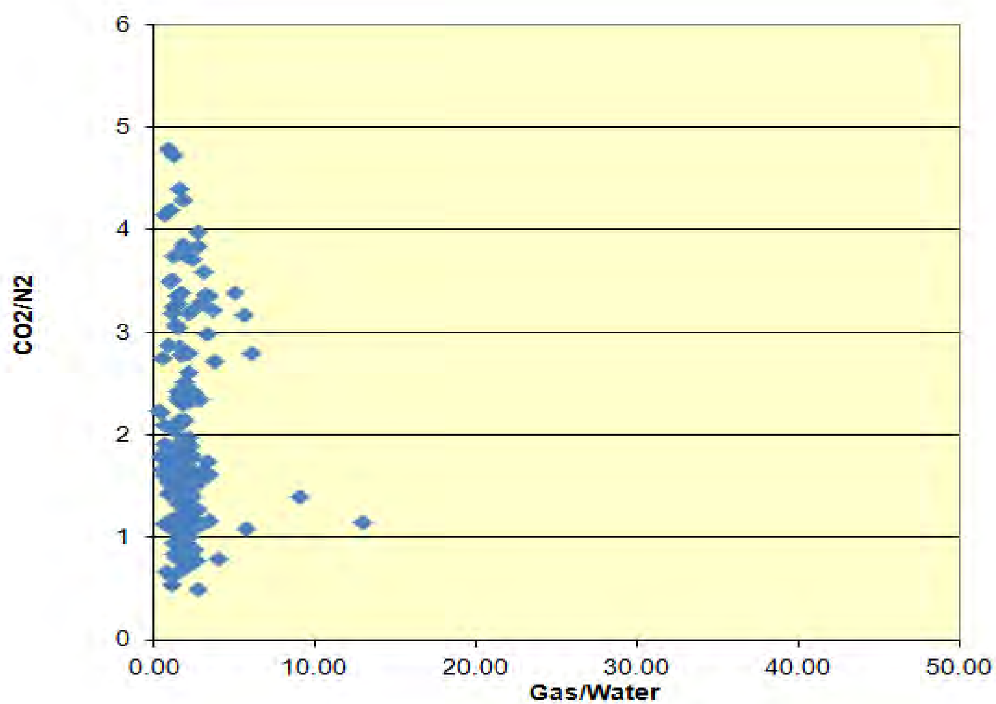
Figure F3

El Centro Well NAFEC-11





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El Centro NAFEC-11
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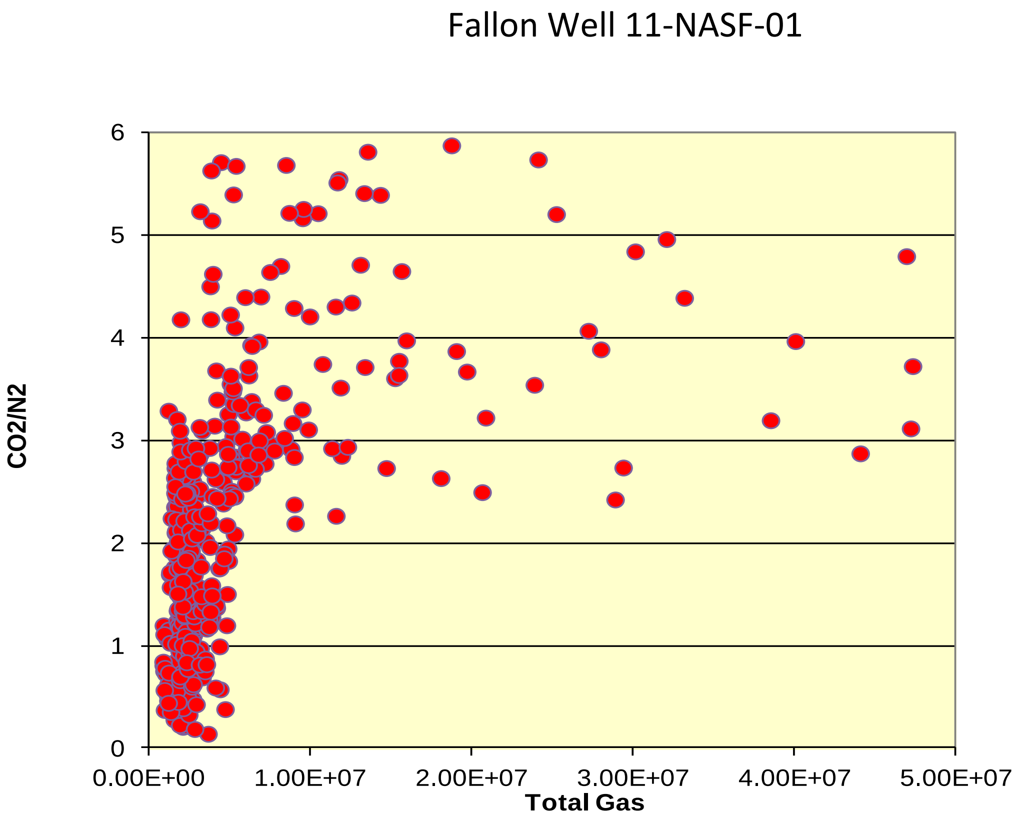
Figure F4



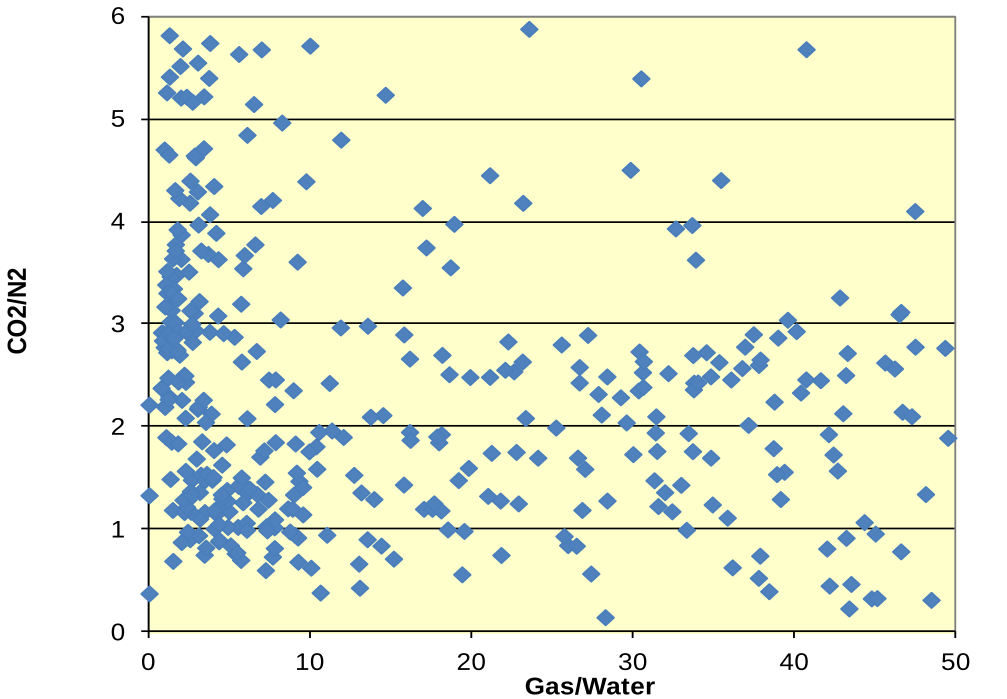


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Figure F5

Fallon Well 11-NASF-02

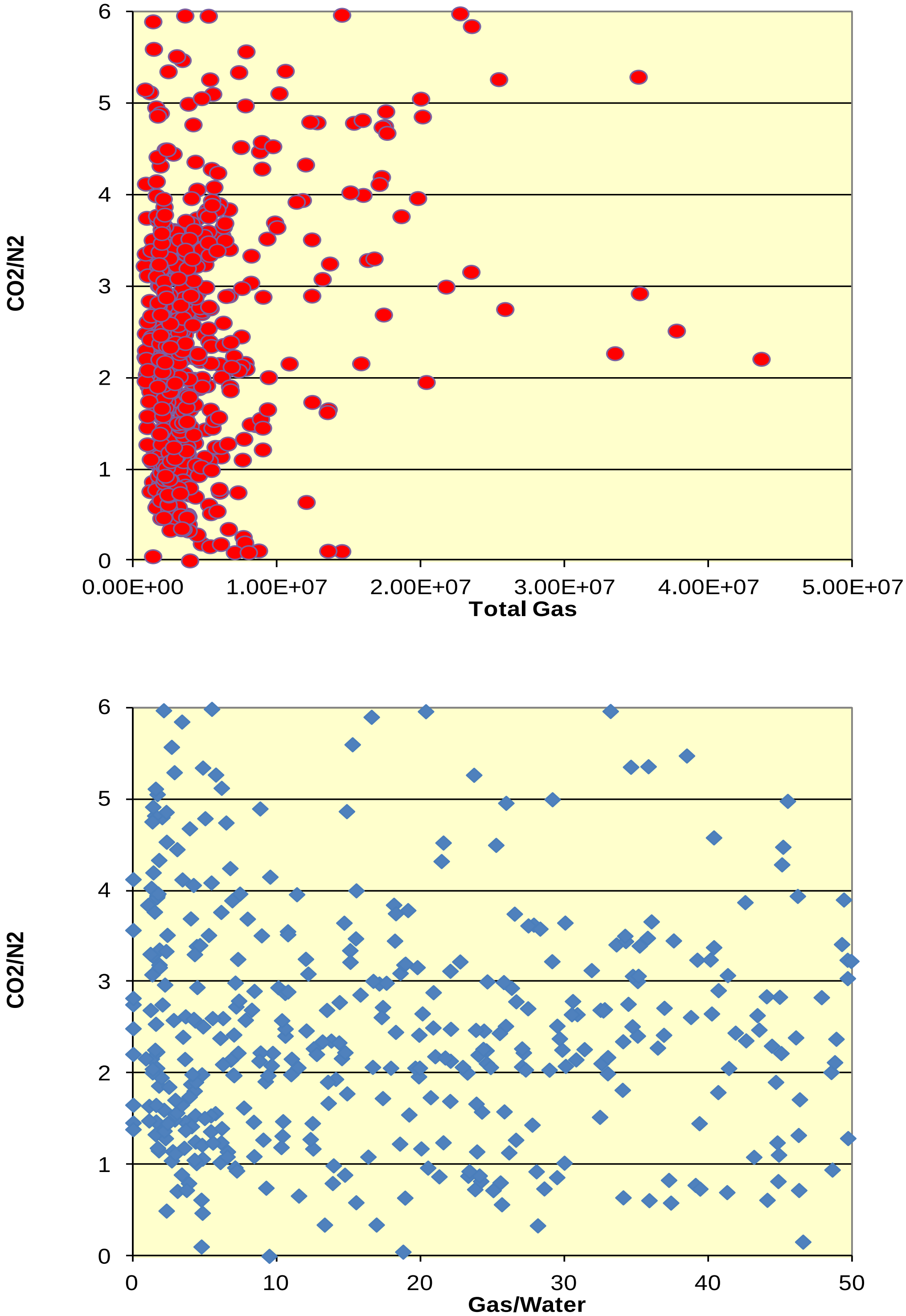

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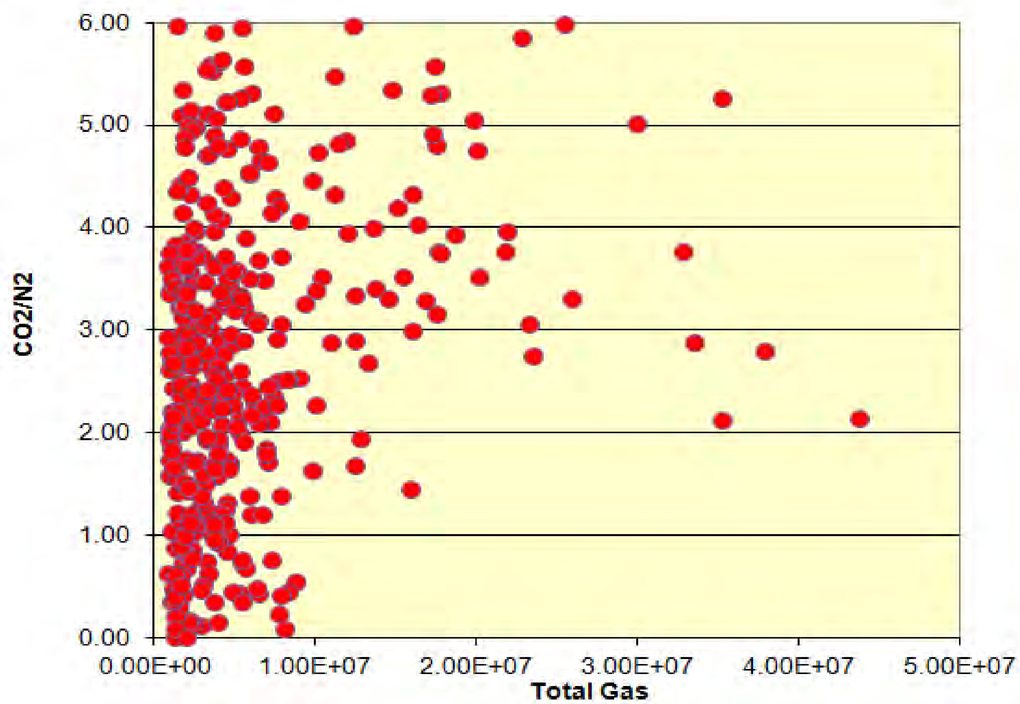
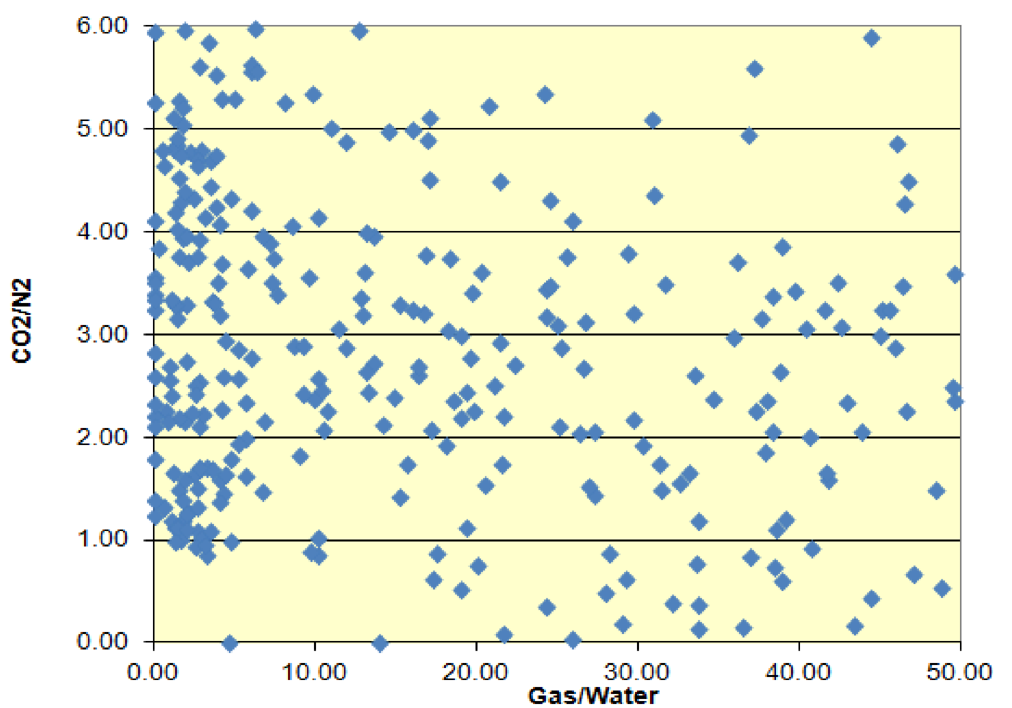
Figure F6

Fallon Well CL82-36





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Fallon CL82-36

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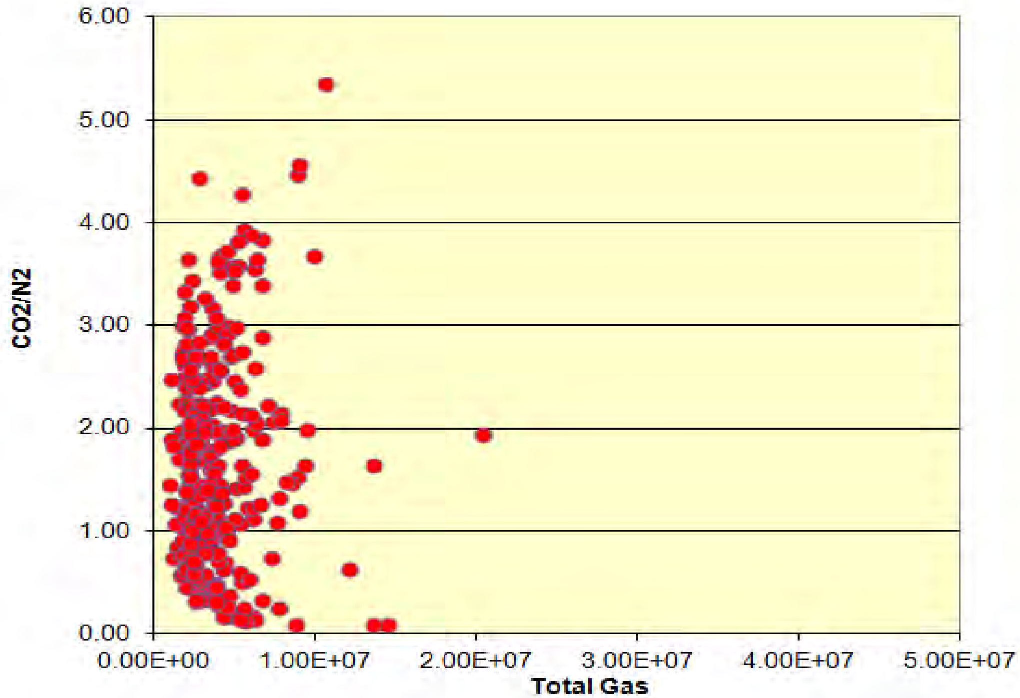
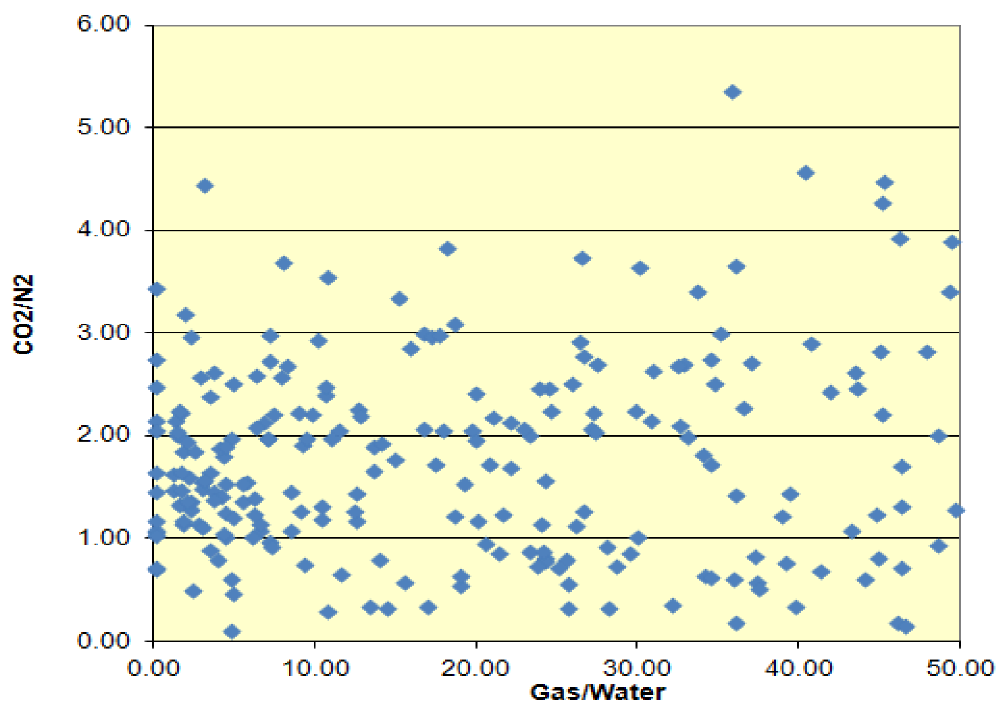
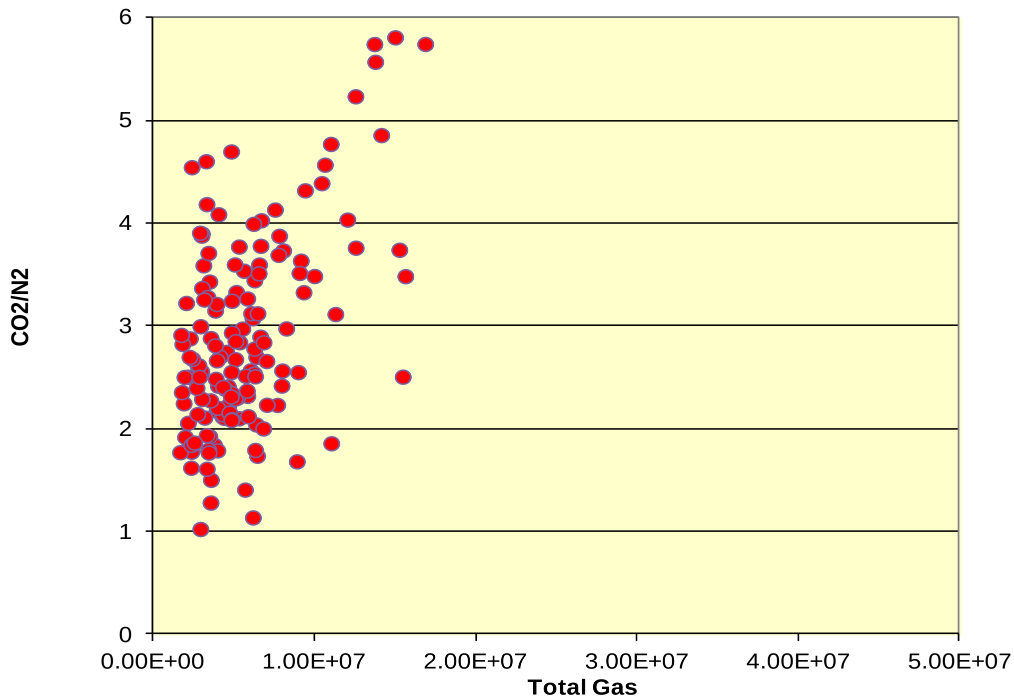
Figure F7

Fallon Well CL84-31





Fallon Well FDU-2D



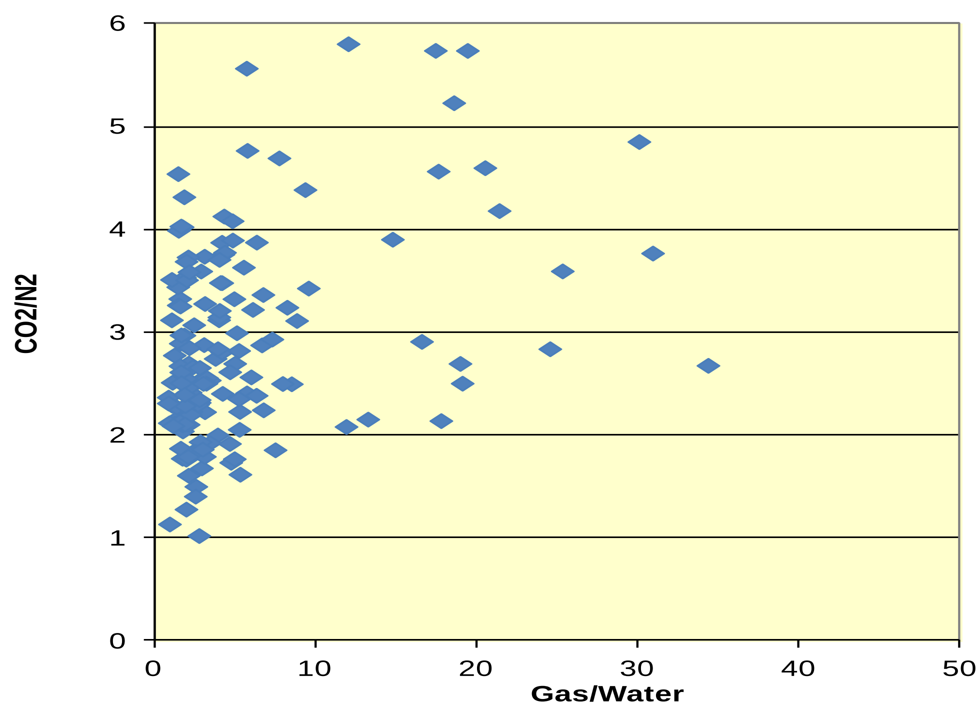


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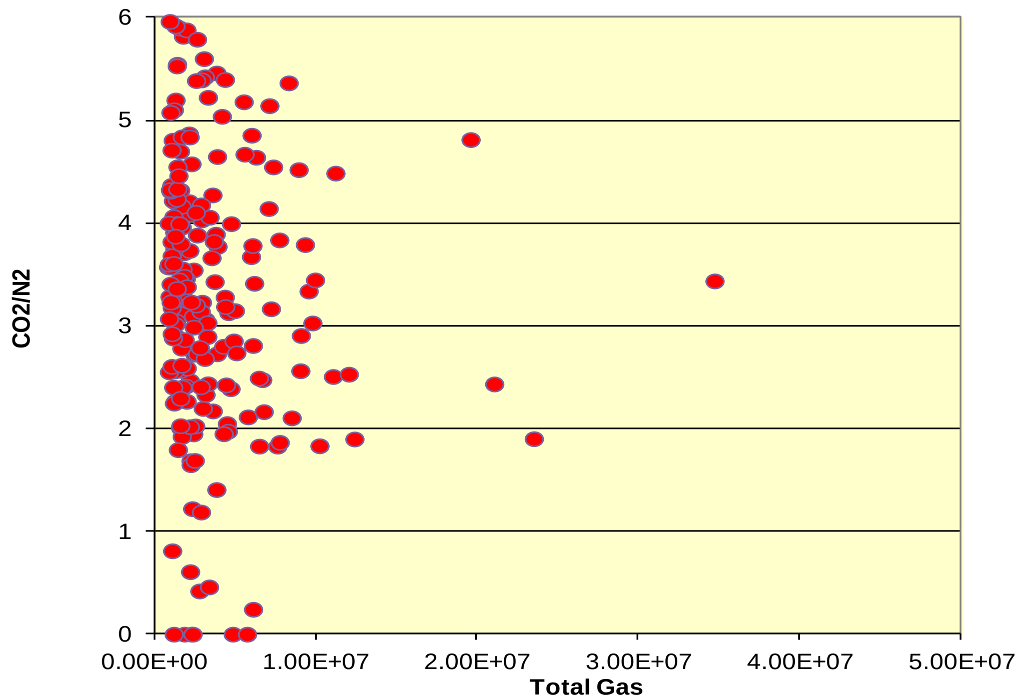
Figure F9

Fallon Well FLTH 88-24



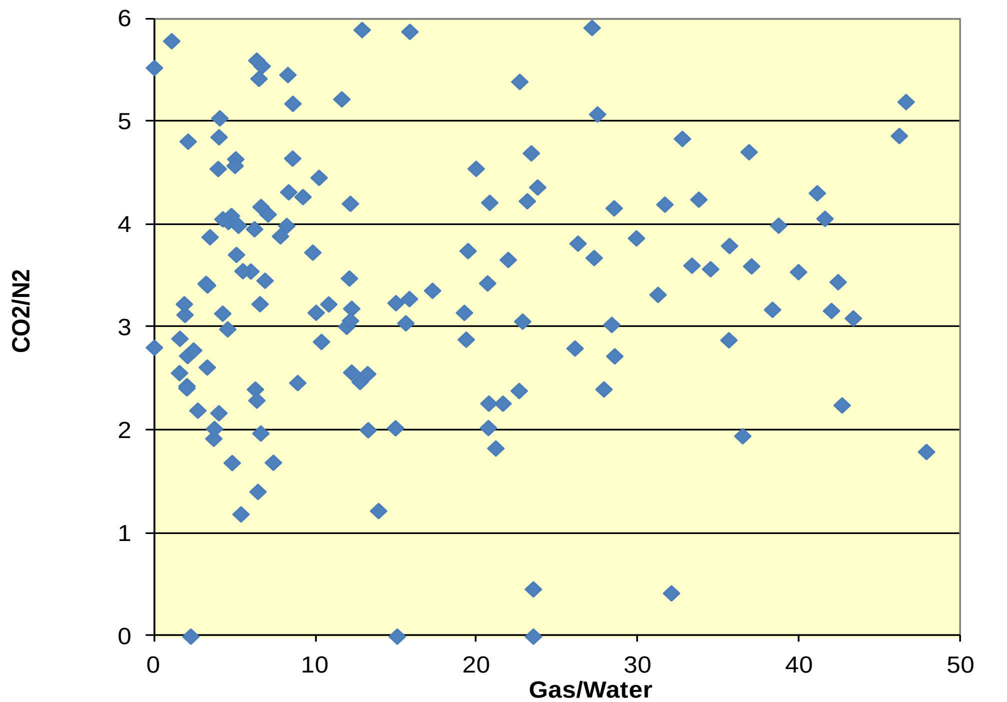


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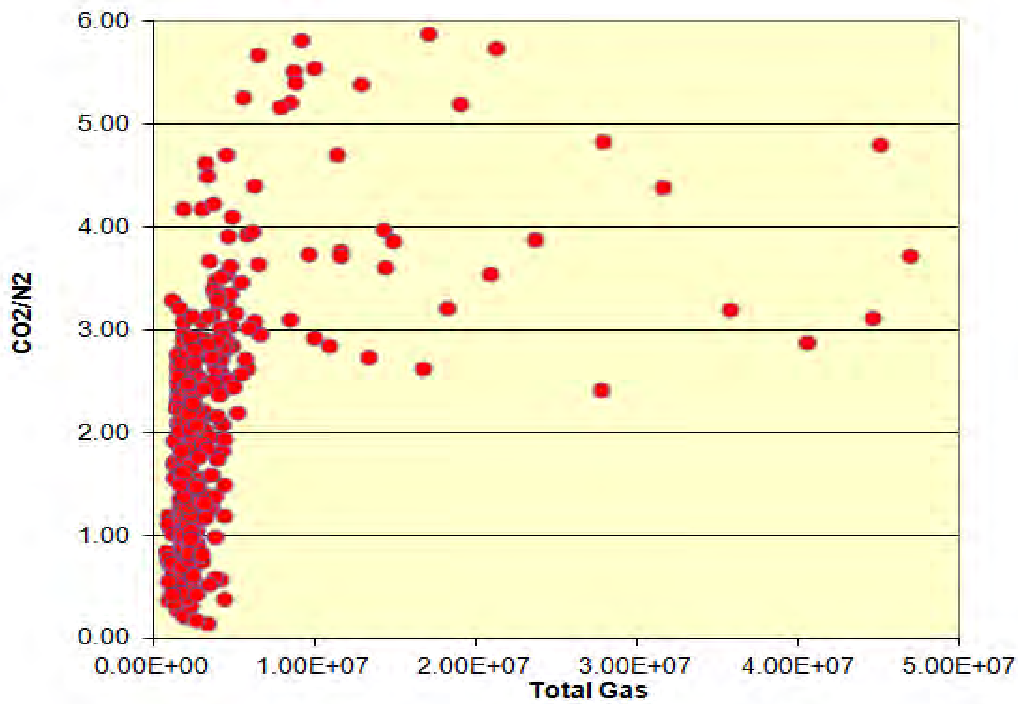
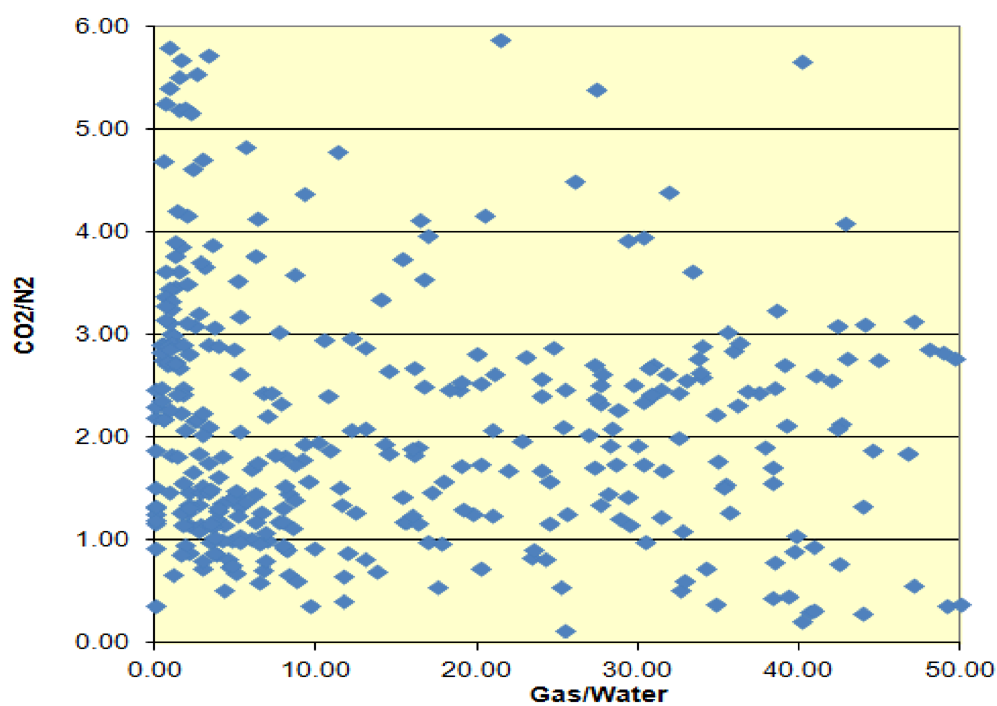
Figure F10

Fallon Well FOH#3





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Fallon FOH#3

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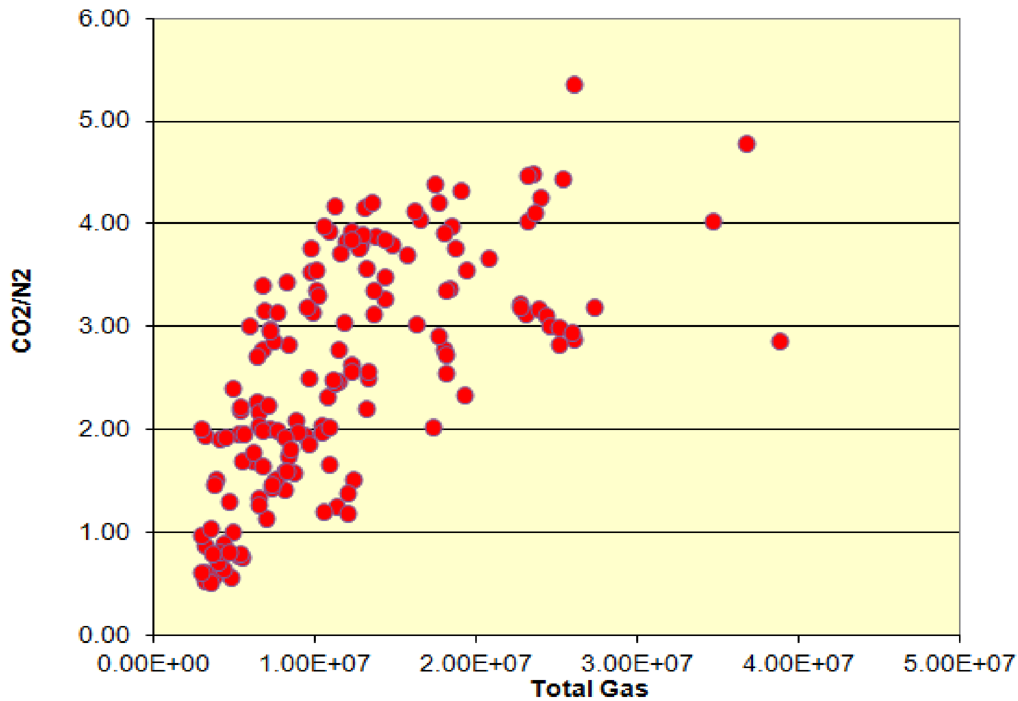
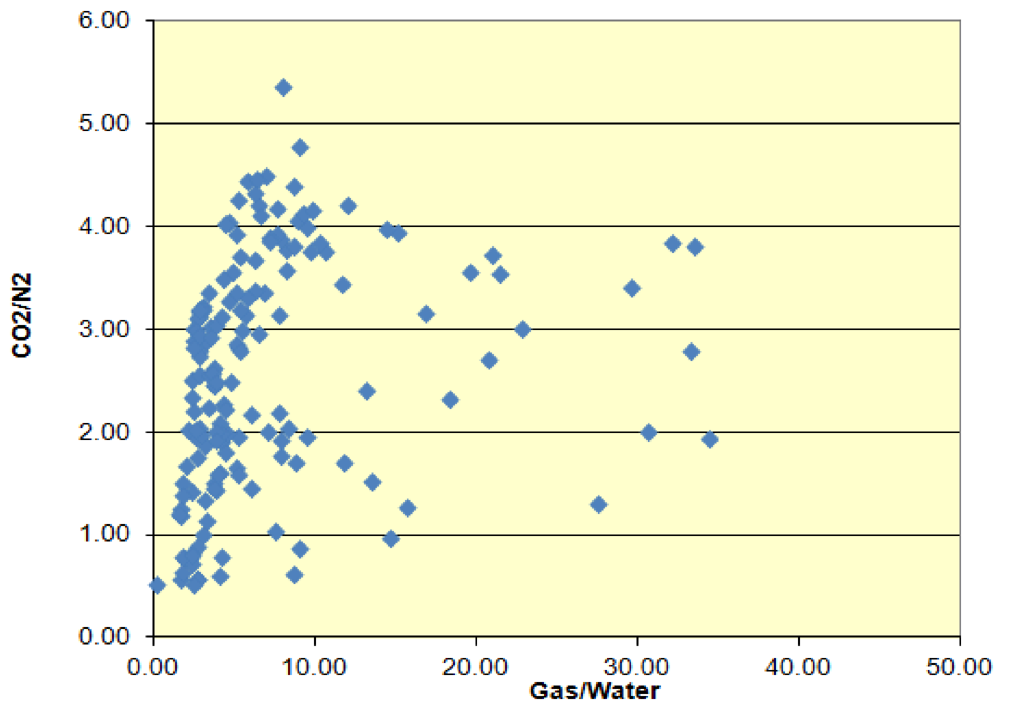
Figure F11

Hawthorne Well HAD#1





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Hawthorne Well HAD#1

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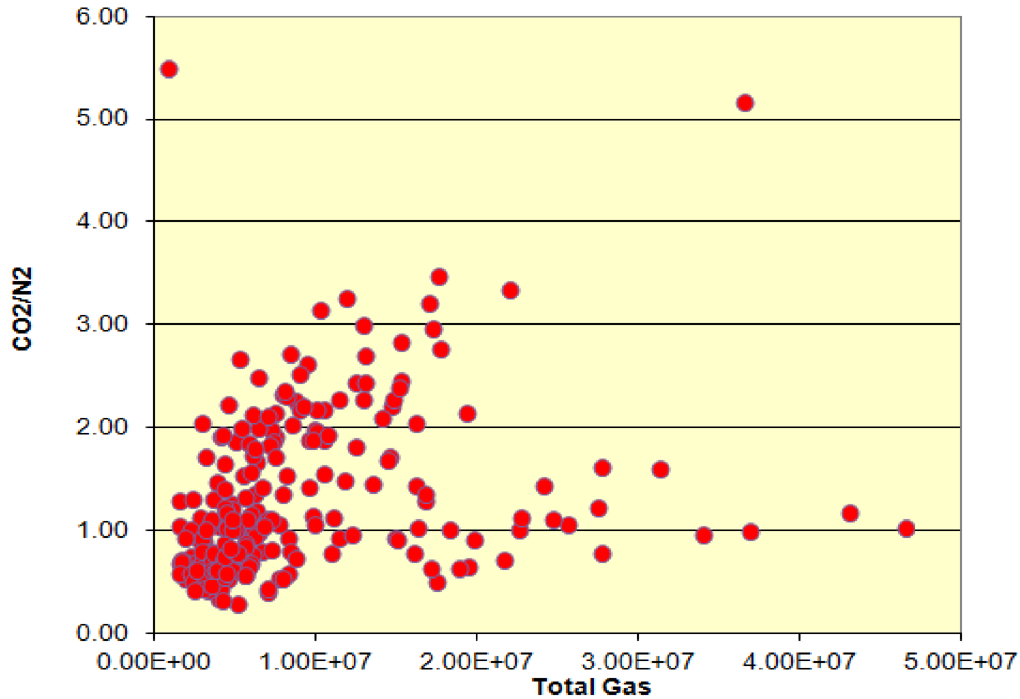
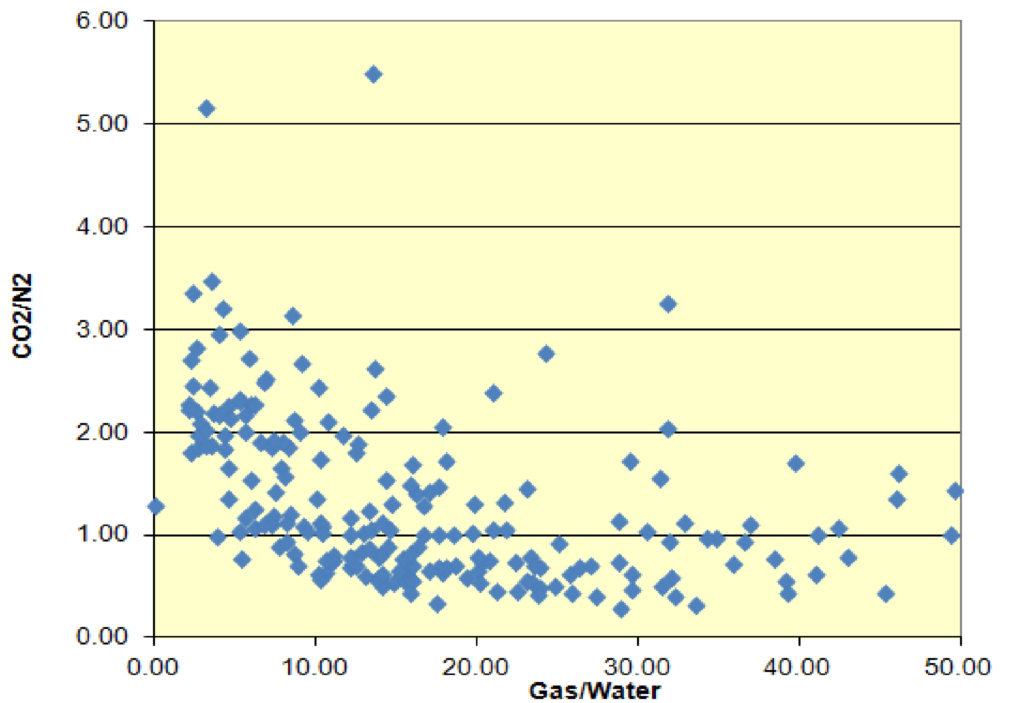
Figure F12

Hawthorne Well HWAAD#2





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Hawthorne Well HWAAD#2
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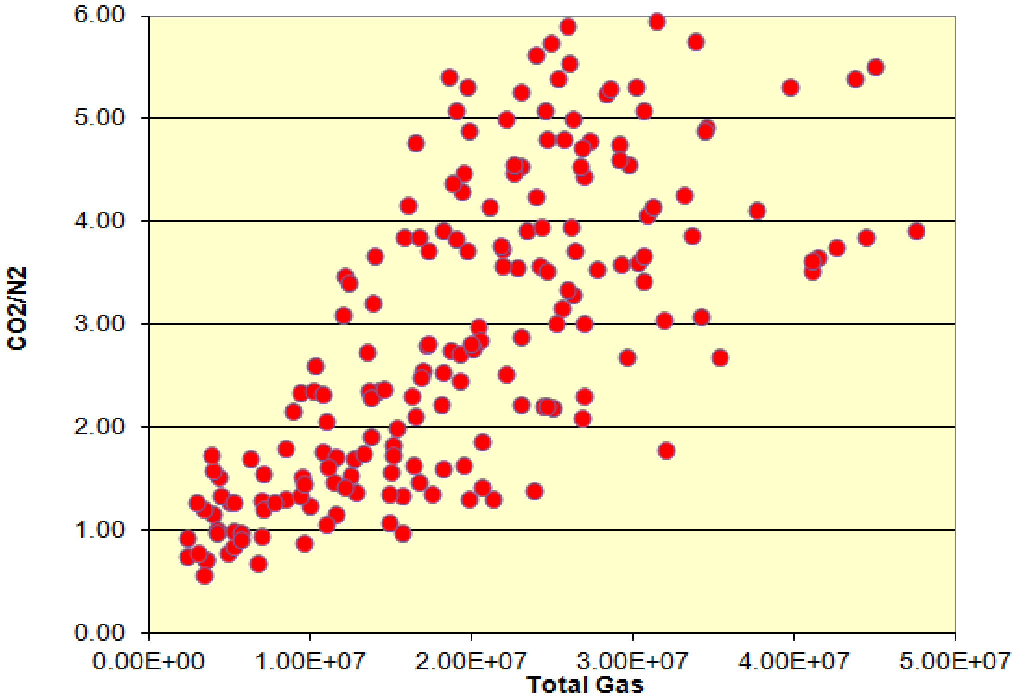
Figure F13

Hawthorne Well HWAAD#3



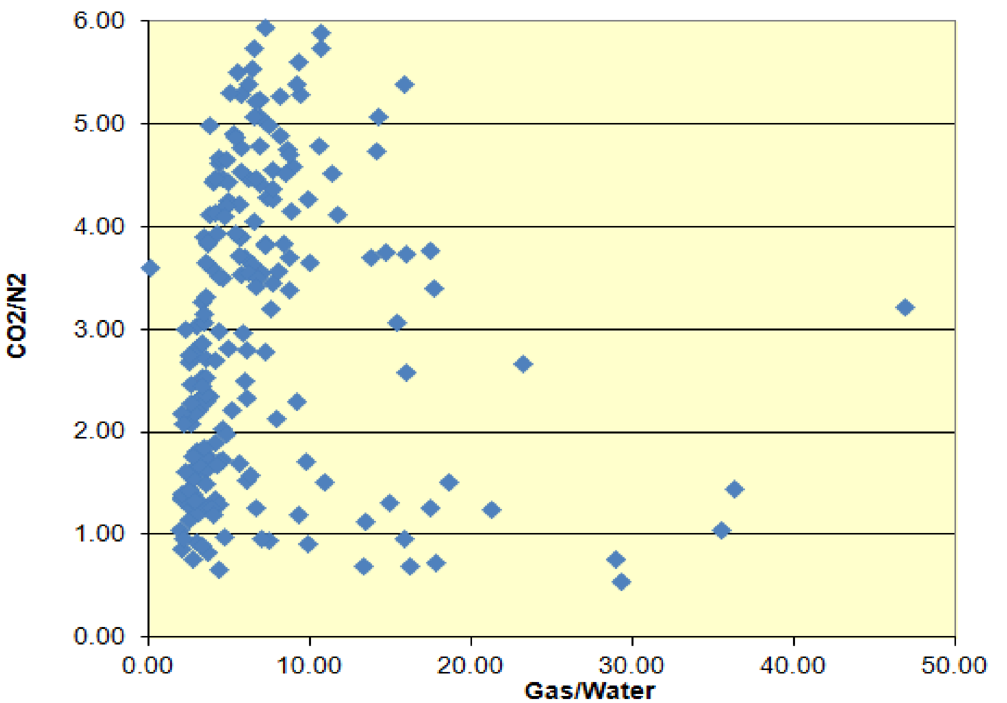


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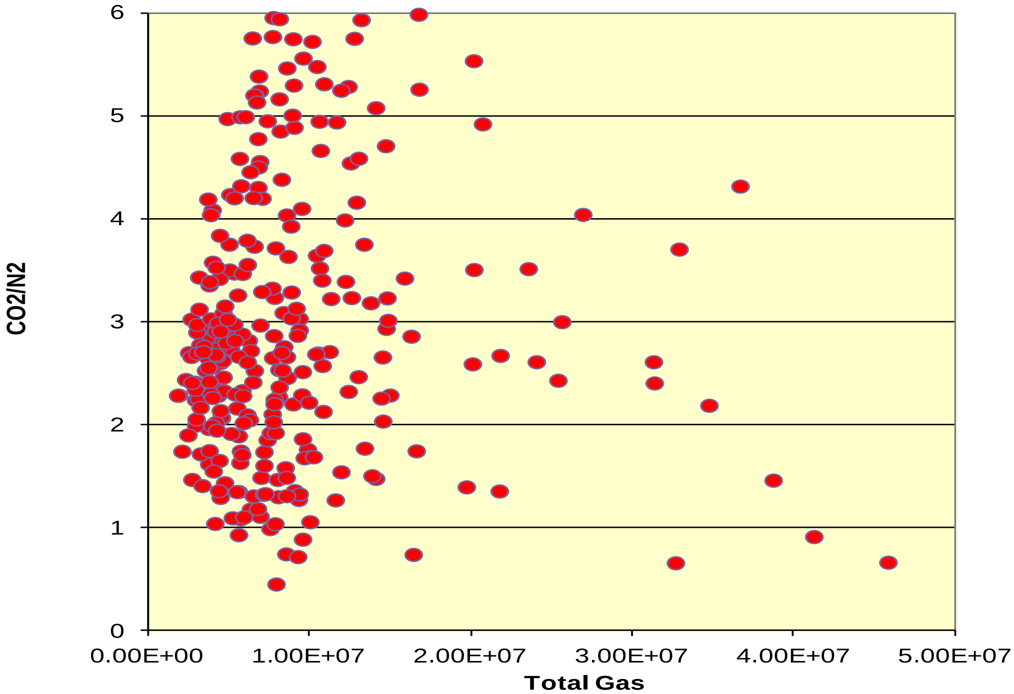
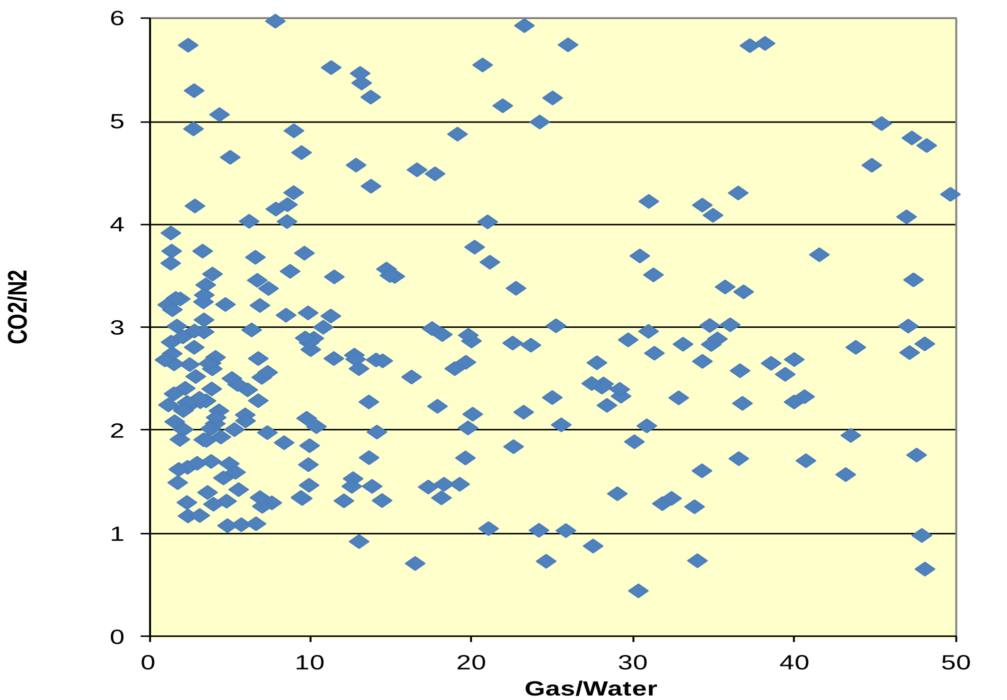
Figure F14

Beowawe Well 57-13





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Beowawe Well 57-13

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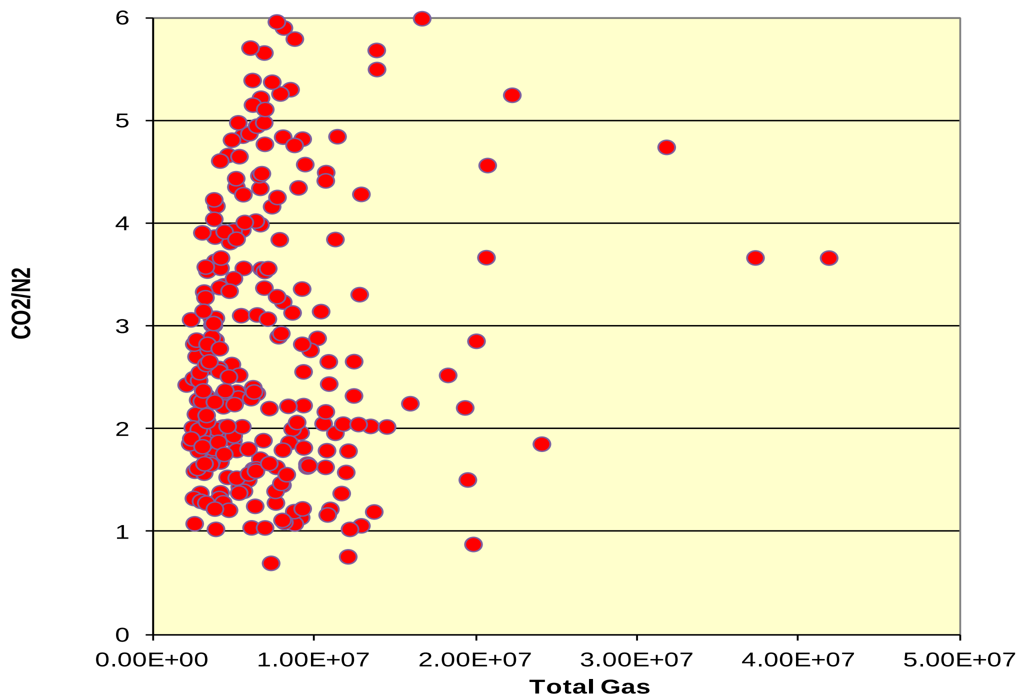
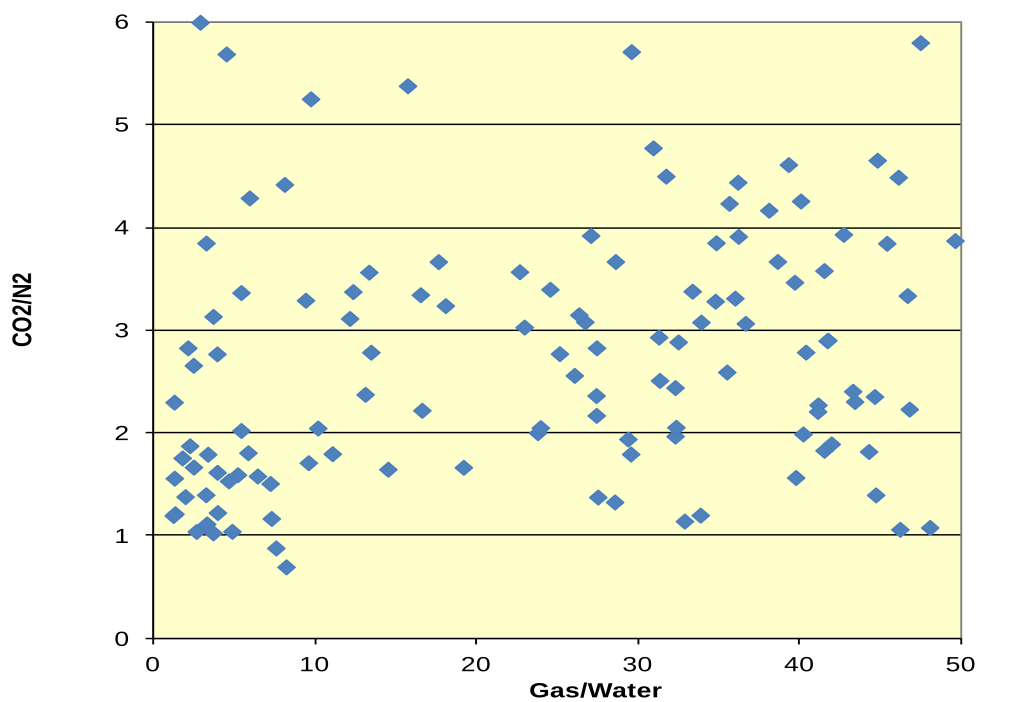
Figure F15

Beowawe Well 77-13





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Beowawe Well 77-13

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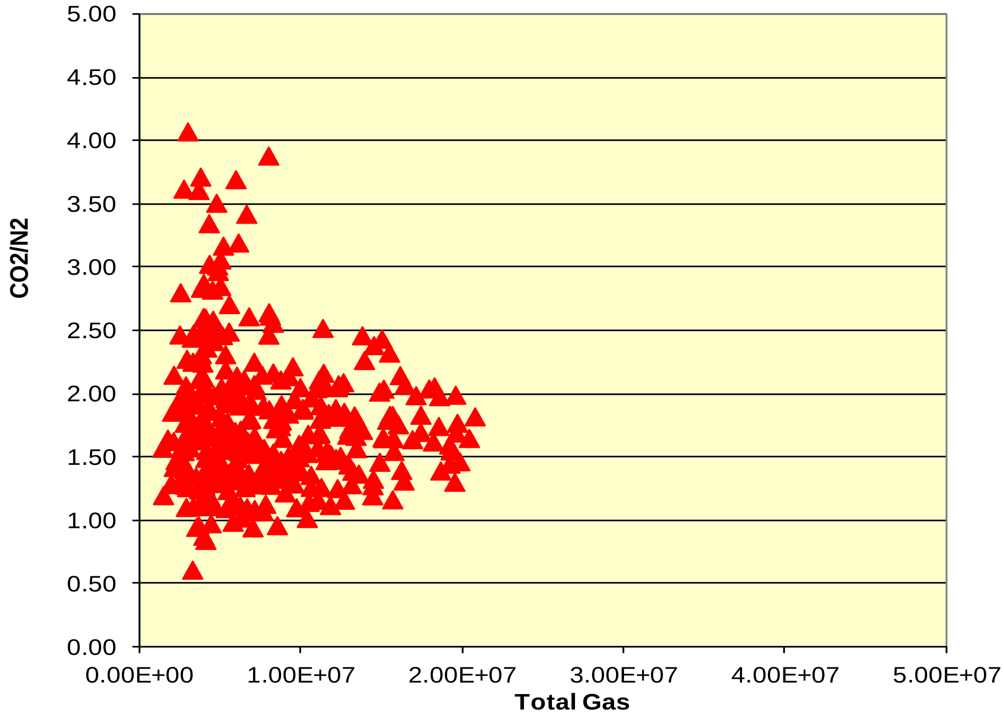
Figure F16

Salton Sea Well Del Ranch



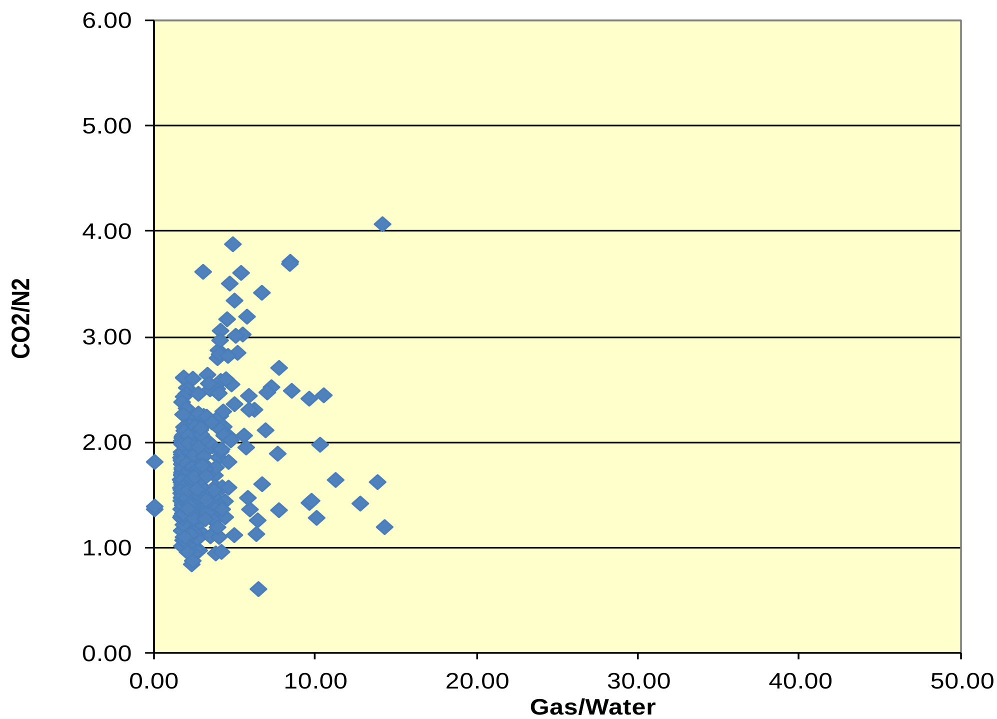


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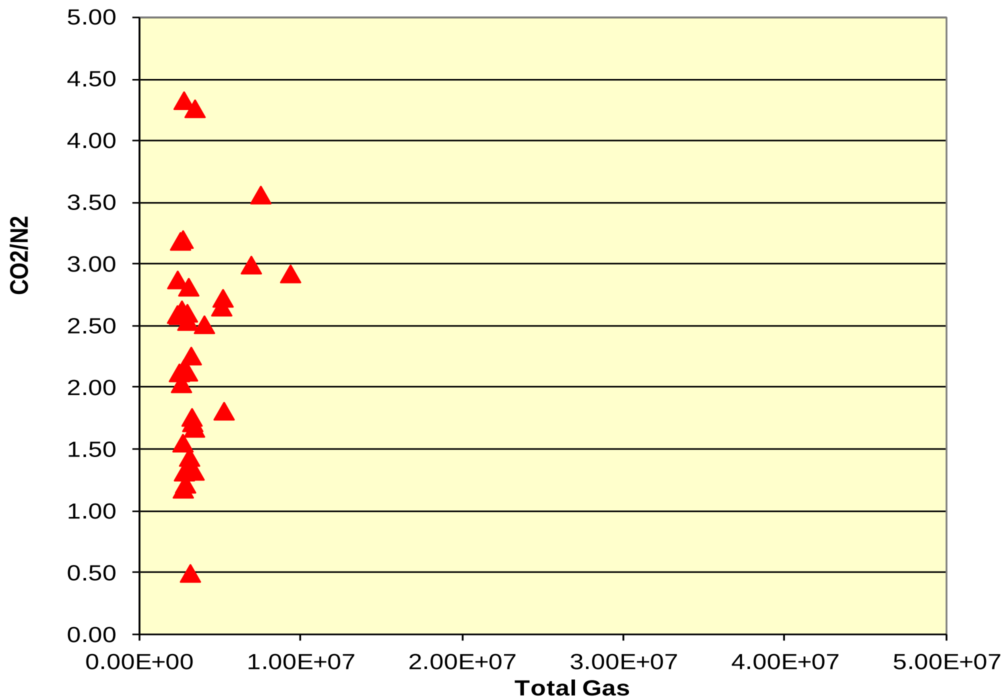
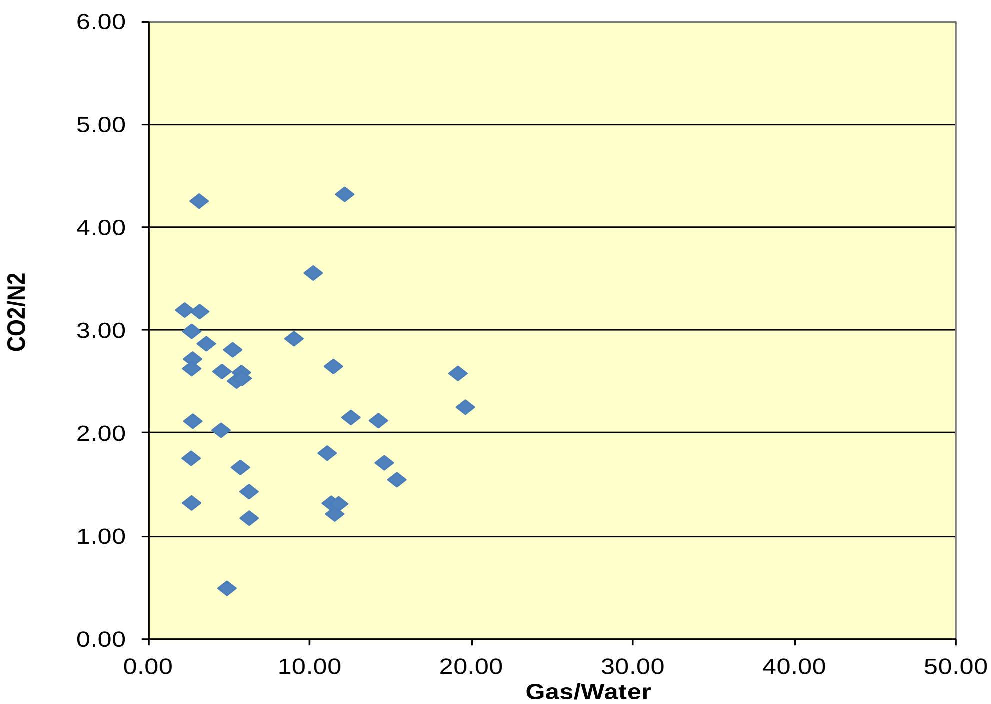
Figure F17

Salton Sea Well Eliw-6





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Salton Sea Well Eliw-6

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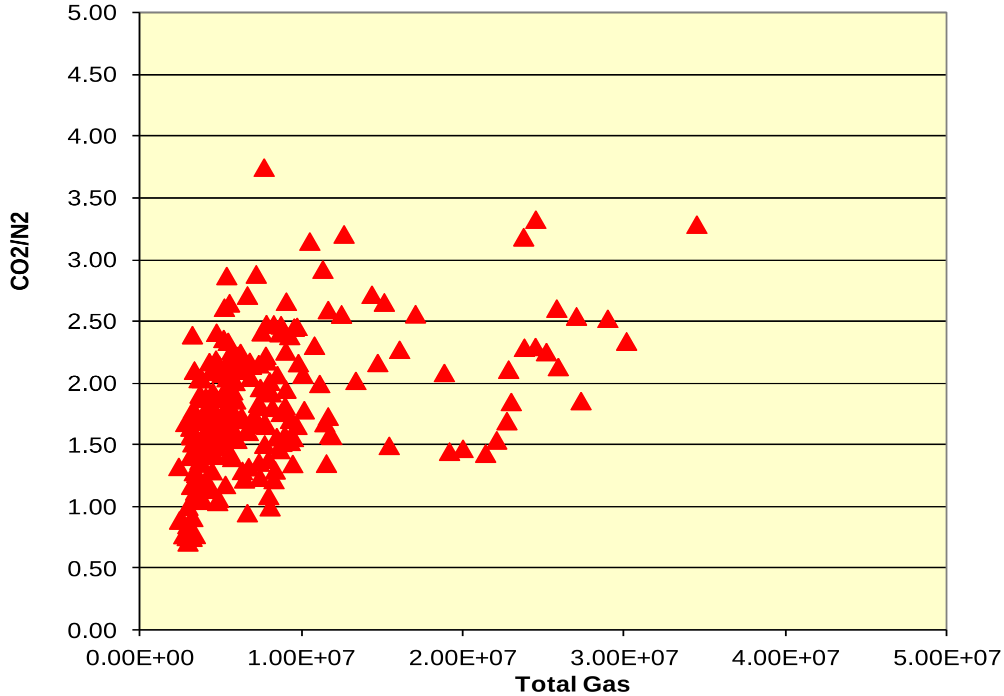
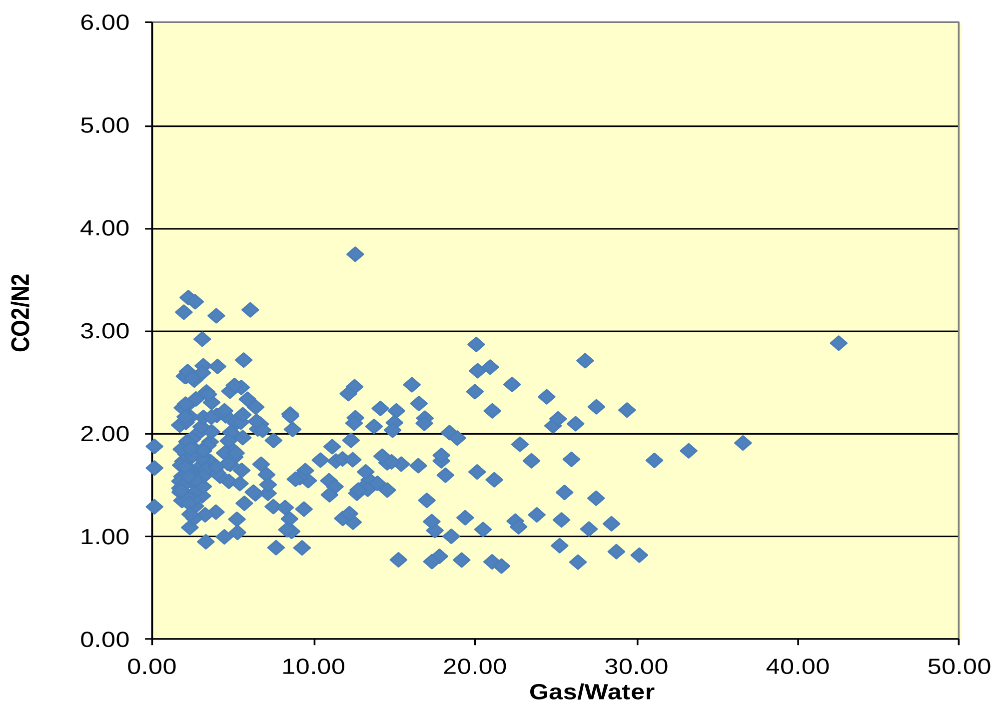
Figure F18

Salton Sea Well Elmore 12





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Salton Sea Well Elmore 12

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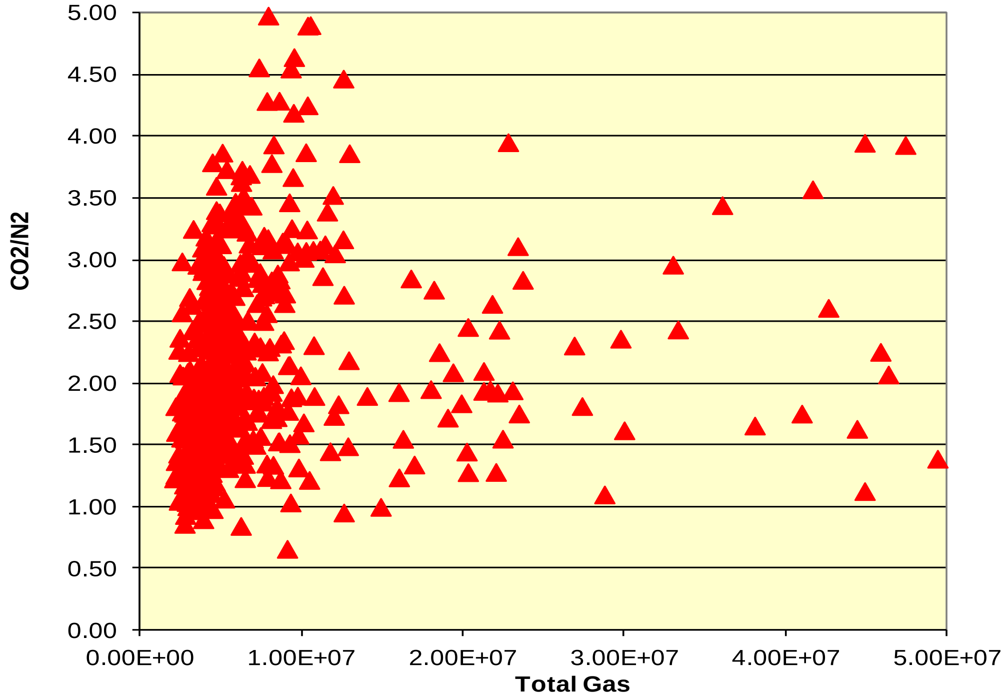
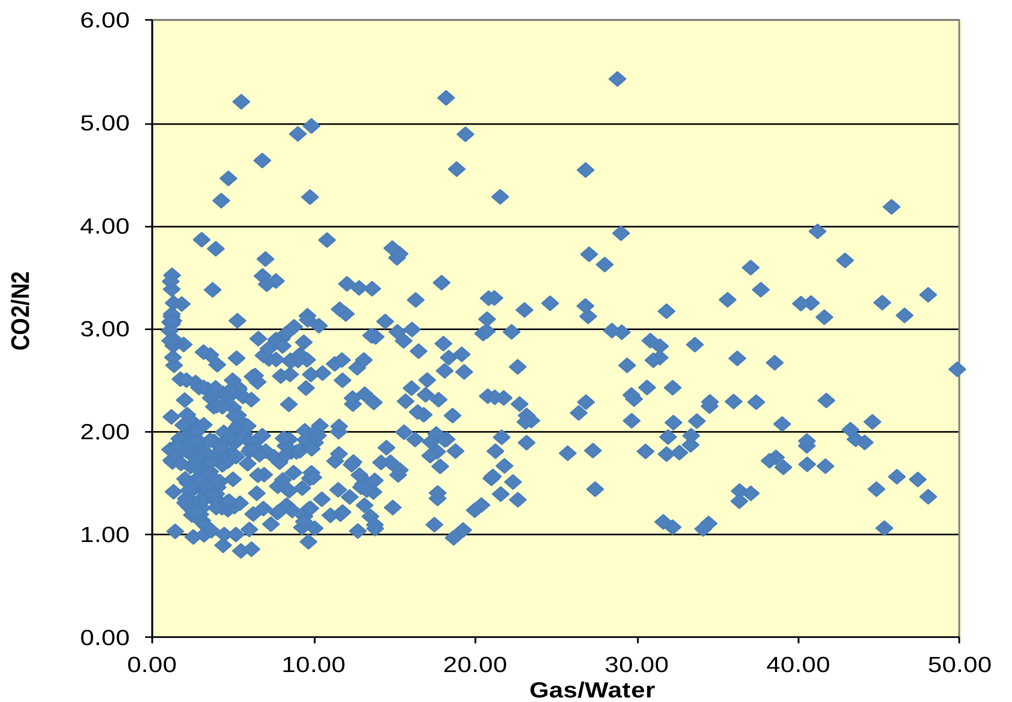
Figure F19

Salton Sea Well Elmore 16





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Salton Sea Well Elmore 16

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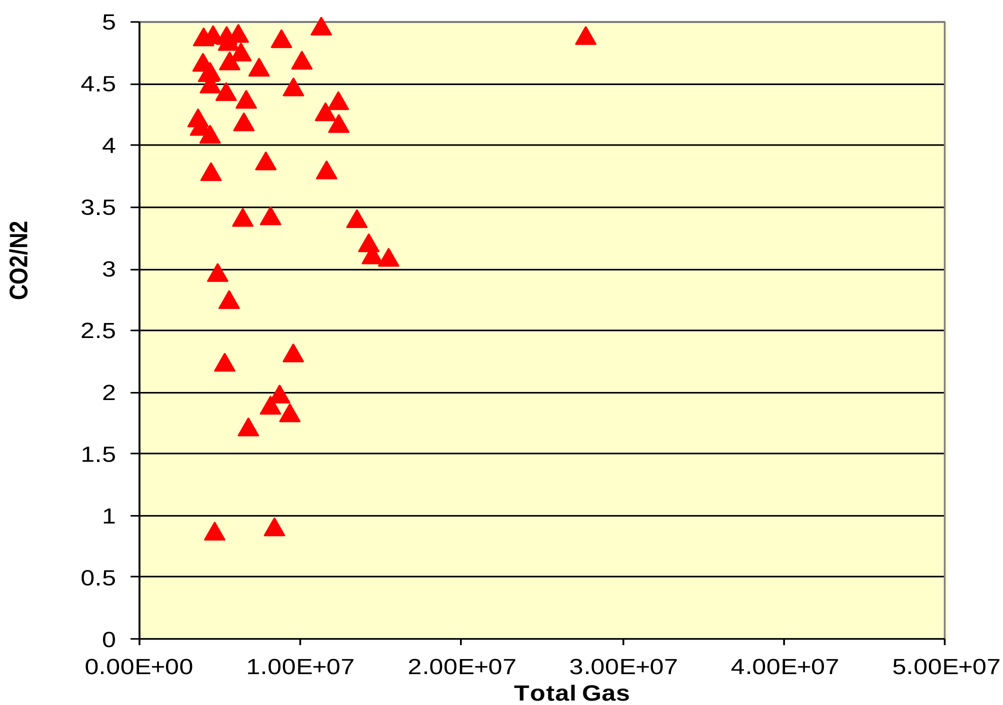
Figure F20

Salton Sea Well River Ranch 4



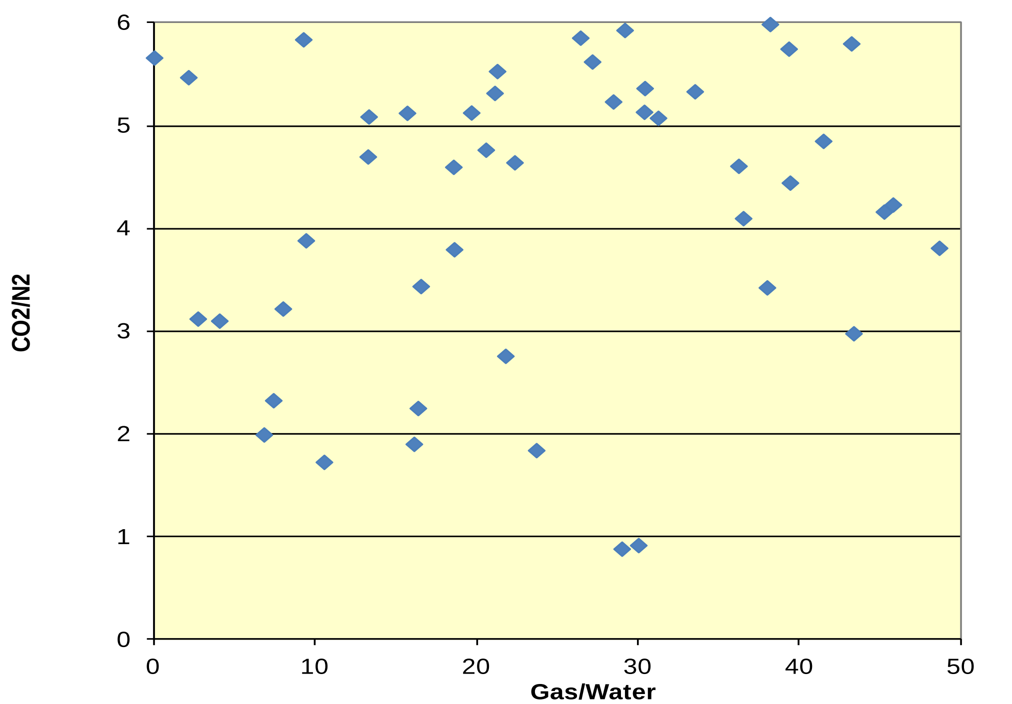


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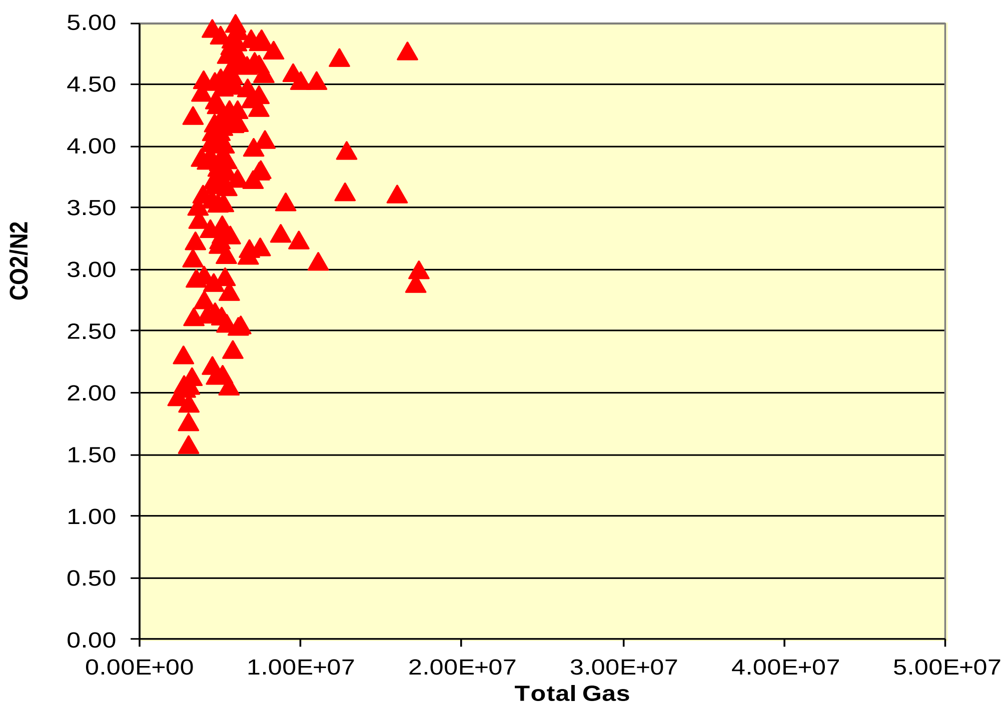
Figure F21

Salton Sea Well River Ranch 5



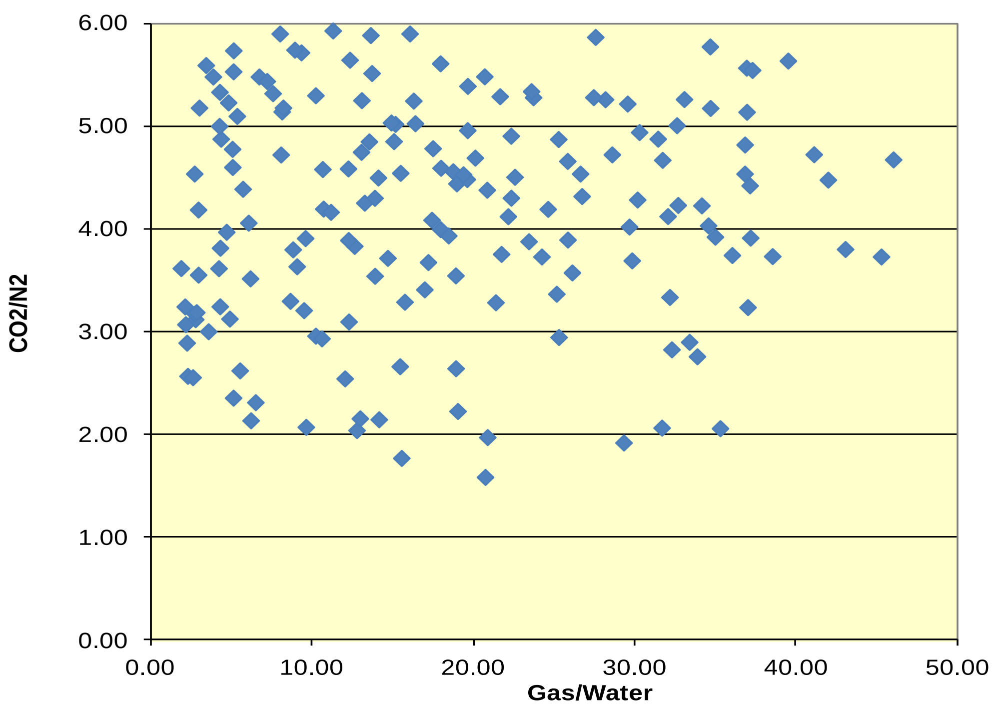


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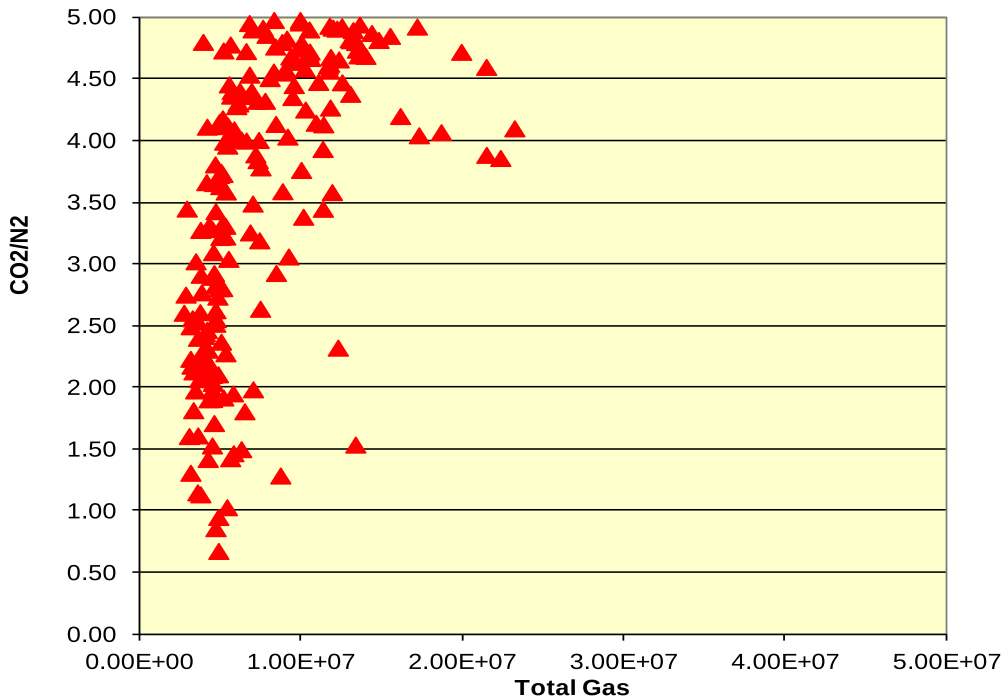
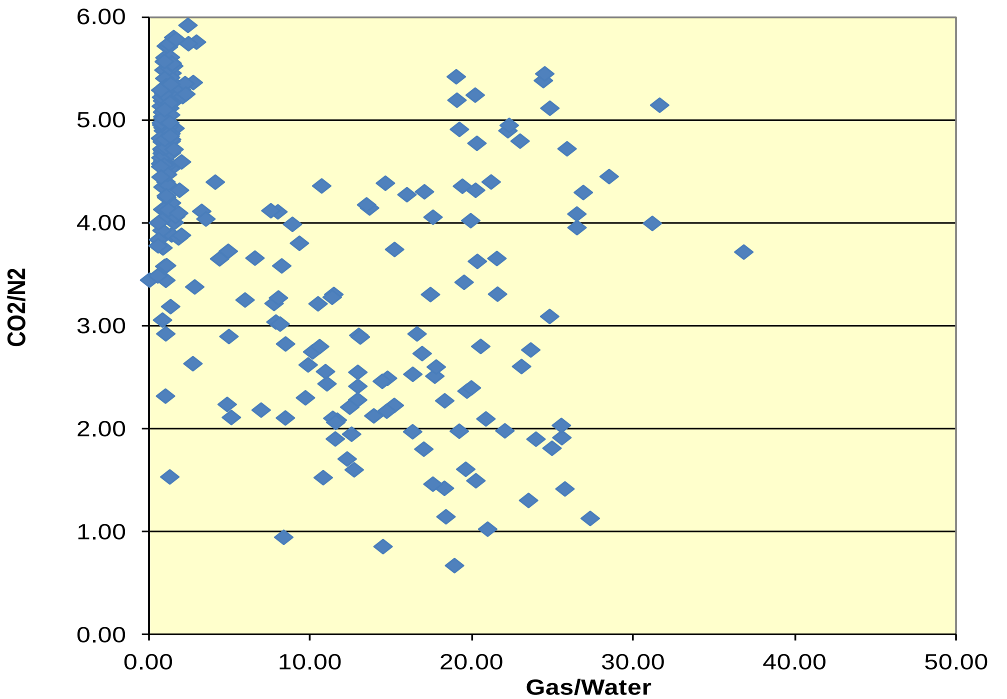
Figure F22

Salton Sea Well Sinclair 24





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Salton Sea Well Sinclair 24
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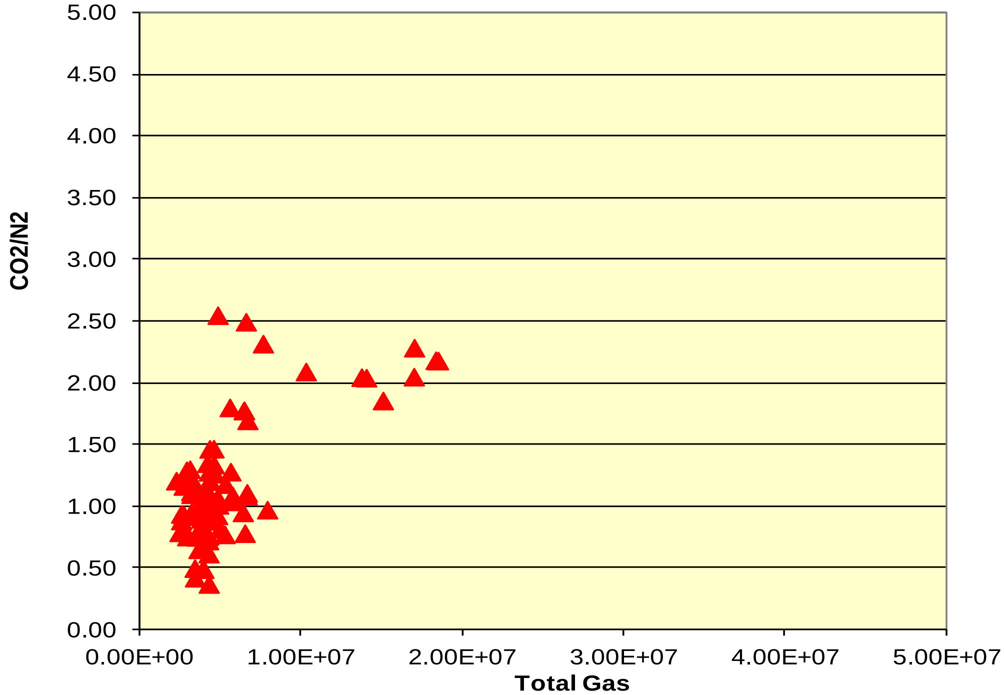
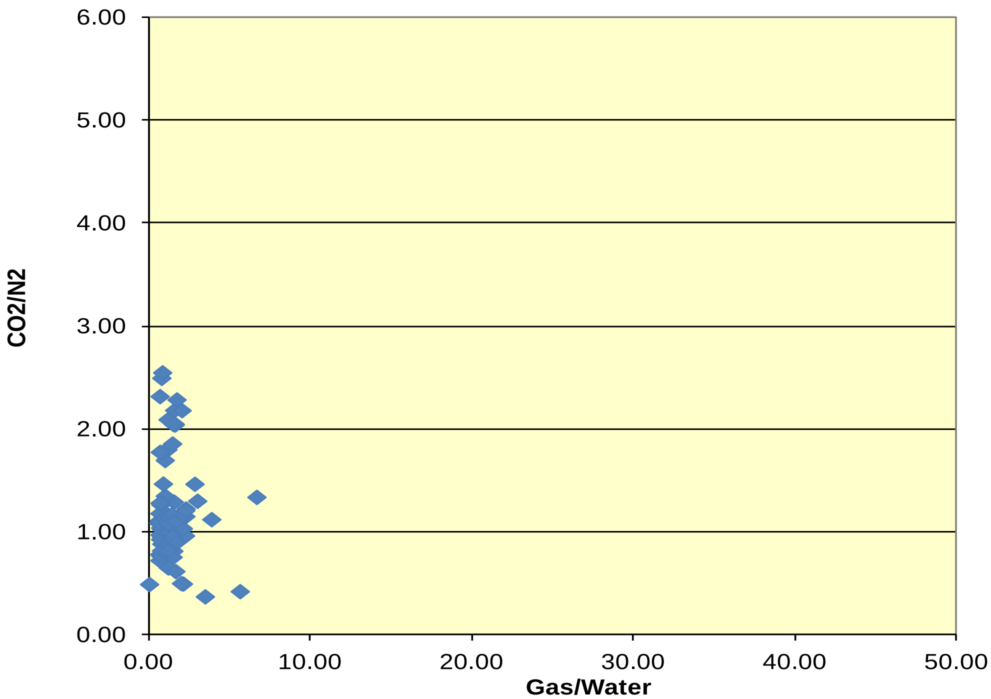
Figure F23

Salton Sea Well Vulcan





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Salton Sea Well Vulcan

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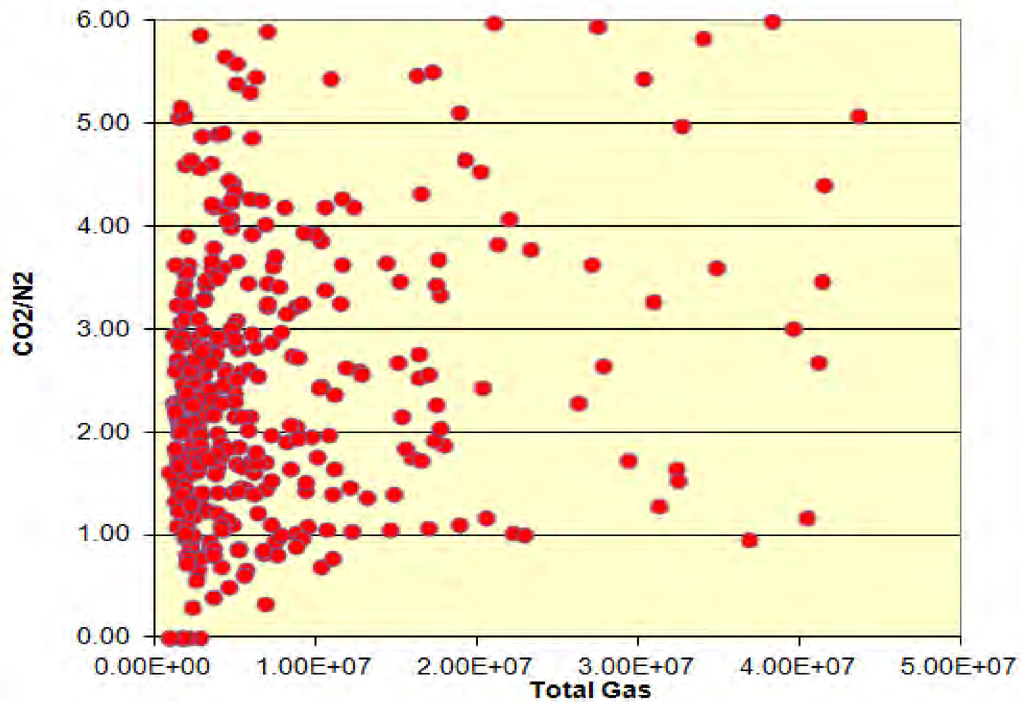
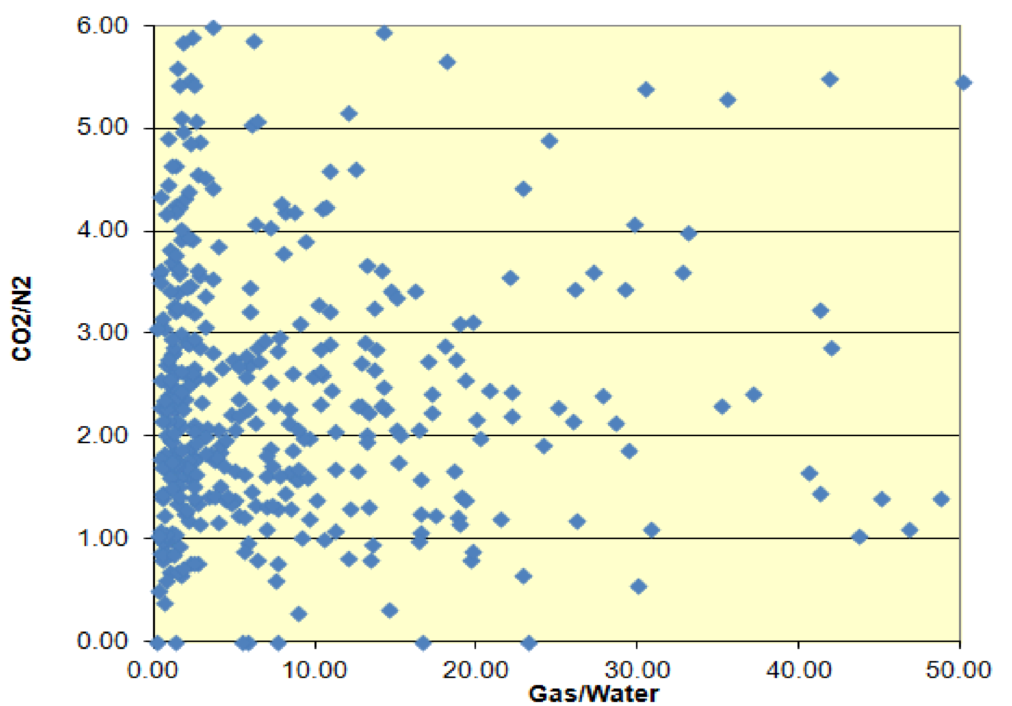
Figure F24

Kahara Well K33





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Kahara Well K33

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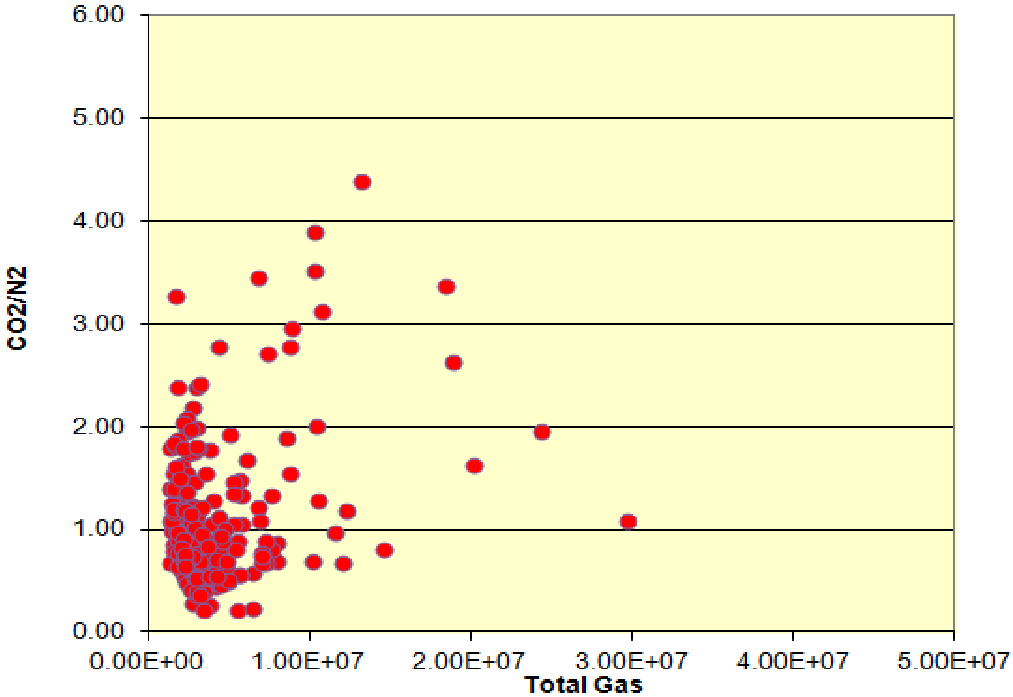
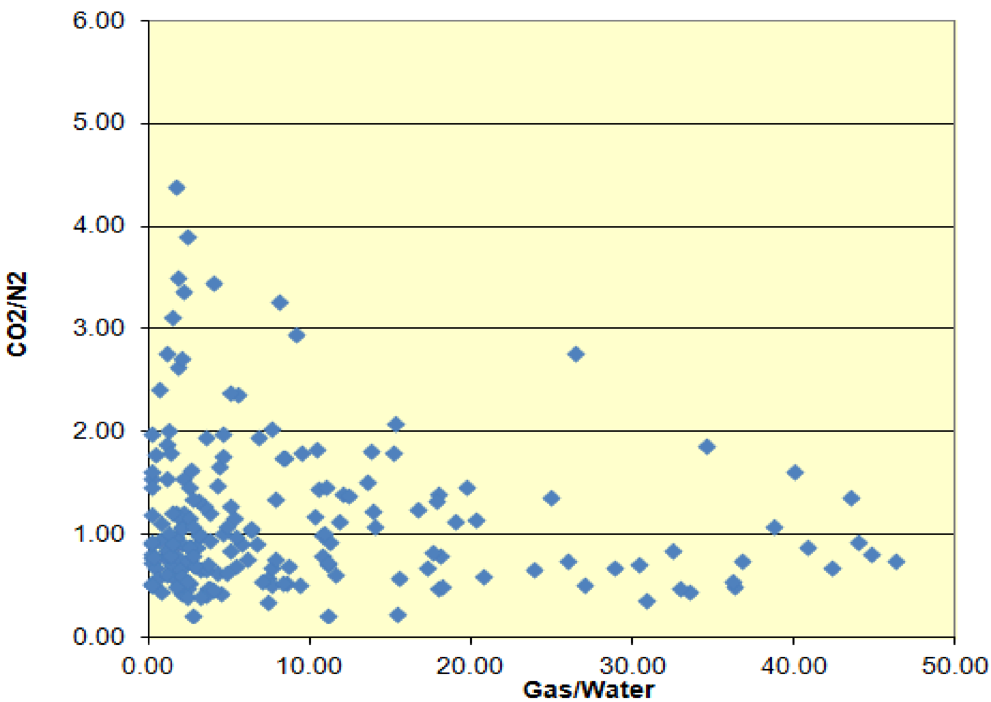
Figure F25

Kahara Well T2





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Kahara Well T2

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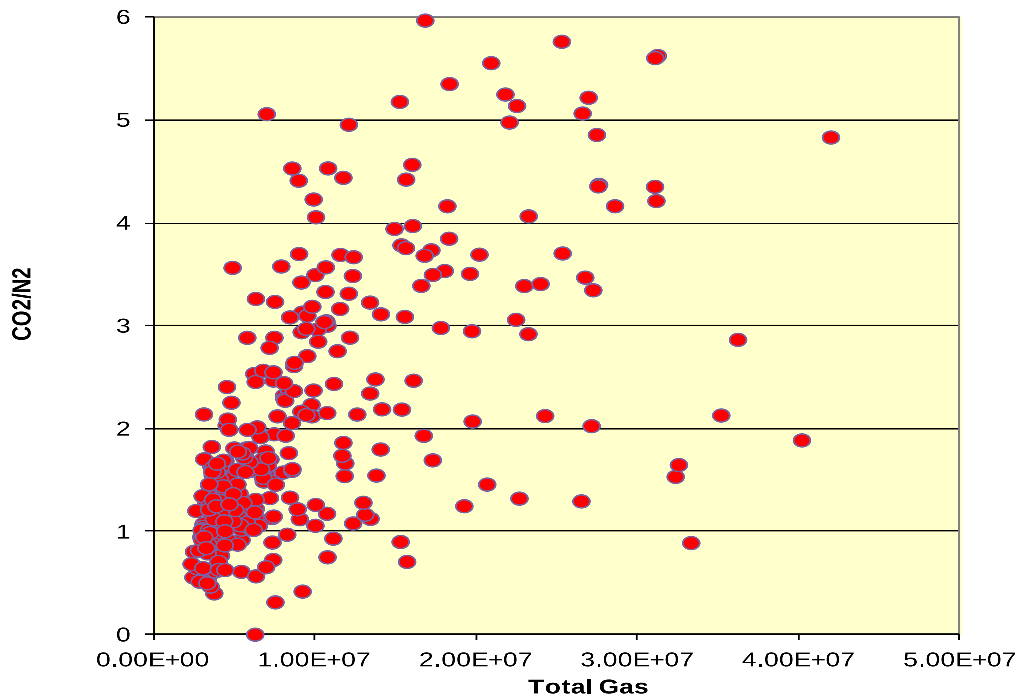
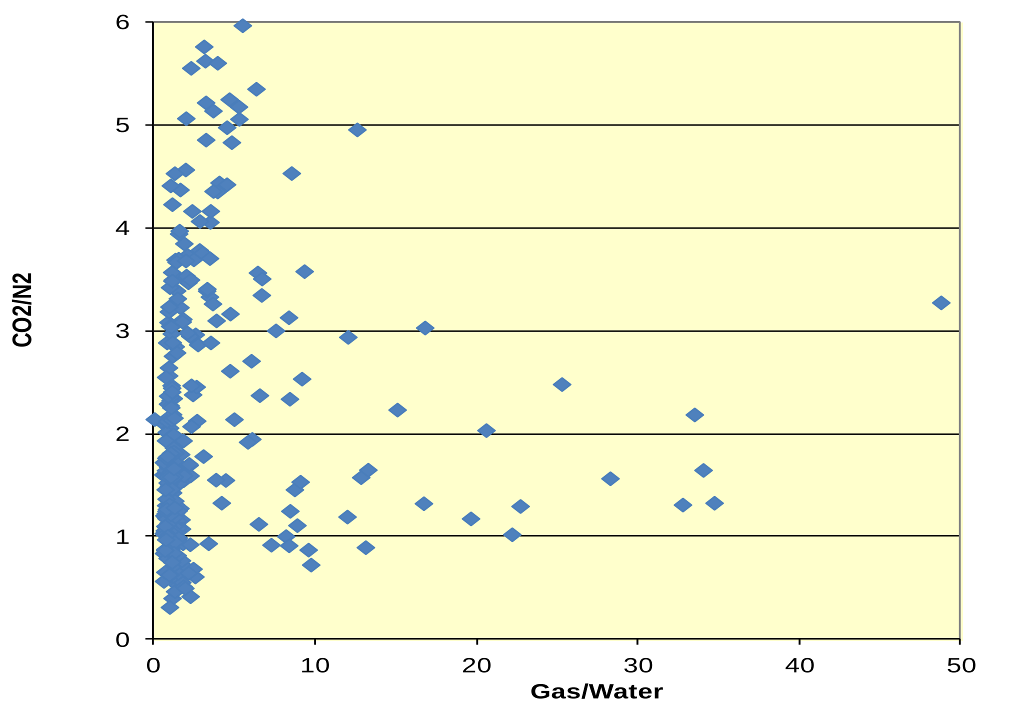
Figure F26

Coso Well 15A-17





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Coso Well 15A-17
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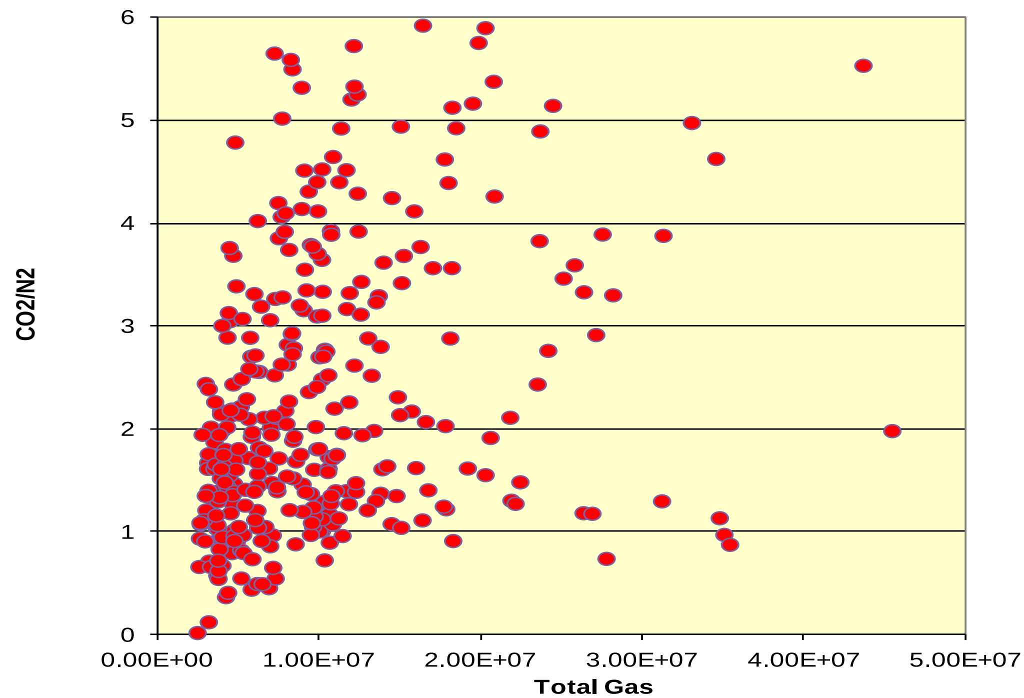
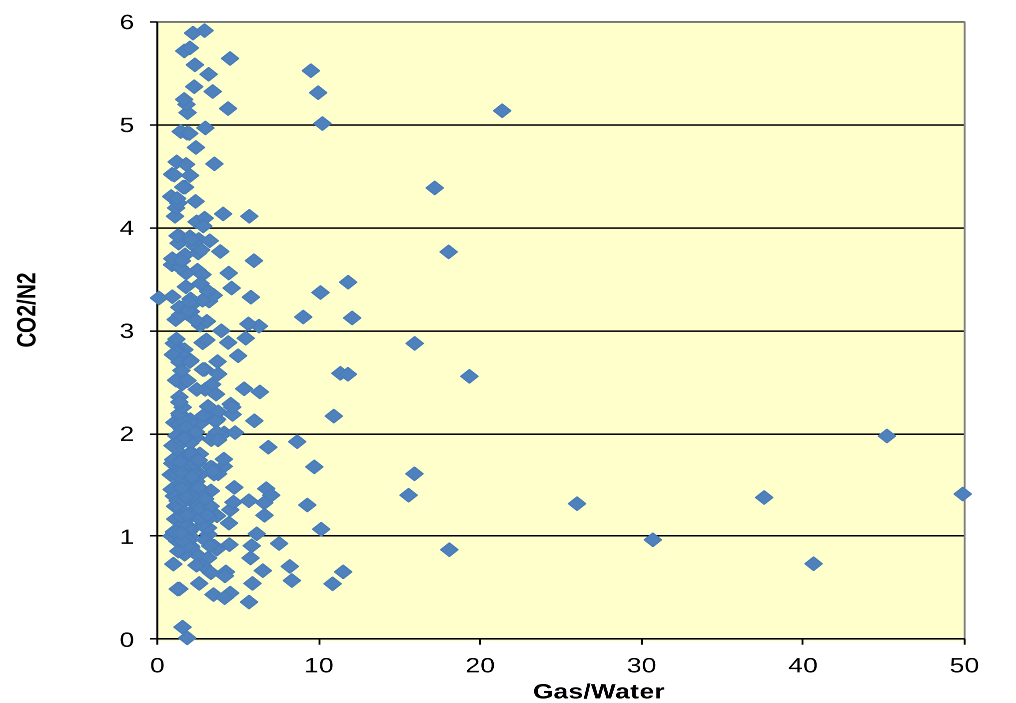
Figure F27

Coso Well 23A-17





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Coso Well 23A-17

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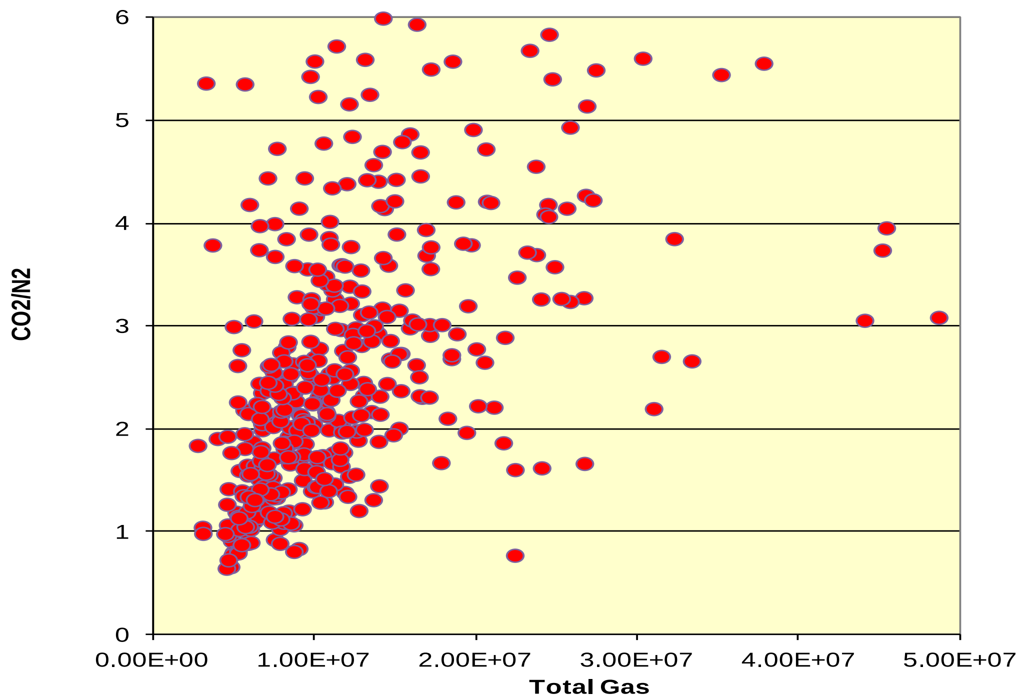
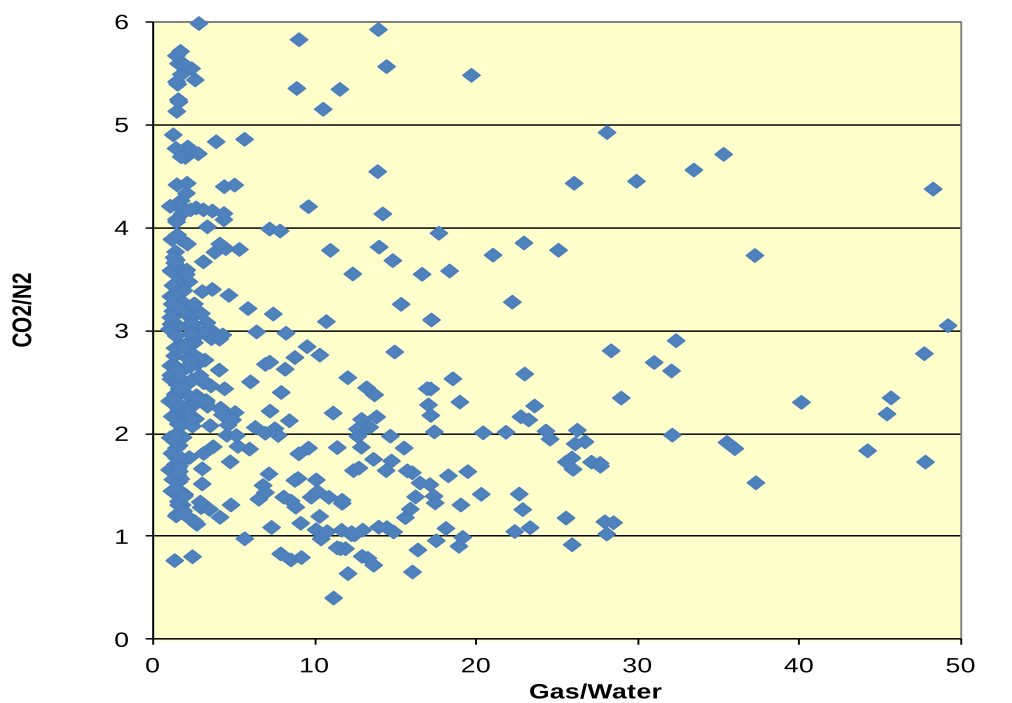
Figure F28

Coso Well 23A-19





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Coso Well 23A-19

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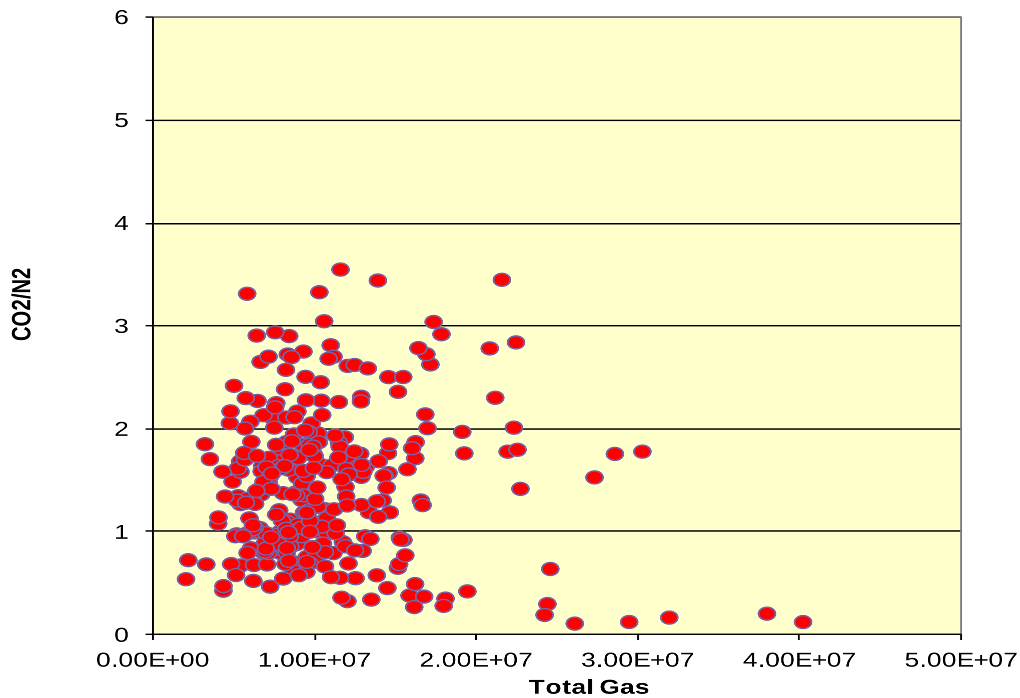
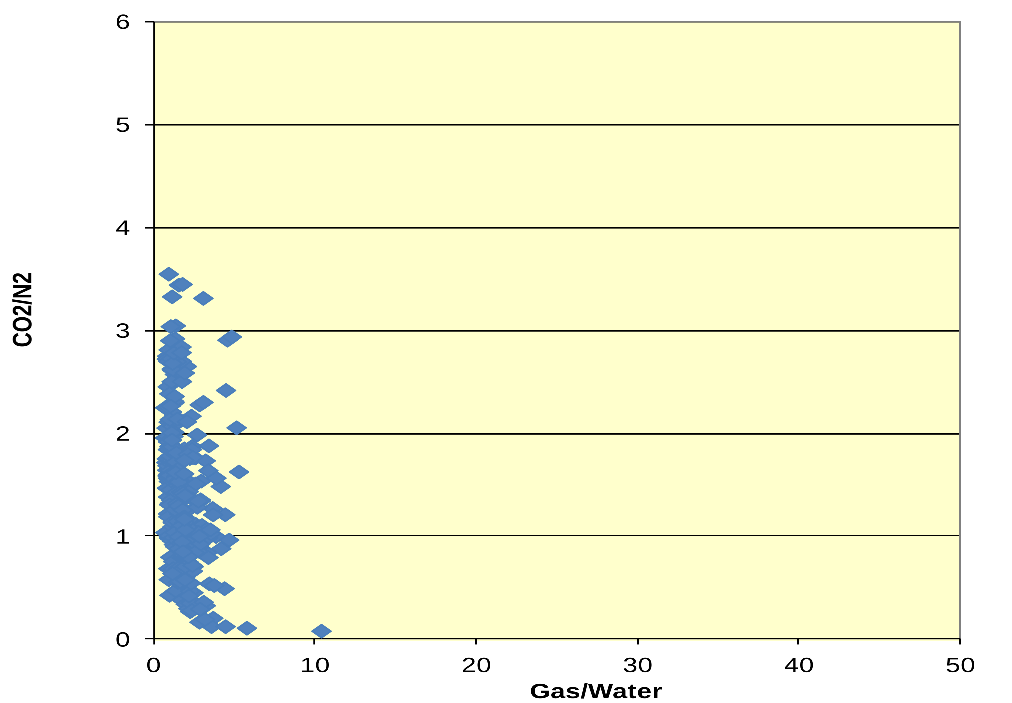
Figure F29

Coso Well 24A-8





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Coso Well 24A-8

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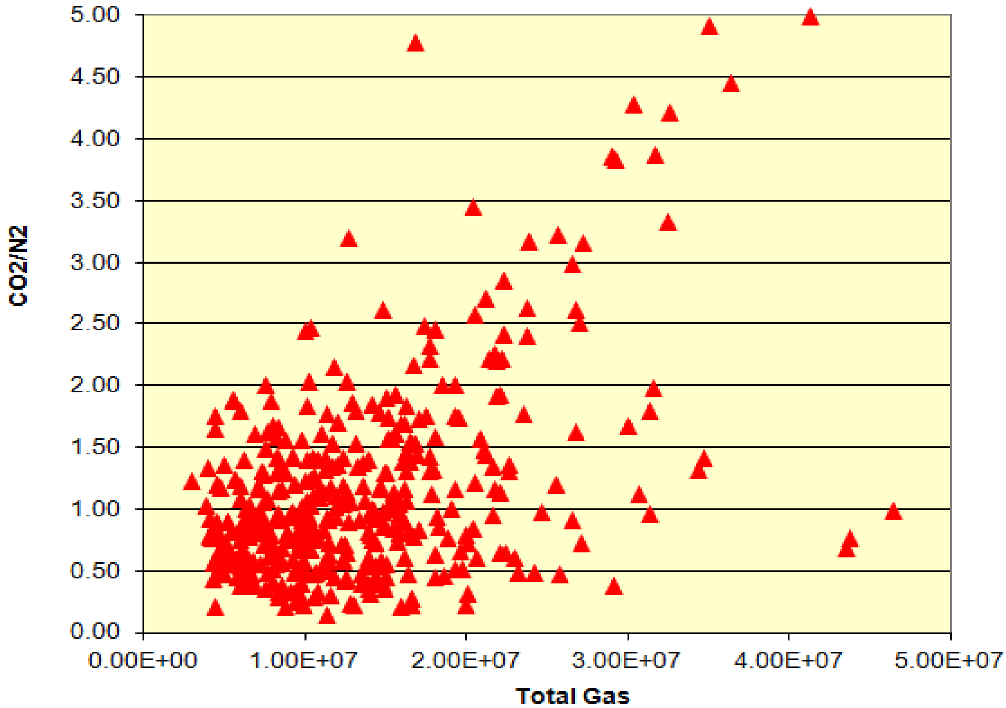
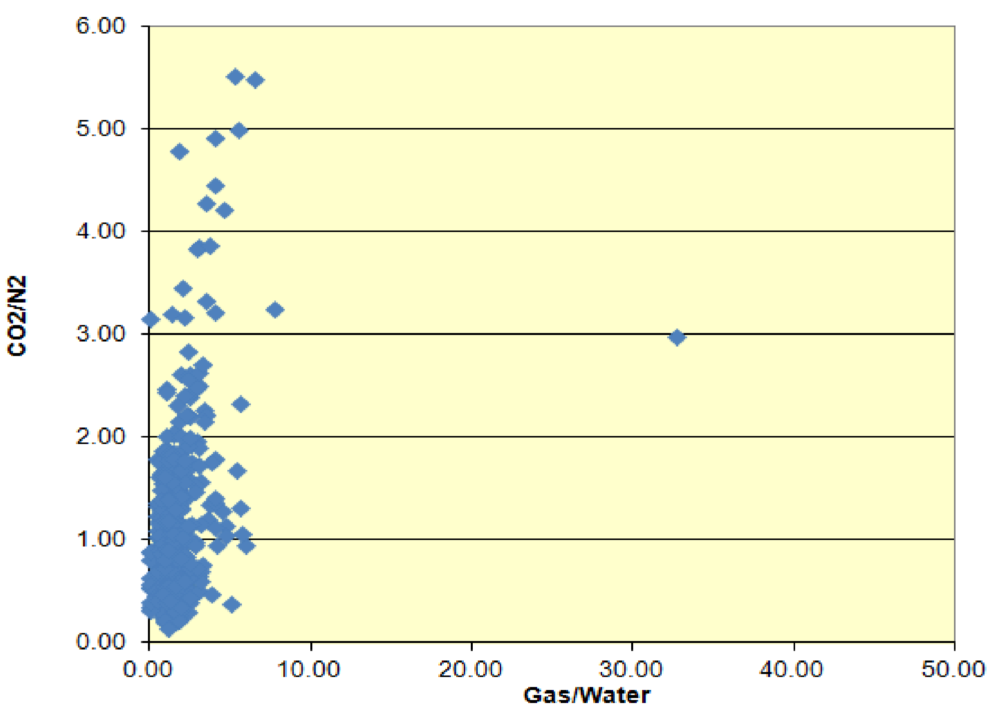
Figure F30

Coso Well 33-7





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Coso Well 33-7

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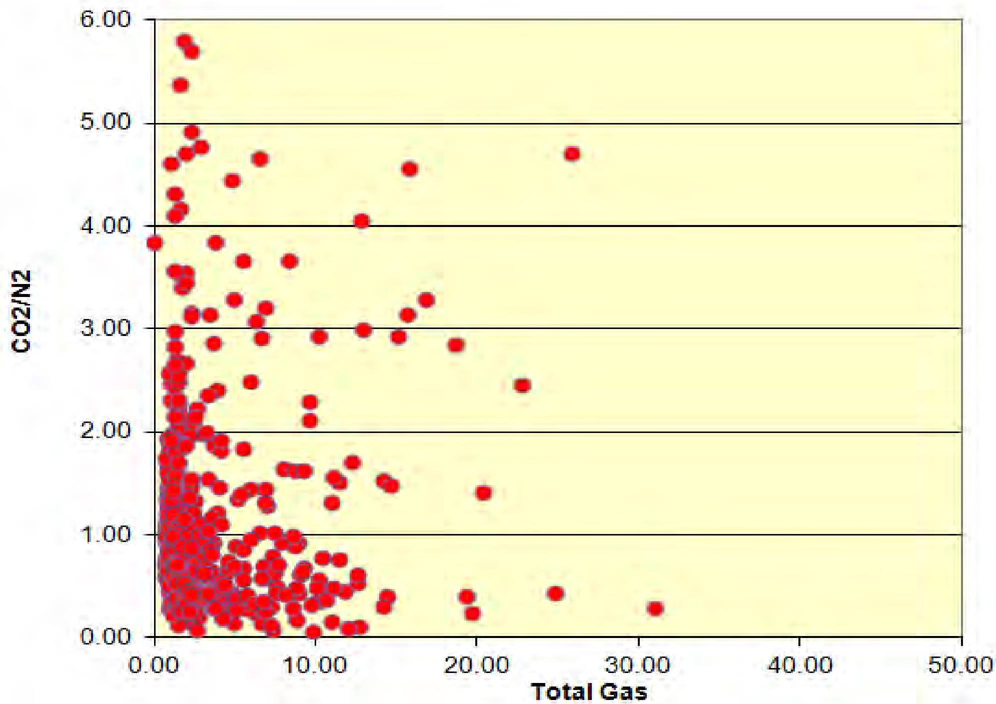
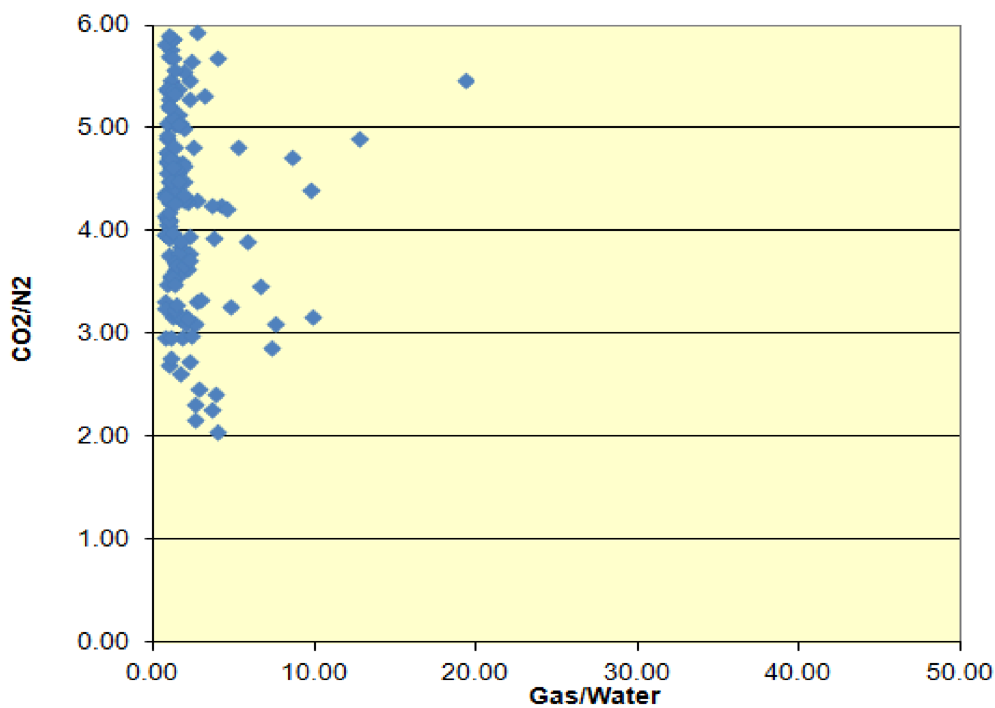
Figure F31

Coso Well 38C-9





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Coso Well 38C-9

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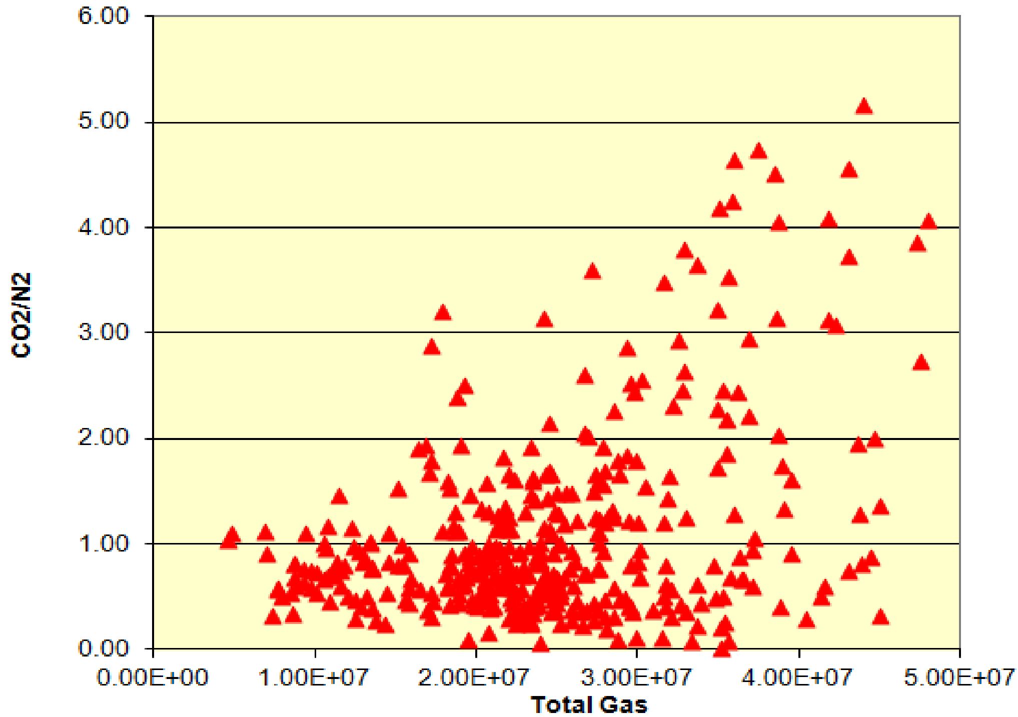
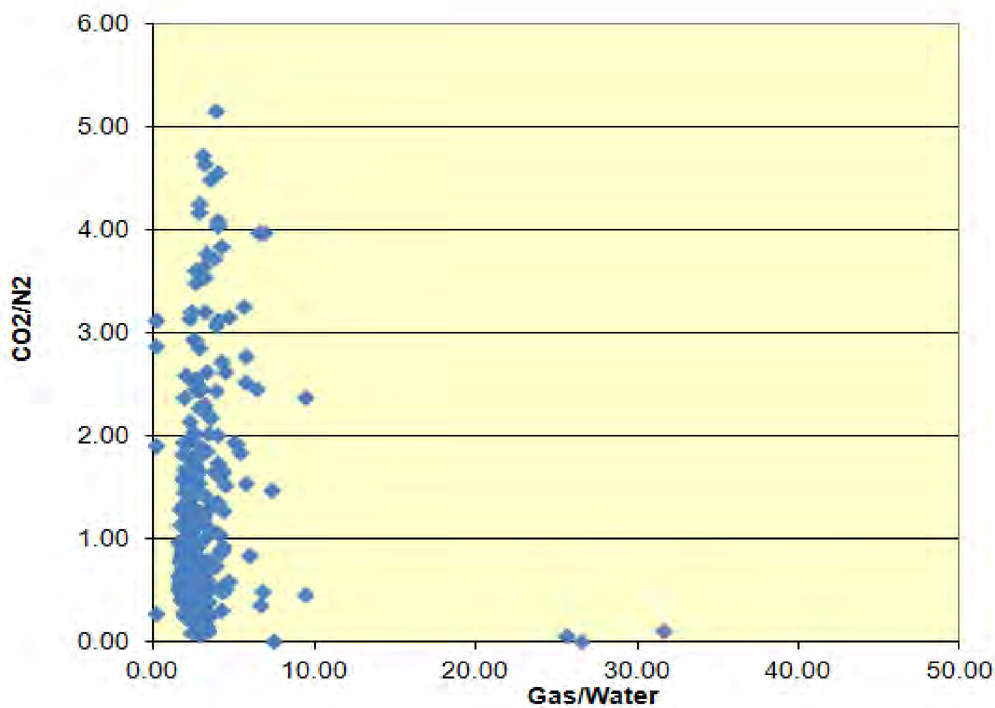
Figure F32

Coso Well 38D-9





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Coso Well 38D-9
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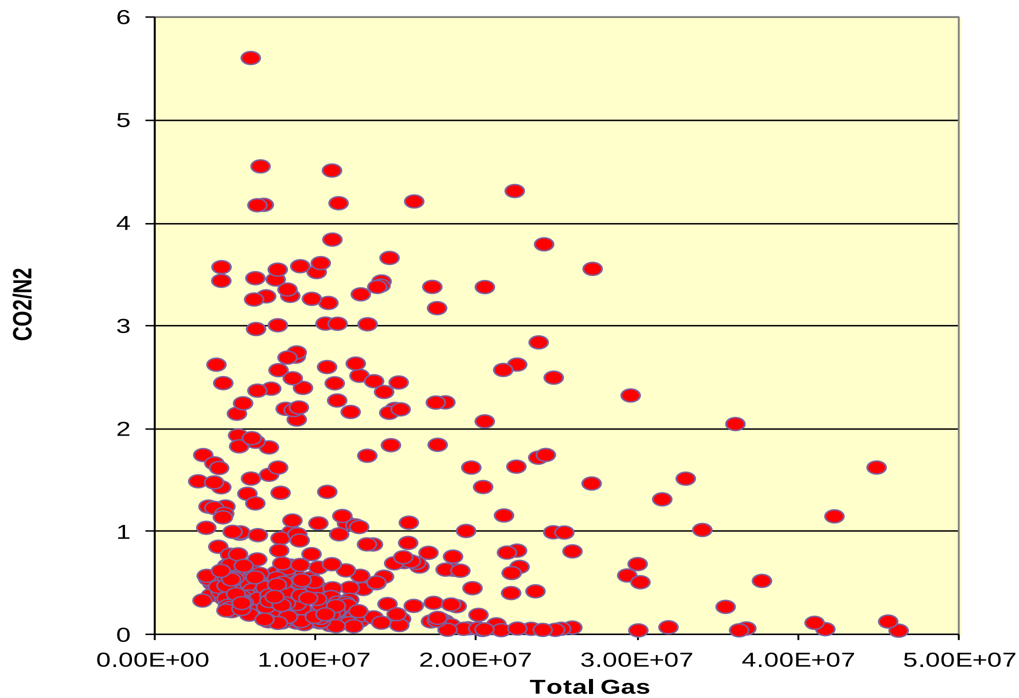
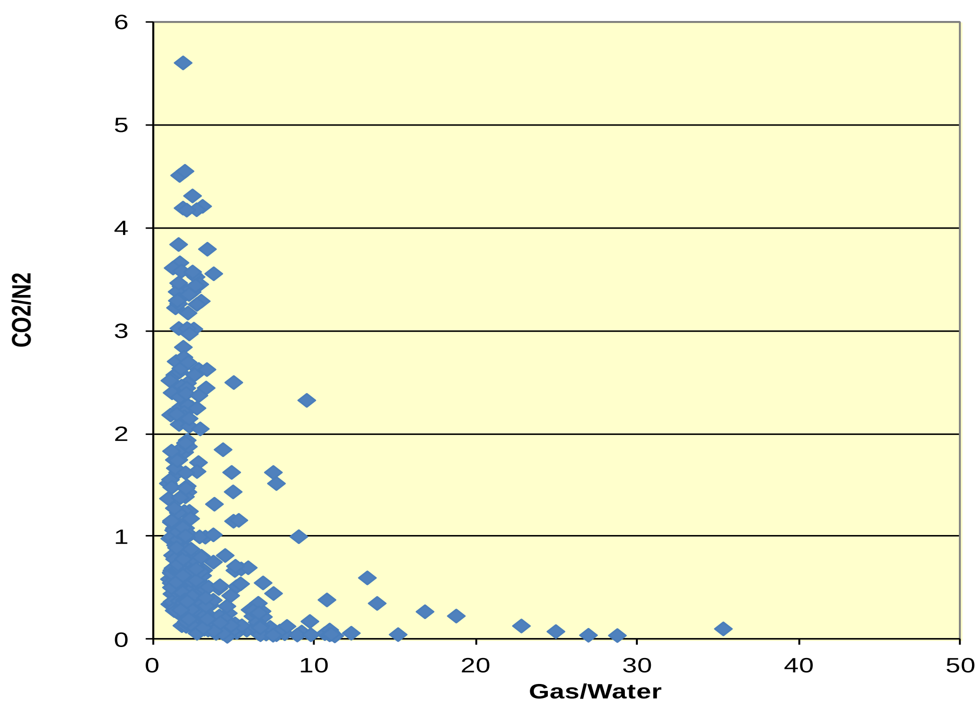
Figure F33

Coso Well 41B-8





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Coso Well 41B-8
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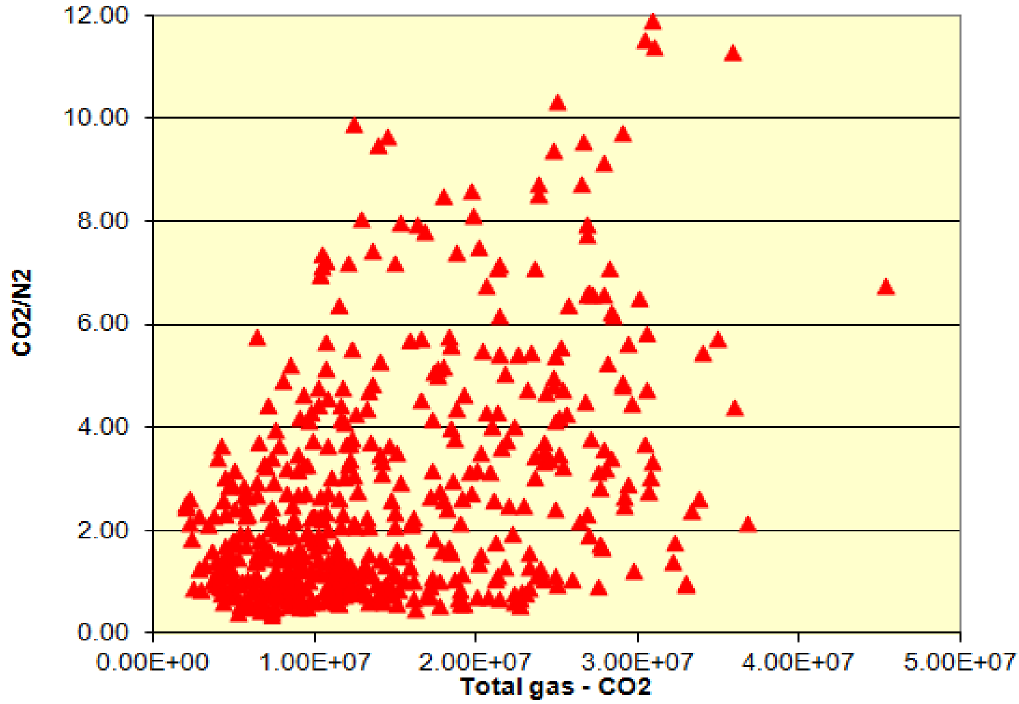
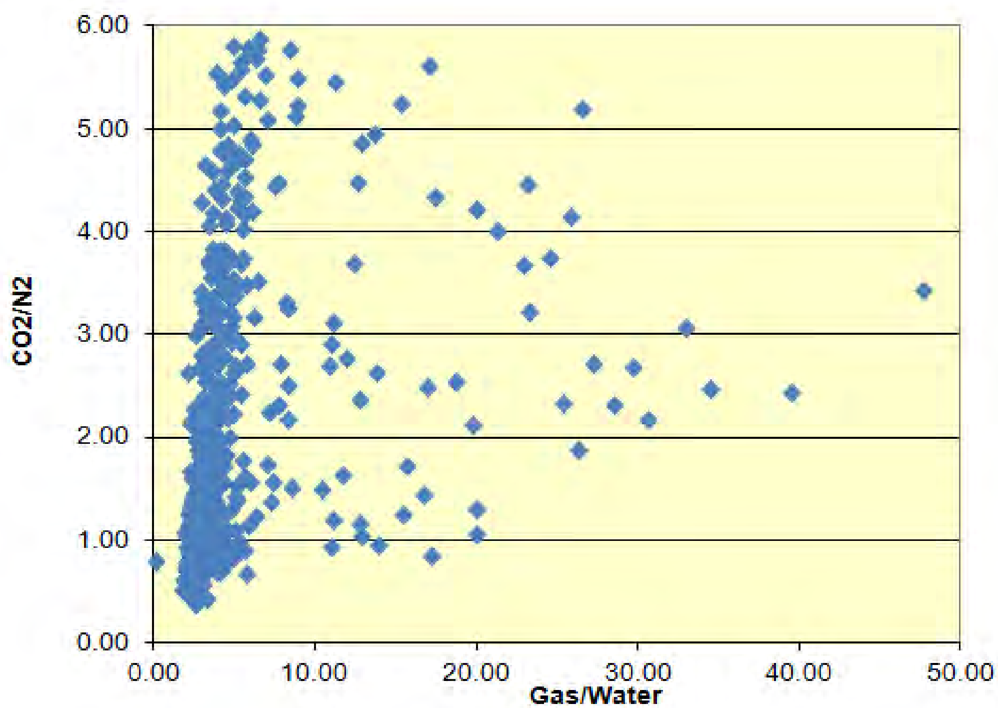
Figure F34

Coso Well 46A-19RD





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Coso Well 46A-19RD

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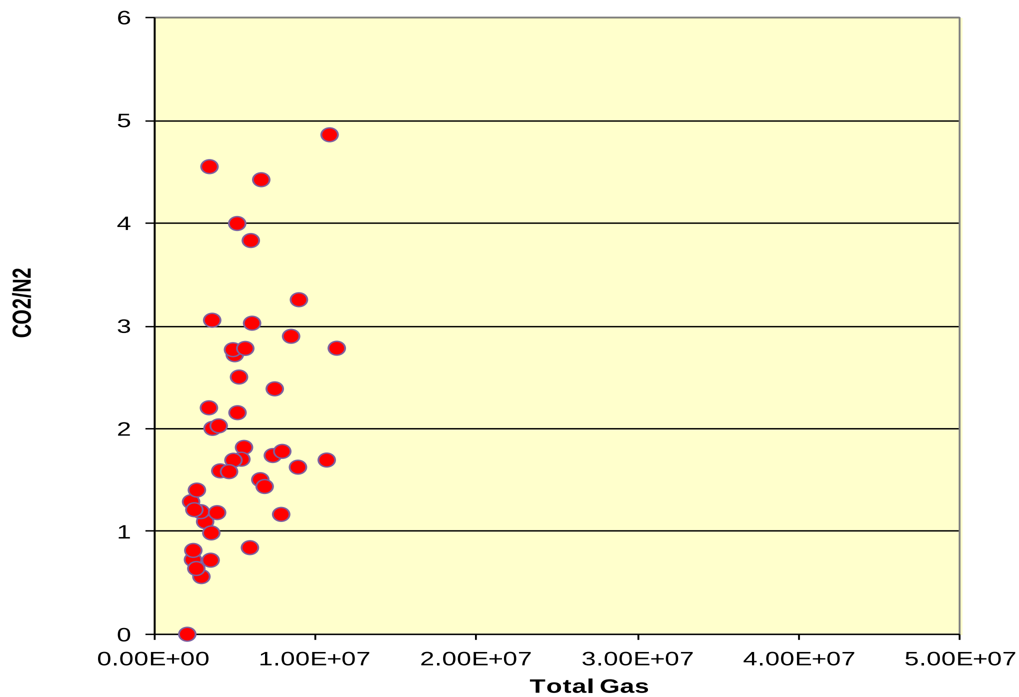
Figure F35

Coso Well 47A-8



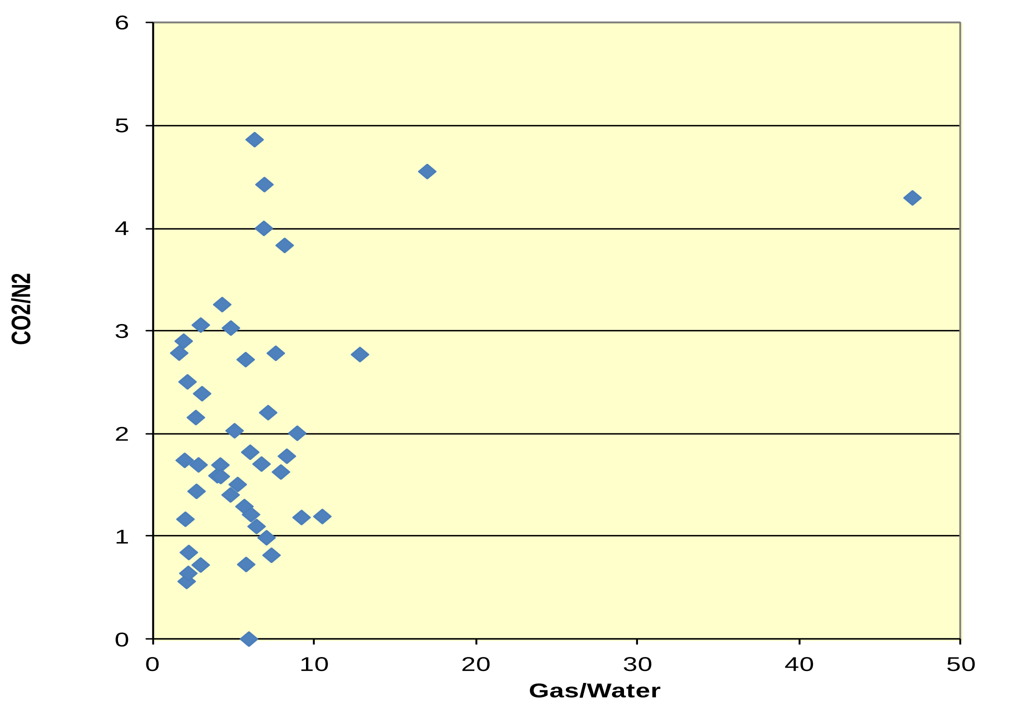


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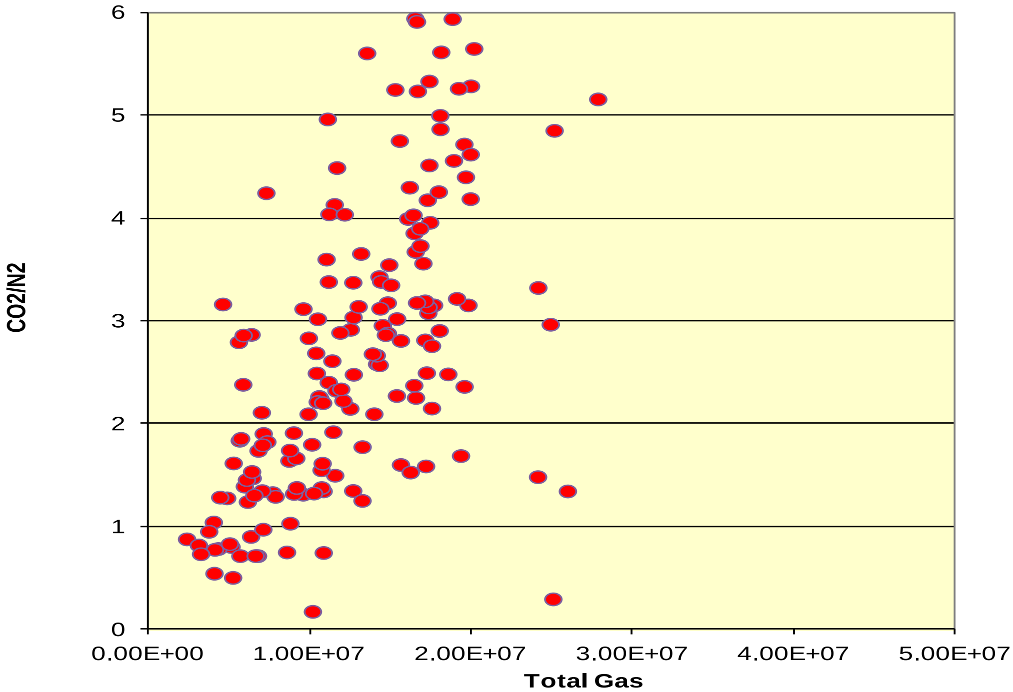
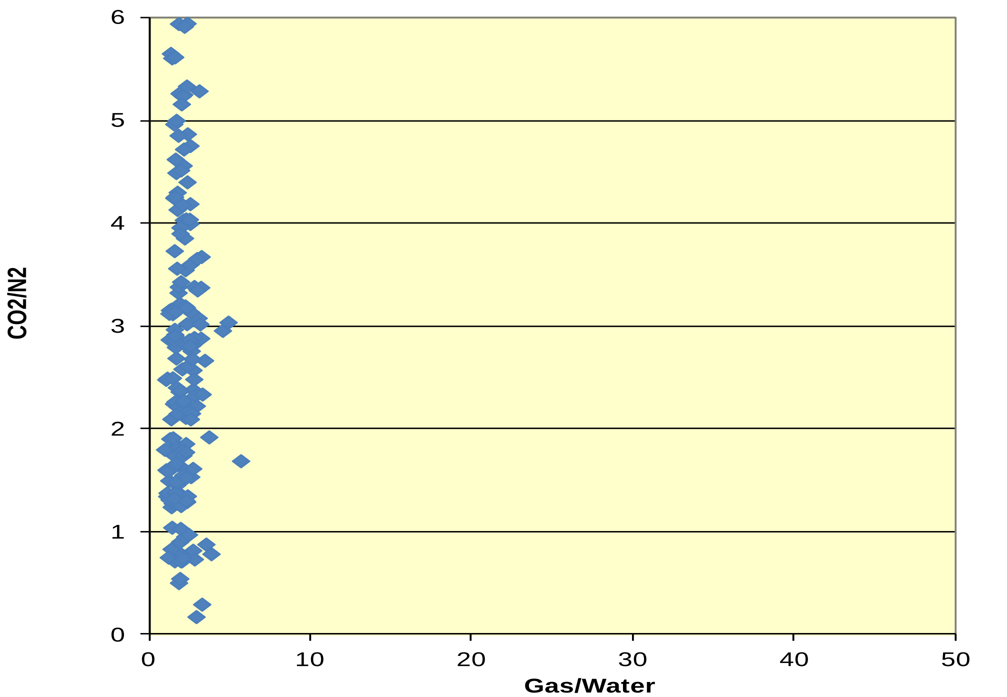
Figure F36

Coso Well 47A-8RD





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Coso Well 47A-8RD
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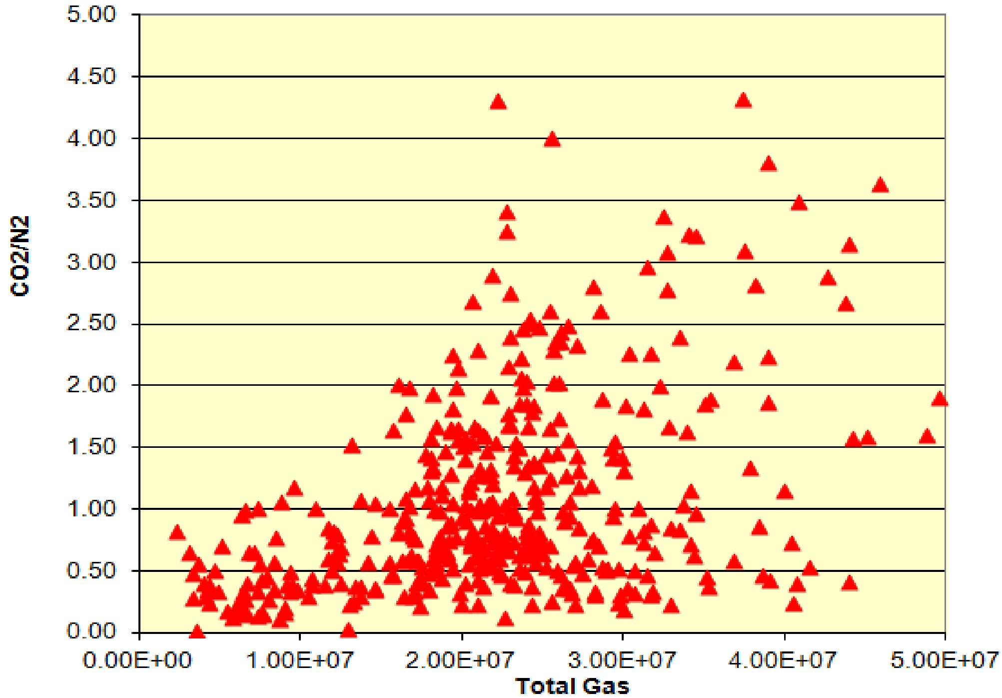
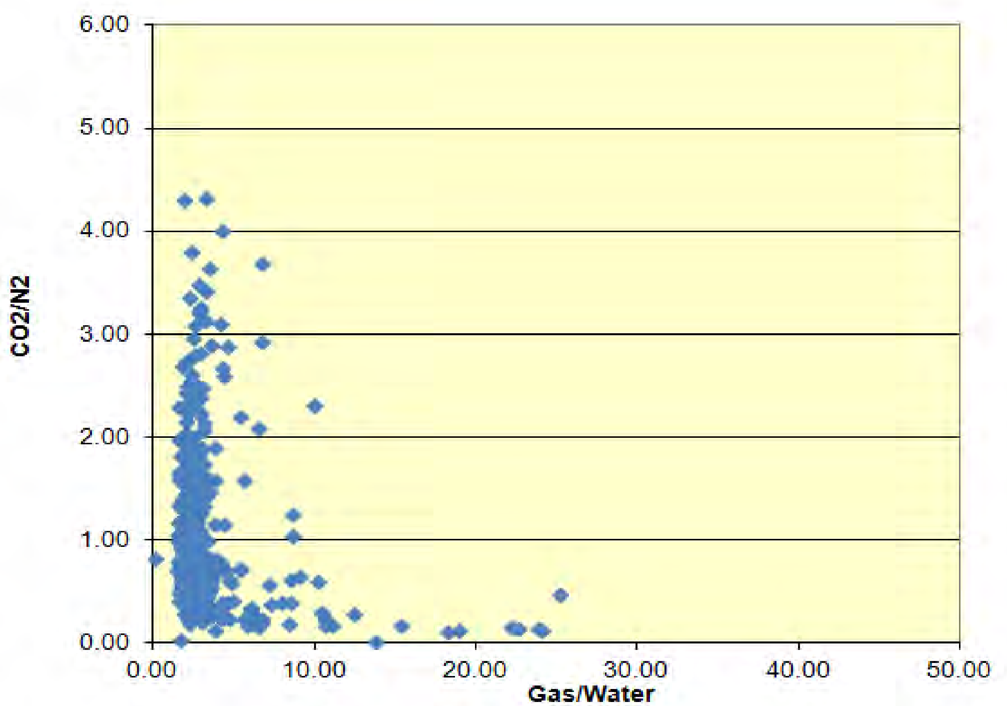
Figure F37

Coso Well 51B-16





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Coso Well 51B-16
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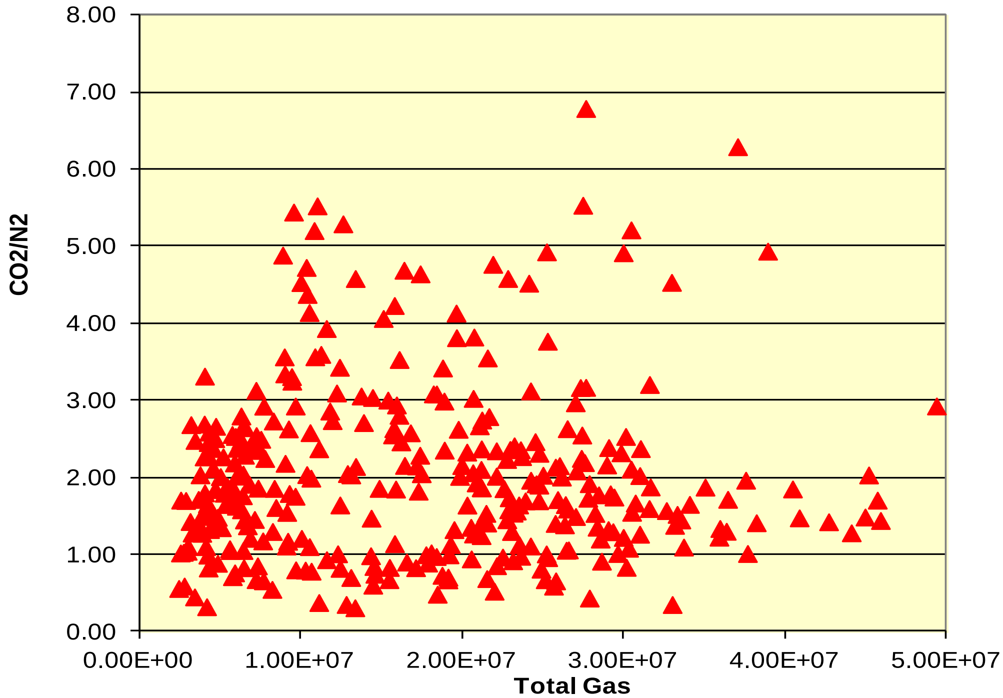
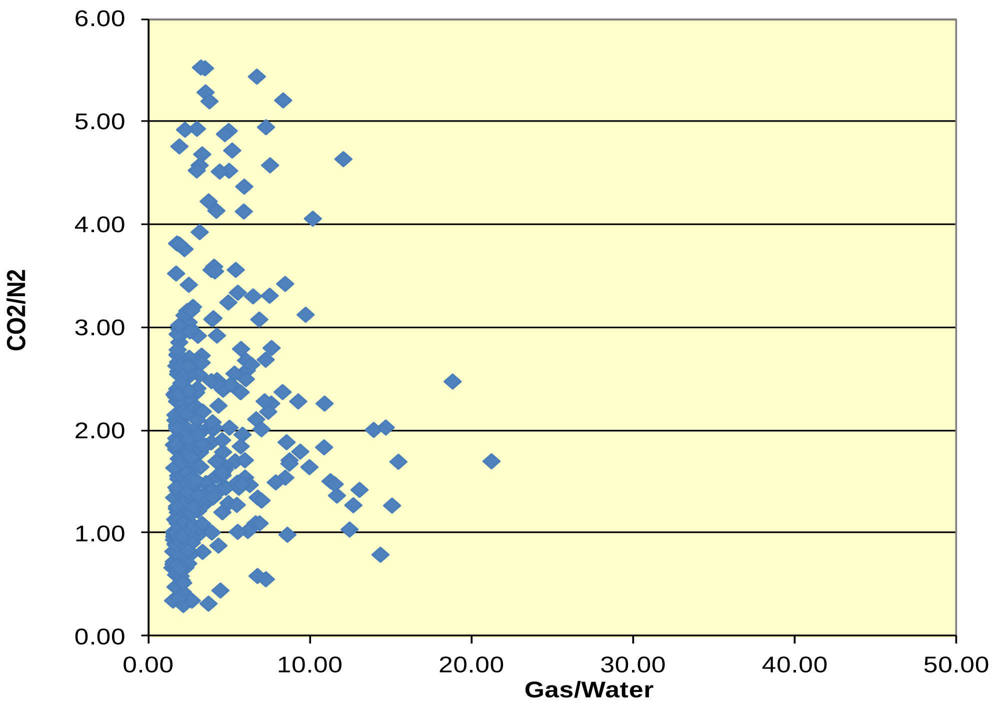
Figure F38

Coso Well 52-20





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Coso Well 52-20
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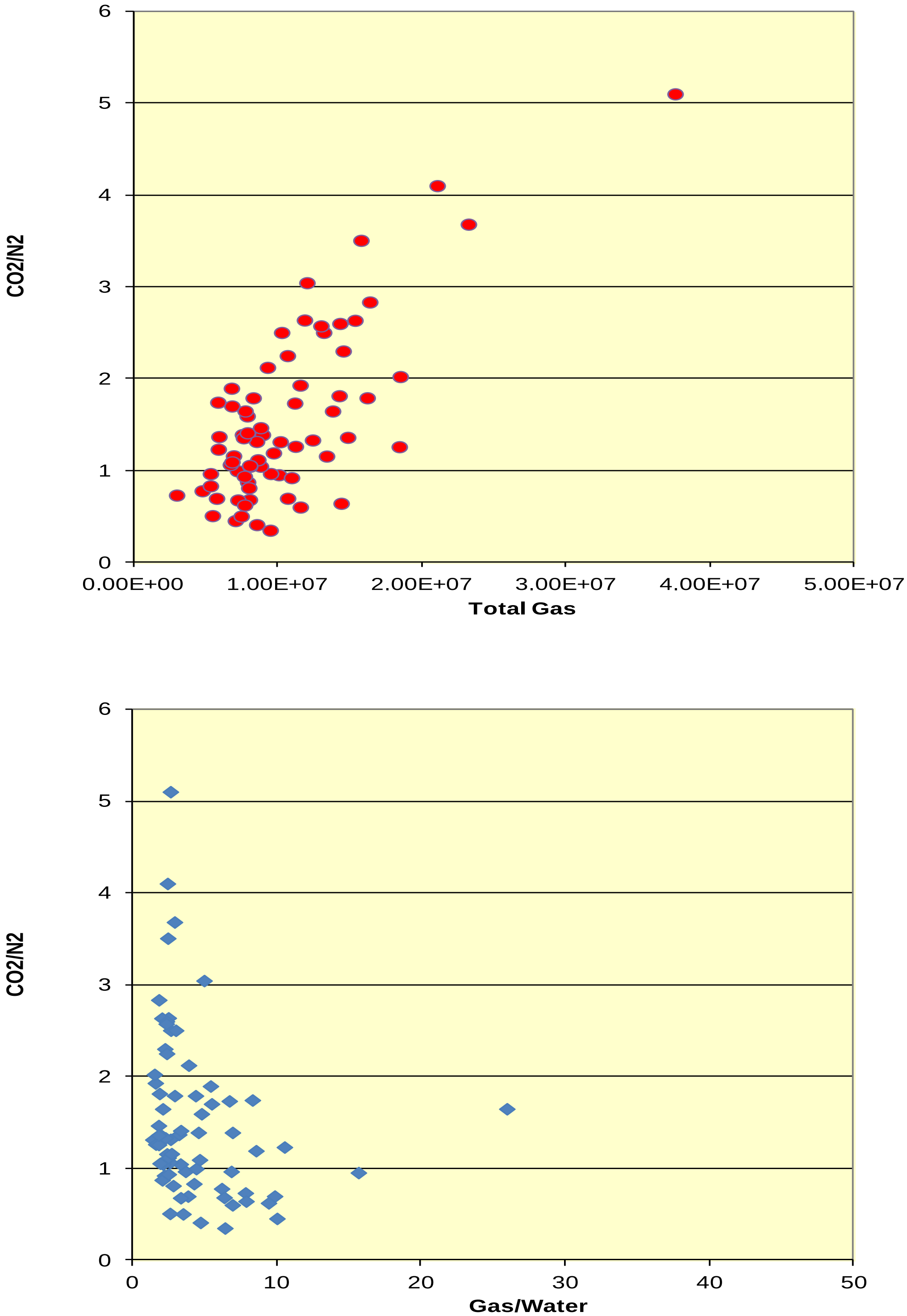
Figure F39

Coso Well 54-7



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Coso Well 54-7

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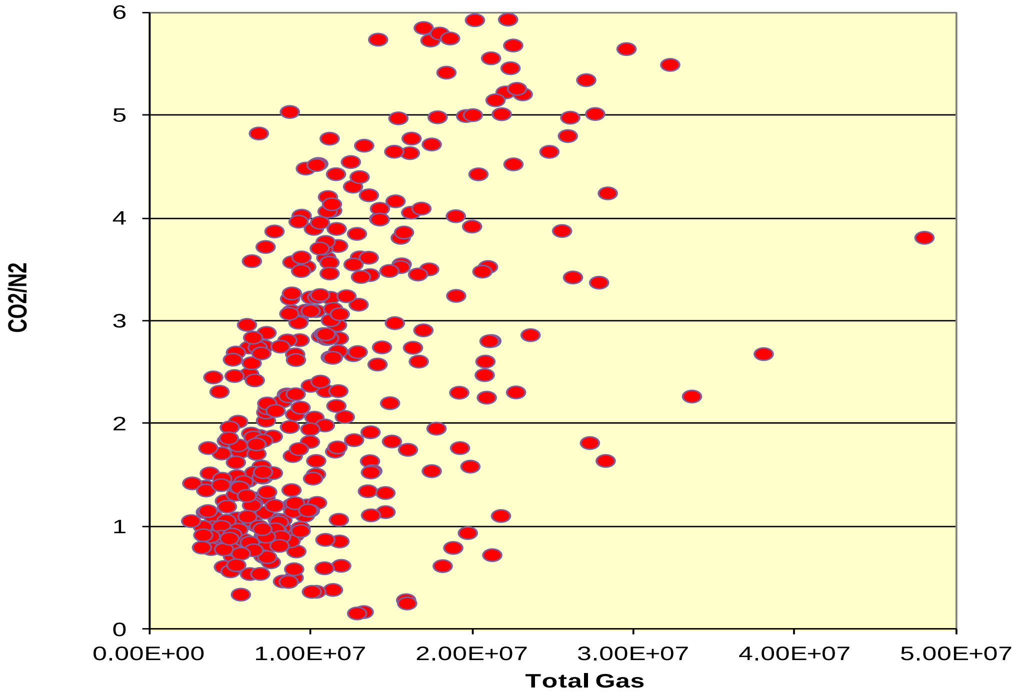
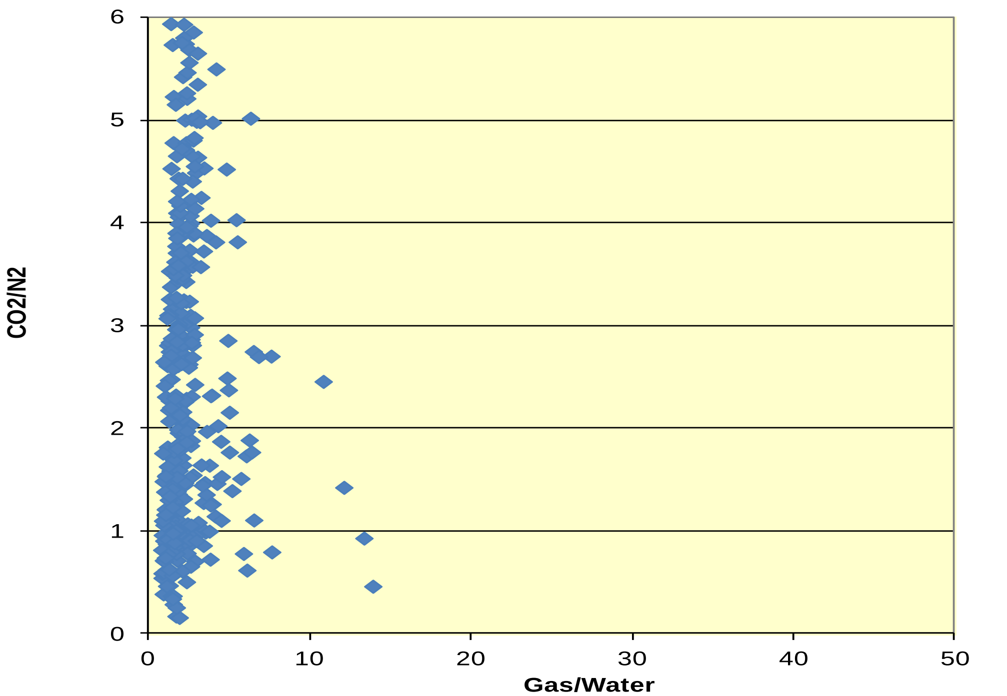
Figure F40

Coso Well 54-7RD





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Coso Well 54-7RD

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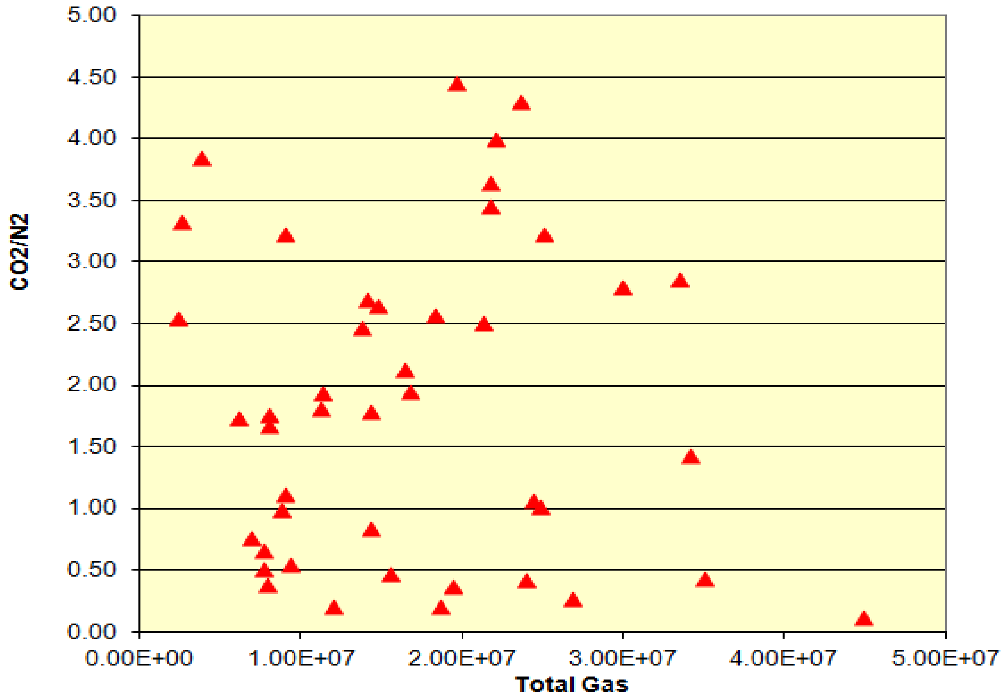
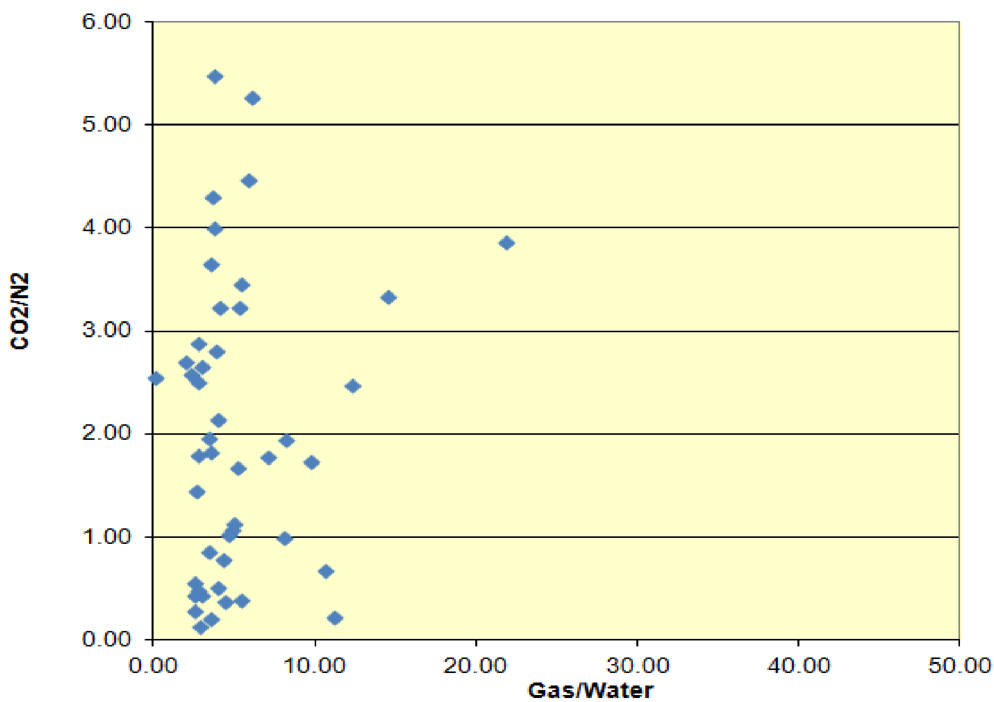
Figure F41

Coso Well 58A-10





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Coso Well 58A-10
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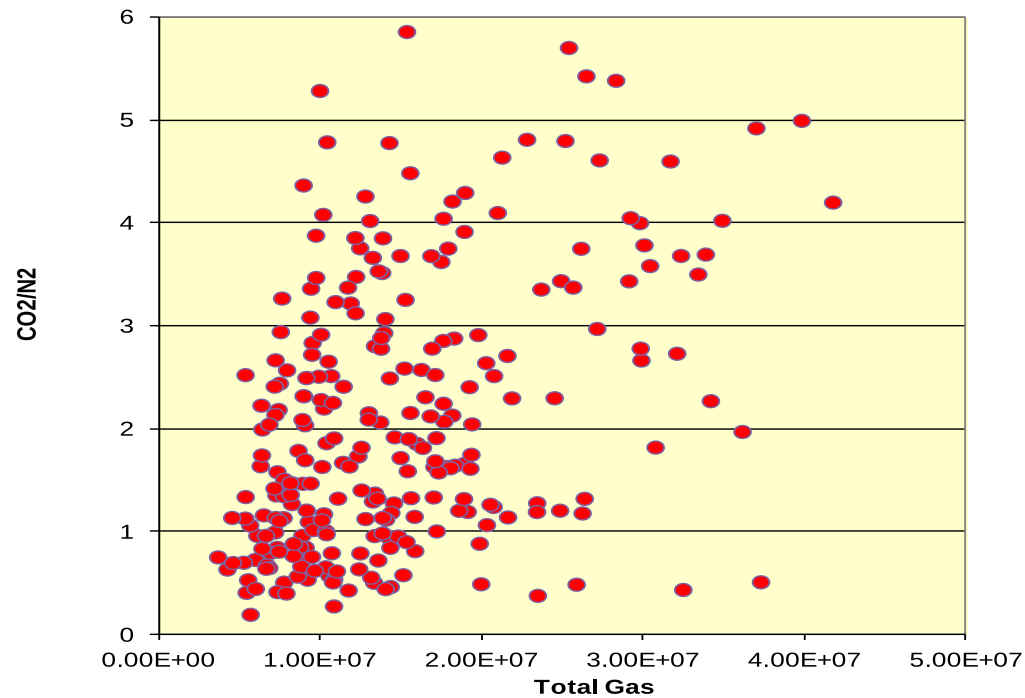
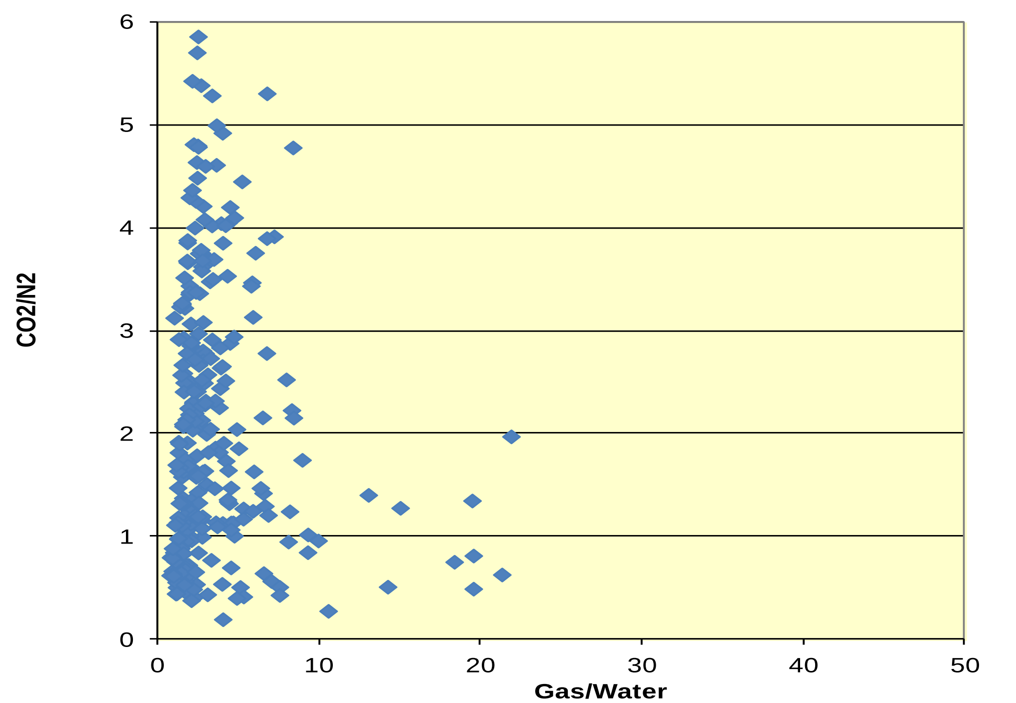
Figure F42

Coso Well 58A-18





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Coso Well 58A-18

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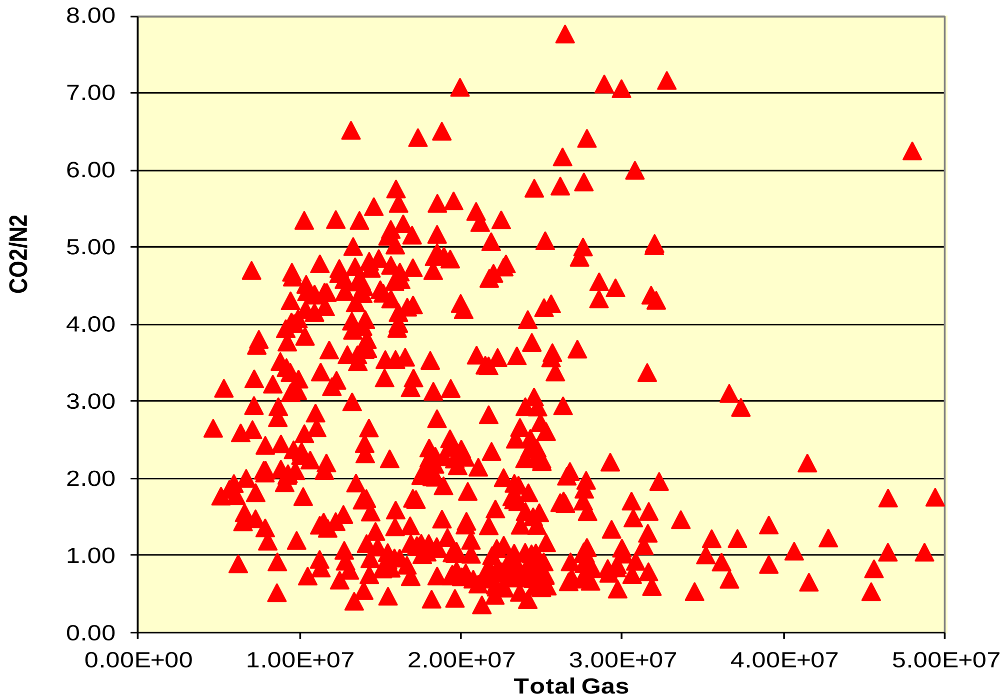
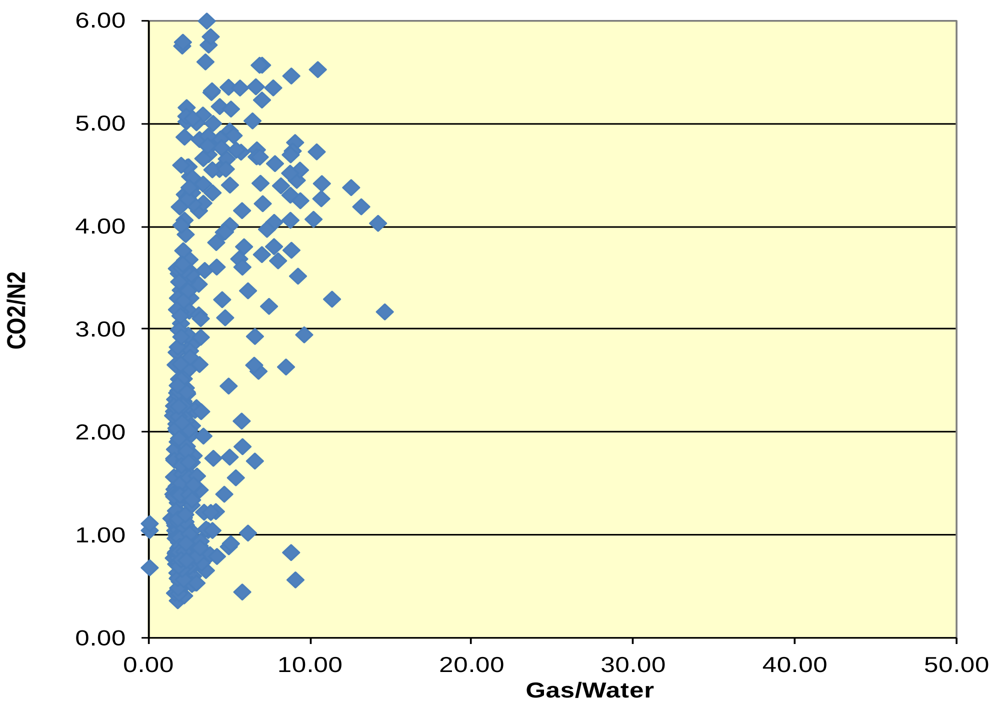
Figure F43

Coso Well 67-17





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Coso Well 67-17

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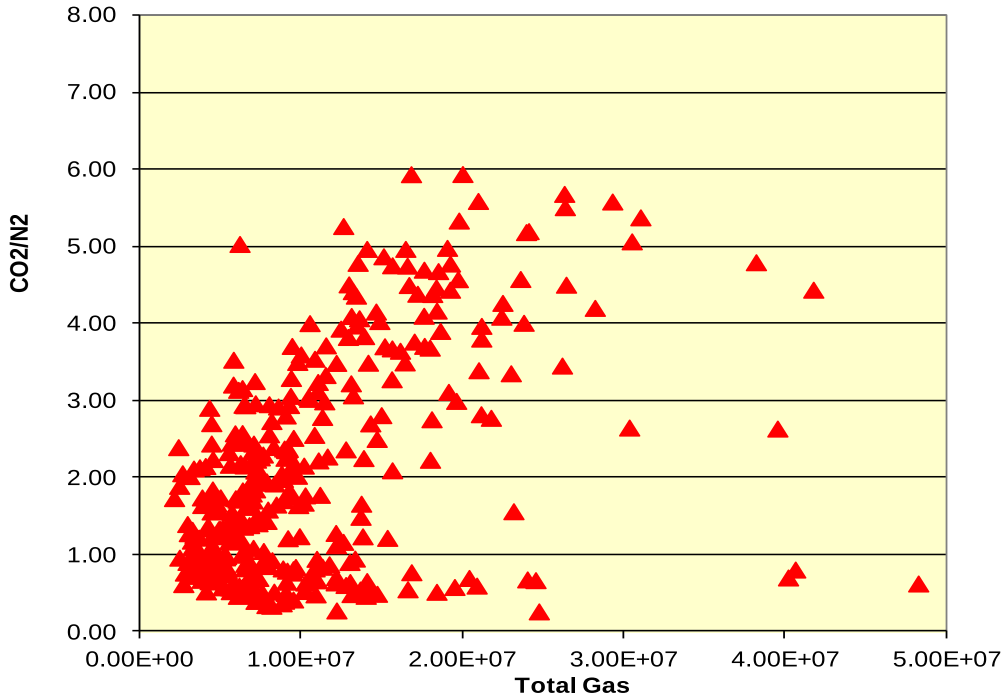
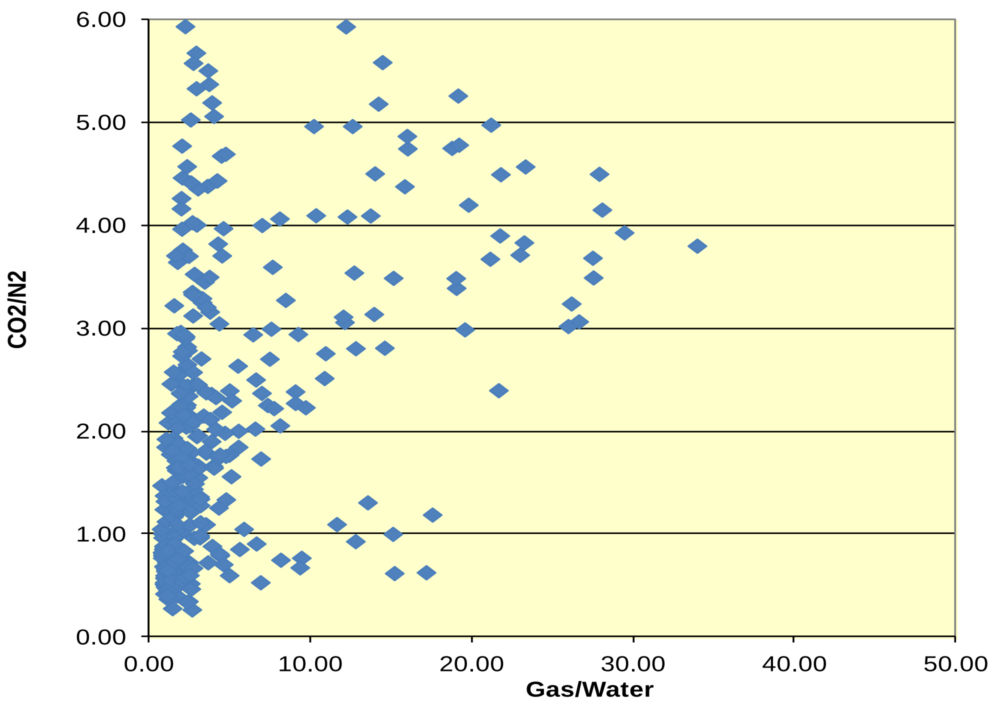
Figure F44

Coso Well 67C-17





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Coso Well 67C-17
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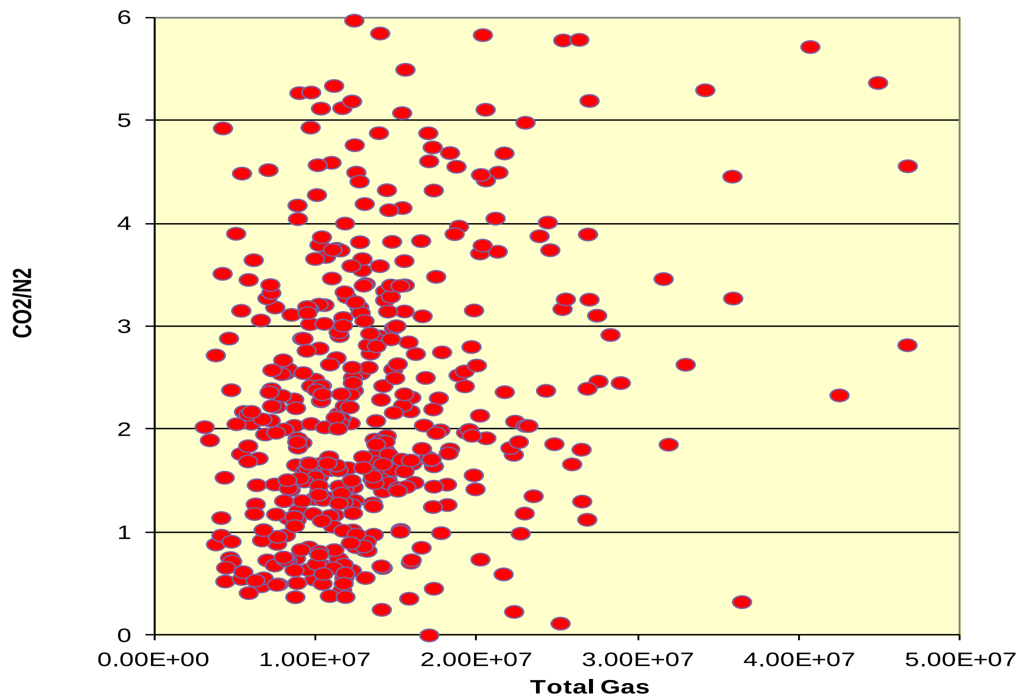
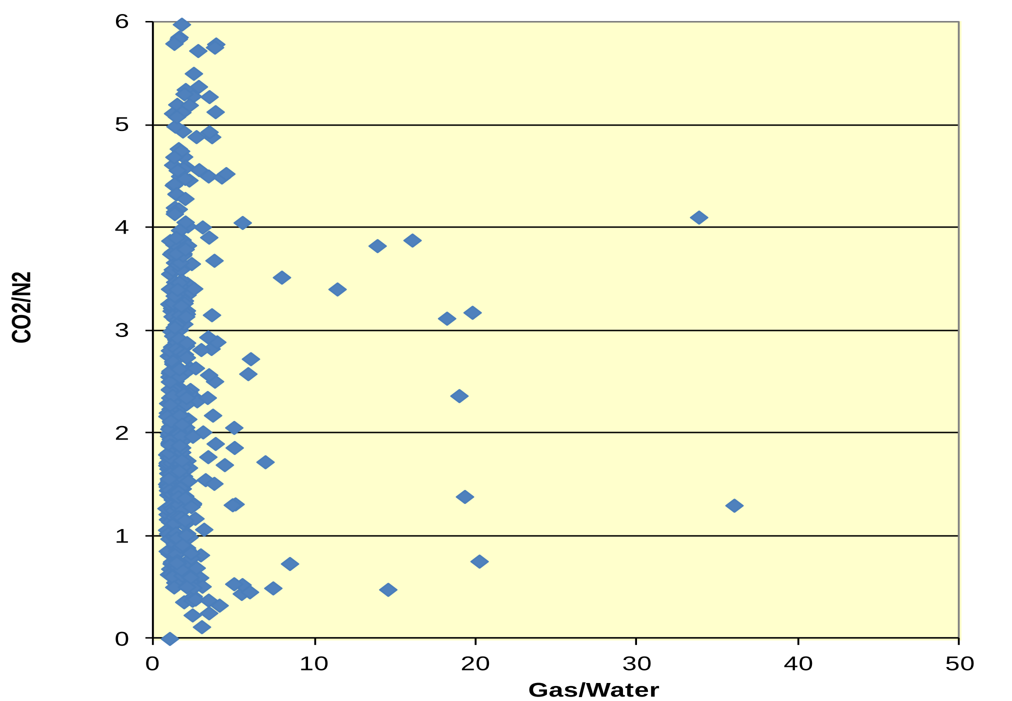
Figure F45

Coso Well 68-6





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Coso Well 68-6
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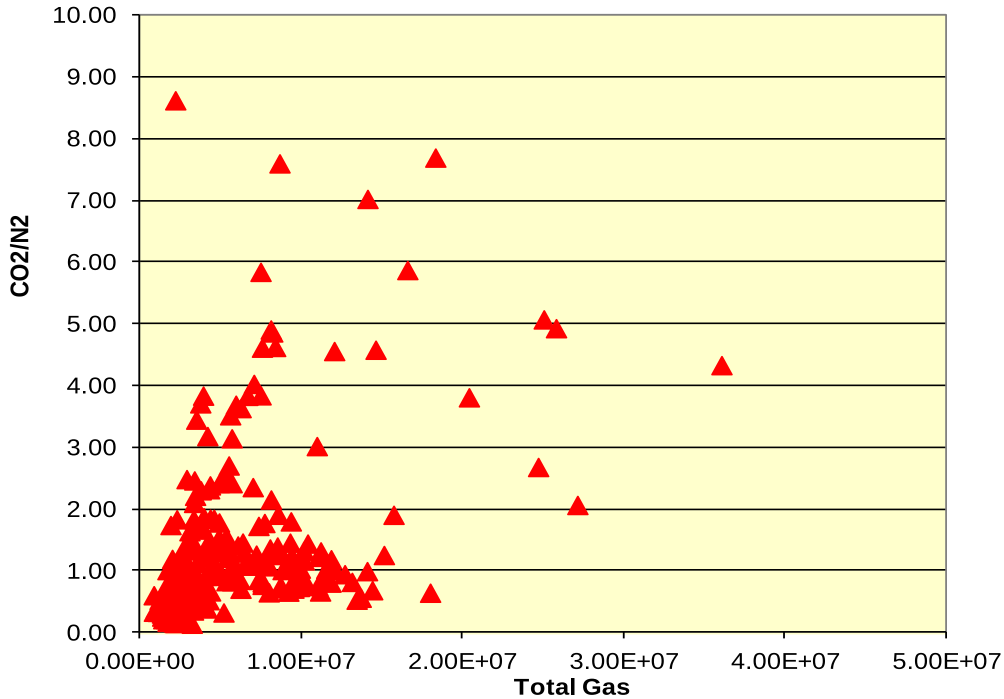
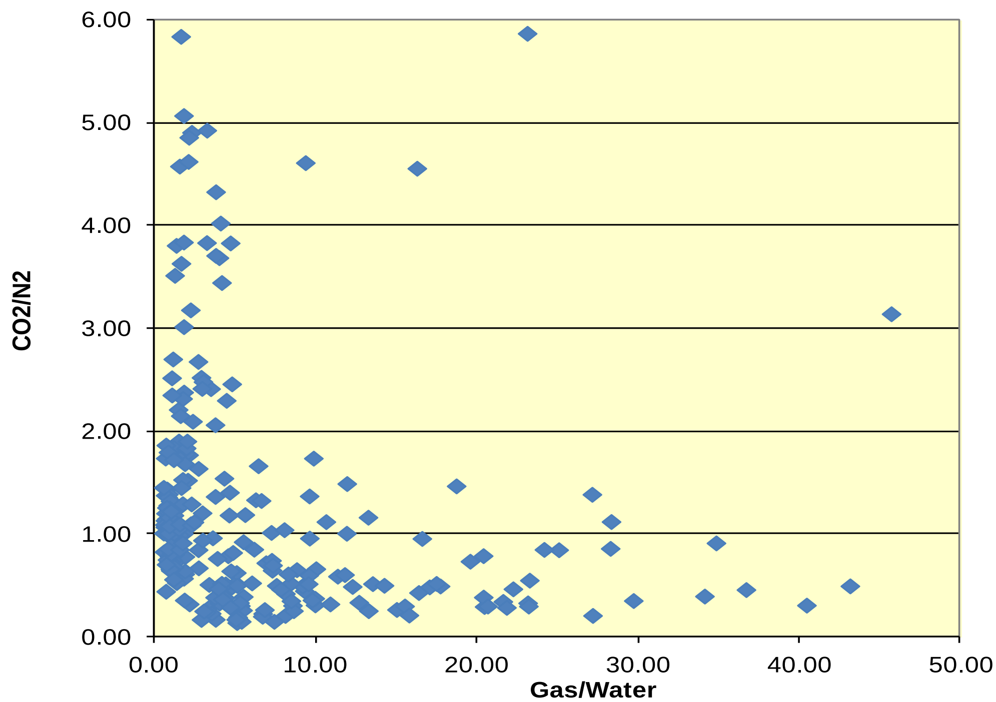
Figure F46

Coso Well 68-20





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Coso Well 68-20

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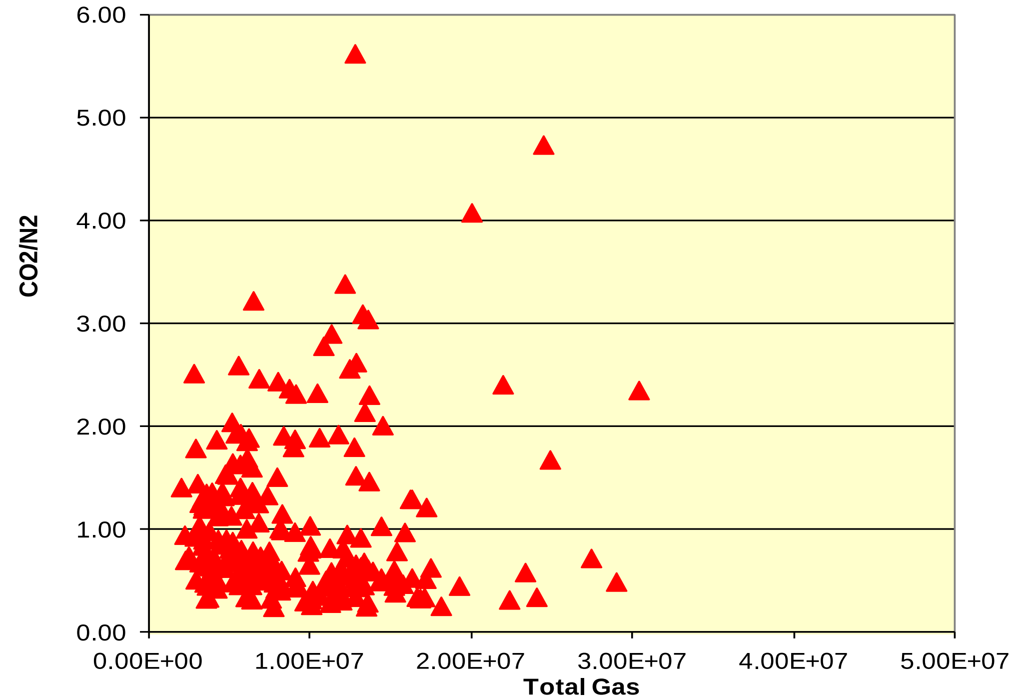
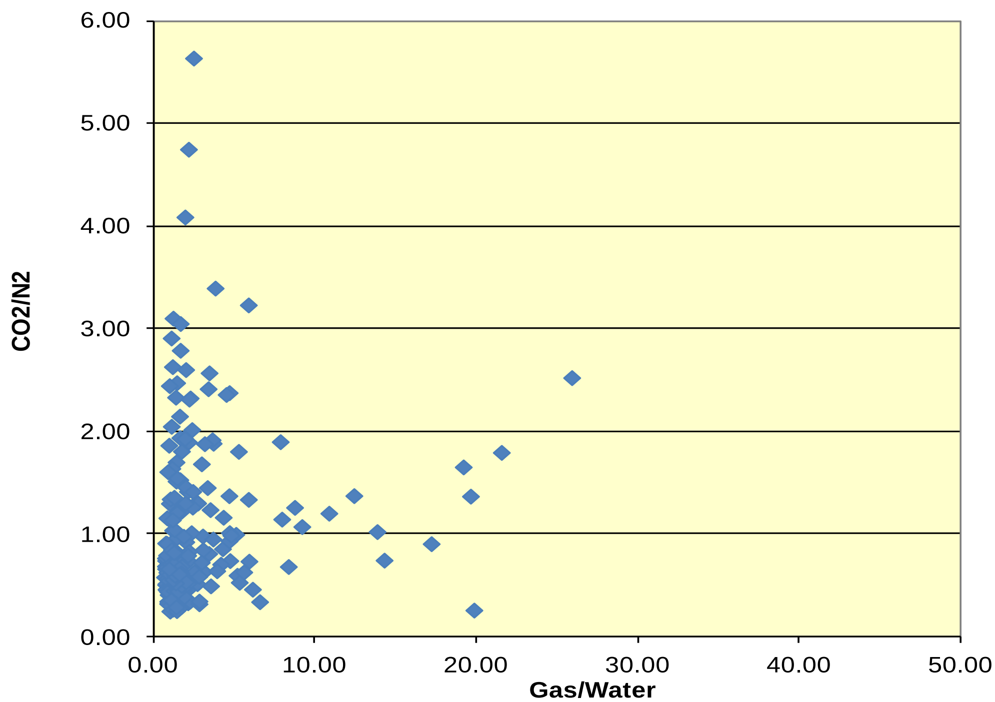
Figure F47

Coso Well 68-20RD





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Coso Well 68-20RD
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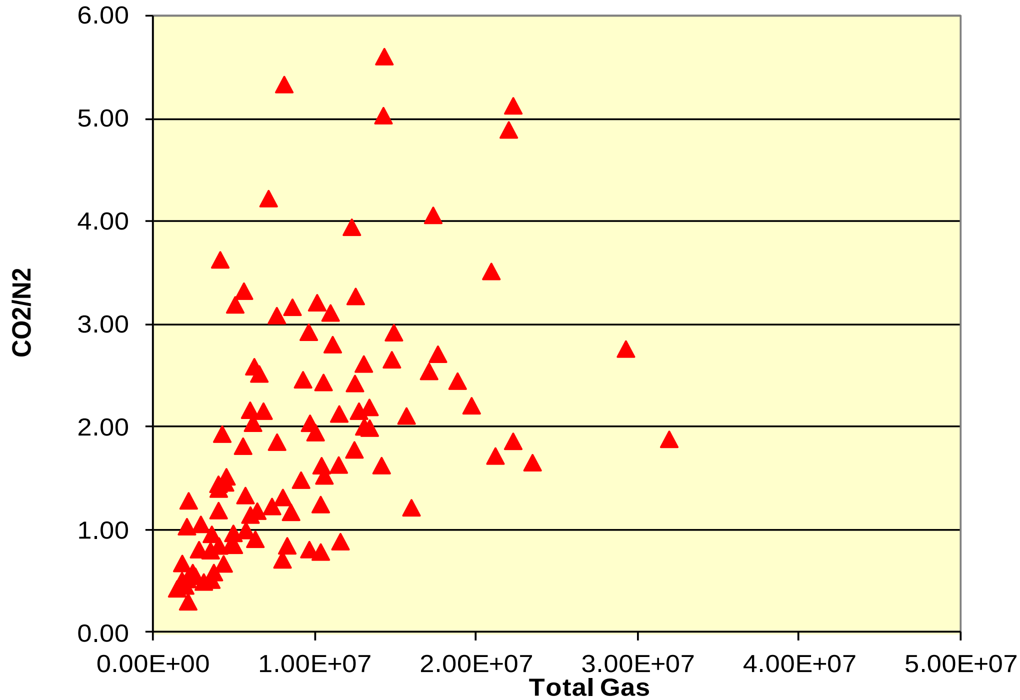
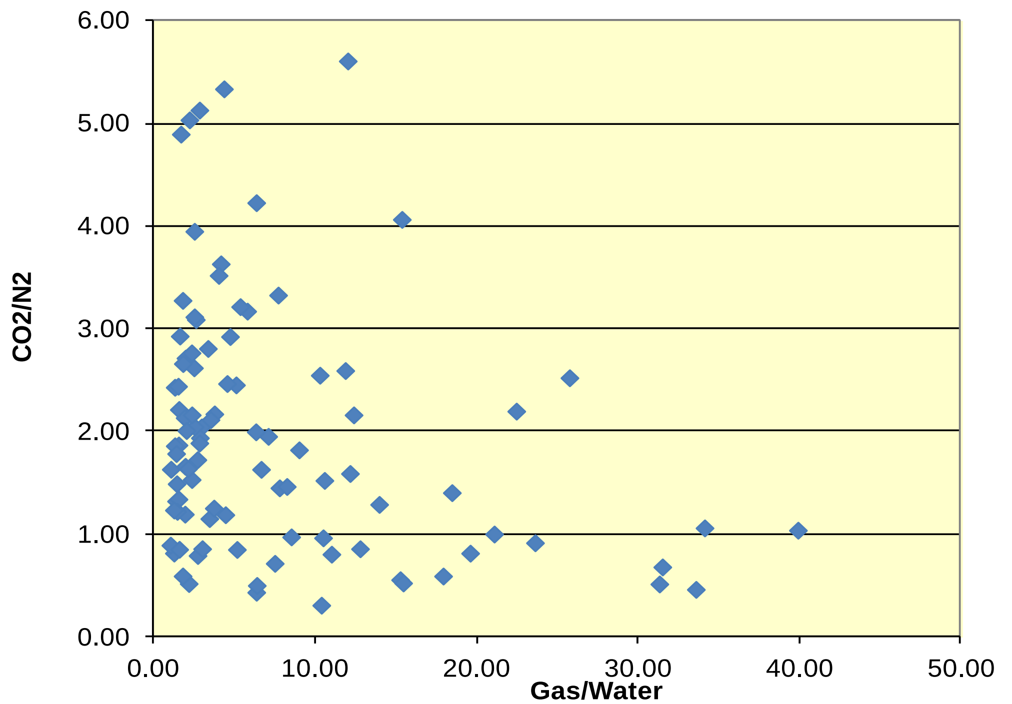
Figure F48

Coso Well 73-19





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Coso Well 73-19

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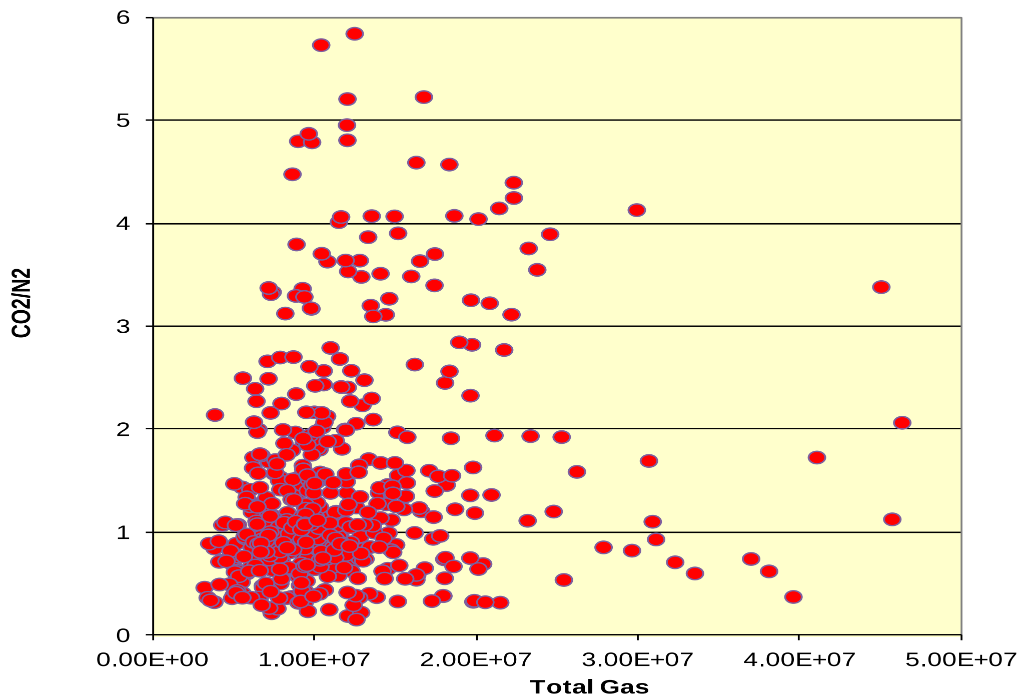
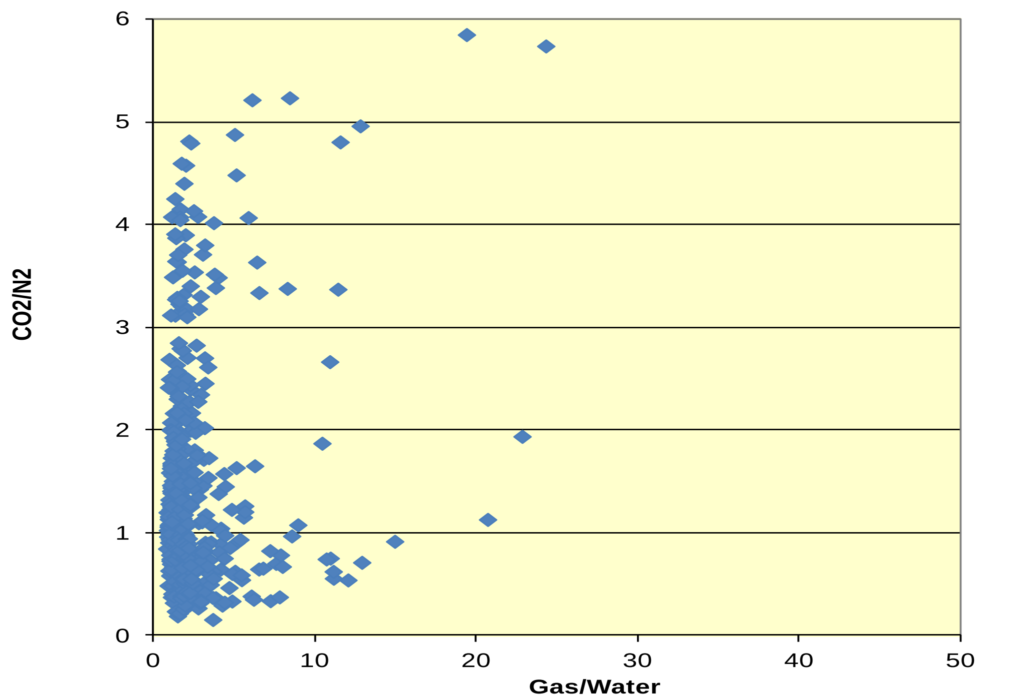
Figure F49

Coso Well 83B-16





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Coso Well 83B-16
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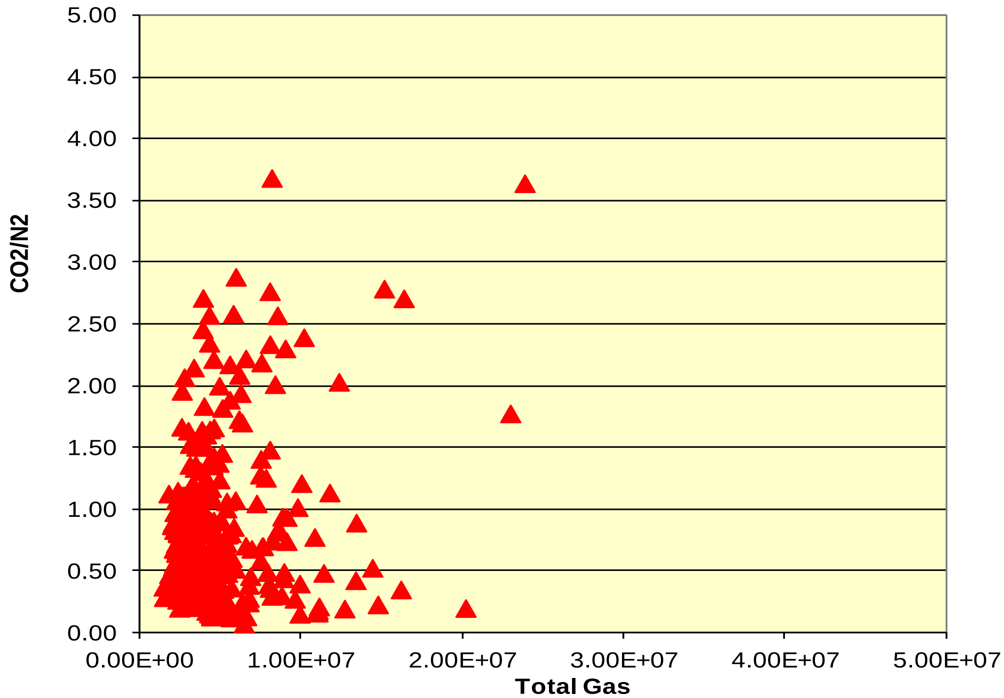
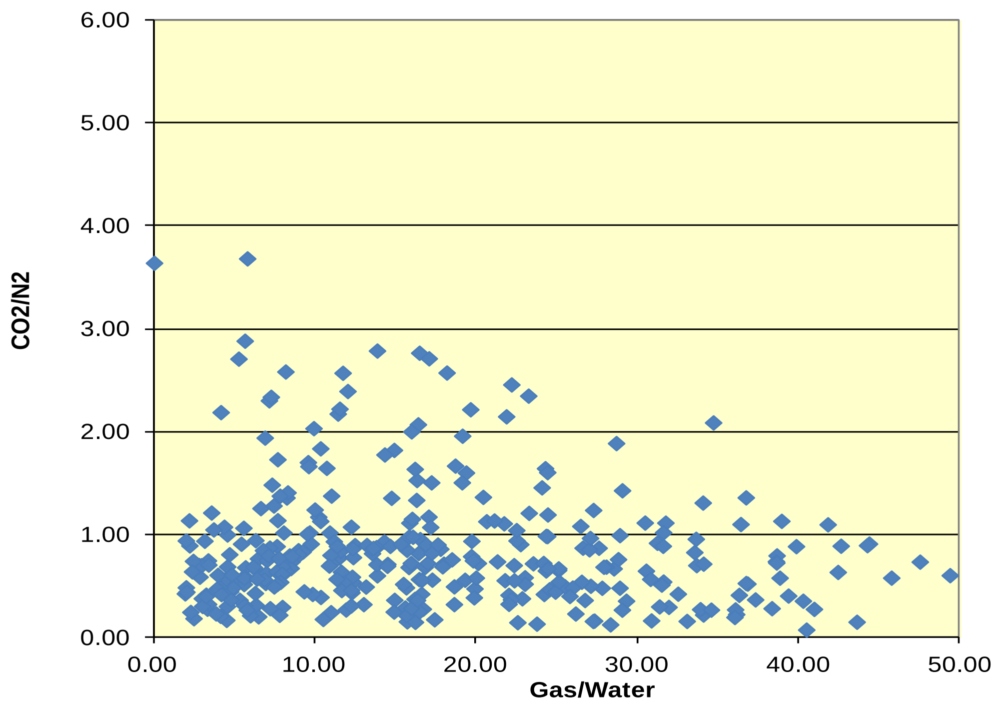
Figure F50

Coso Well 84-30





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Coso Well 84-30

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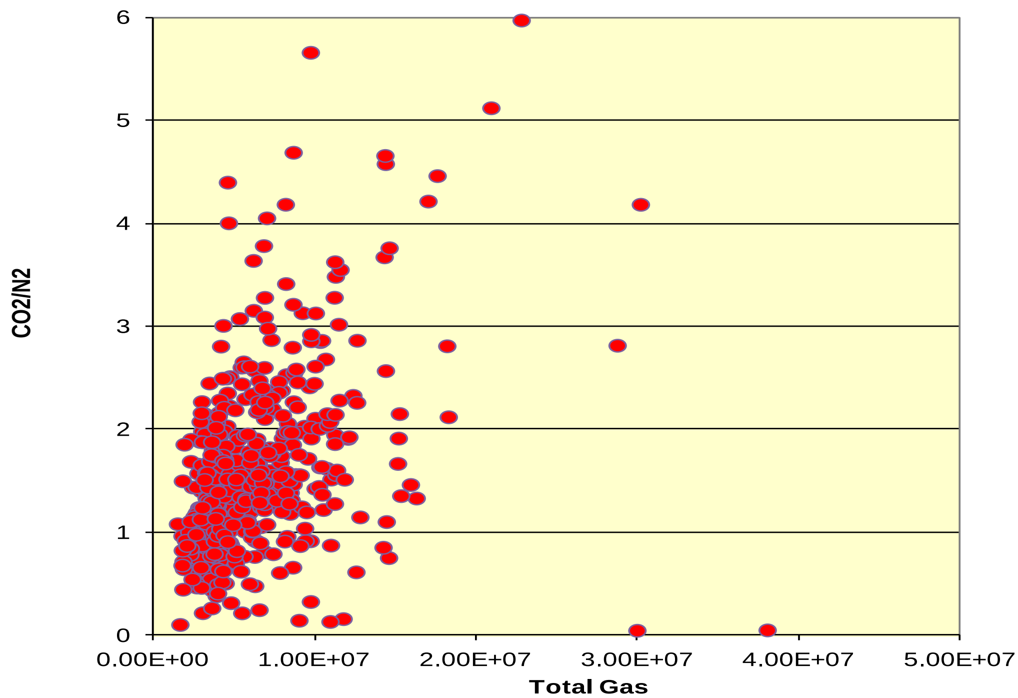
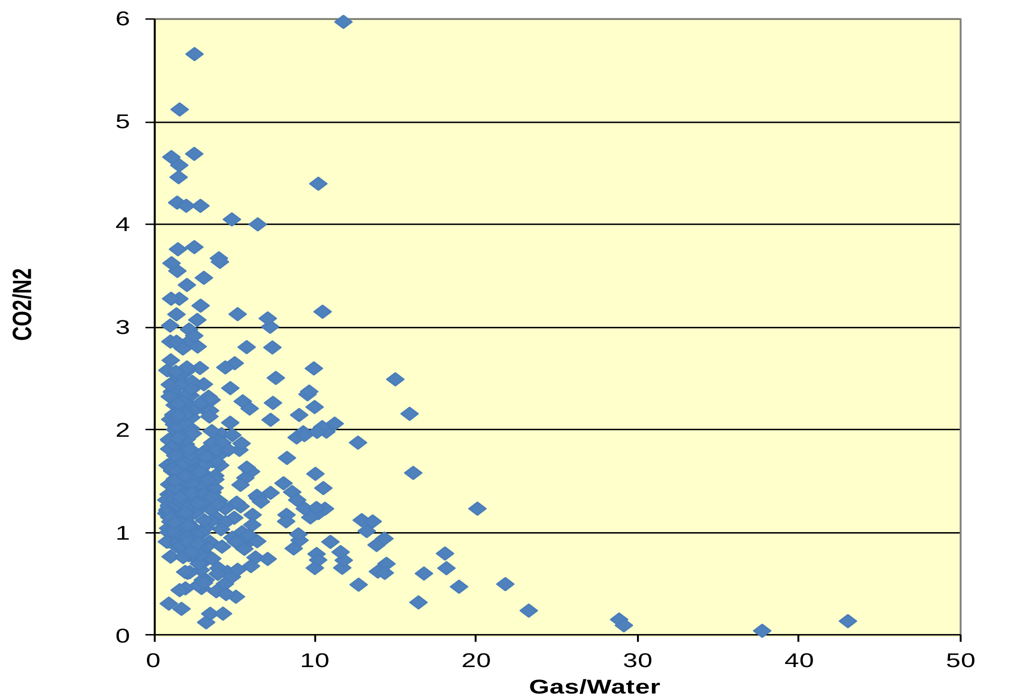
Figure F51

Coso Well 86-17





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Coso Well 86-17
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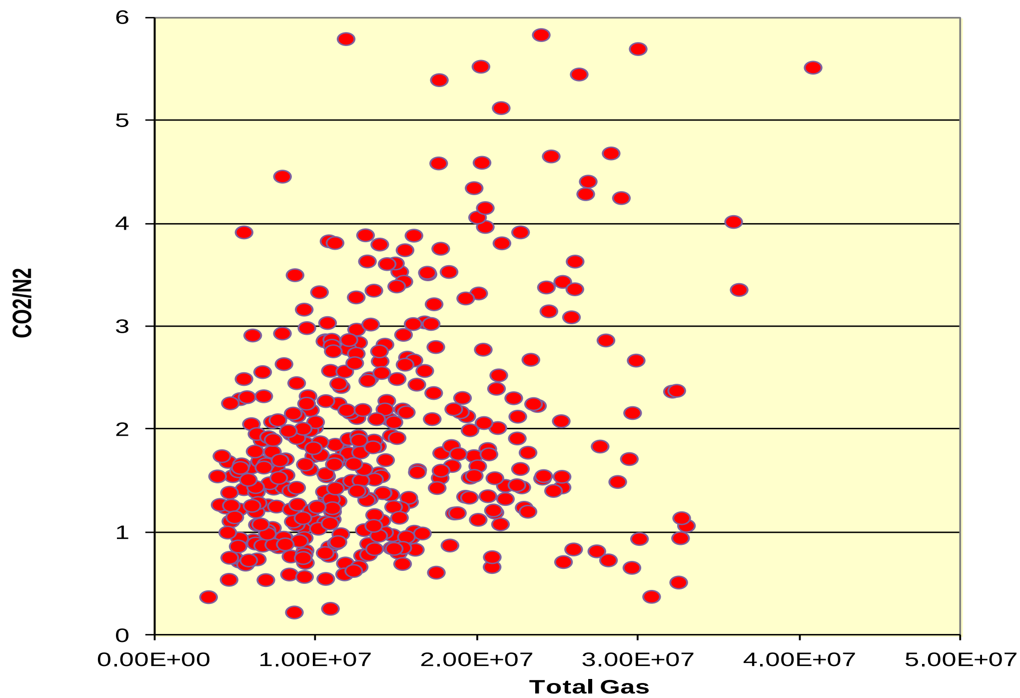
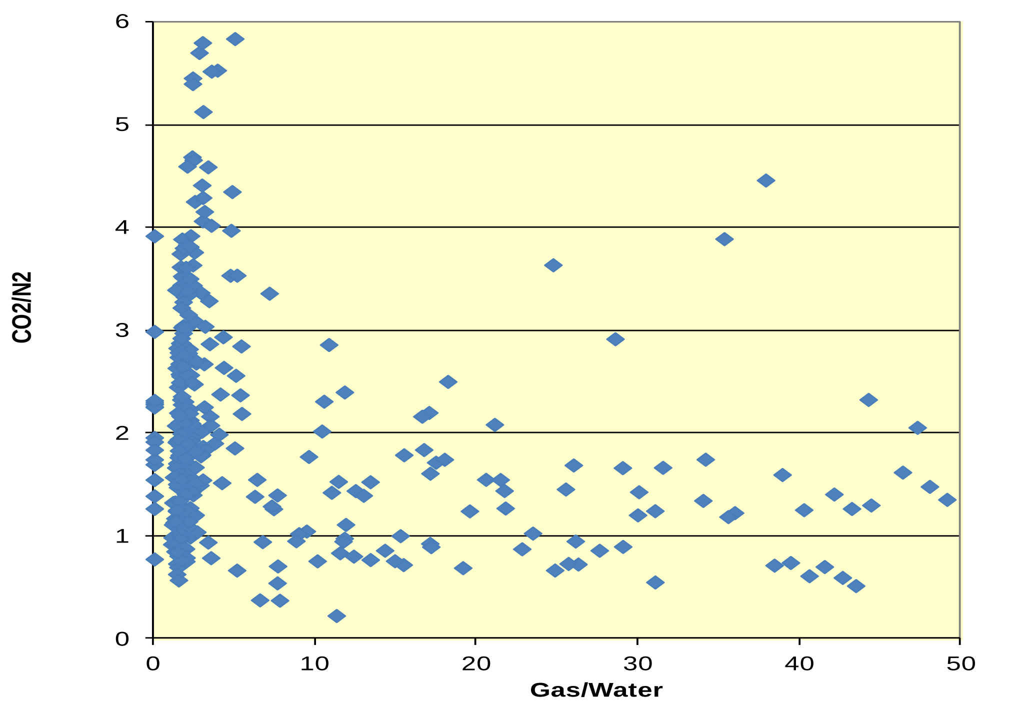
Figure F52

Coso Well 88-20





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Coso Well 88-20

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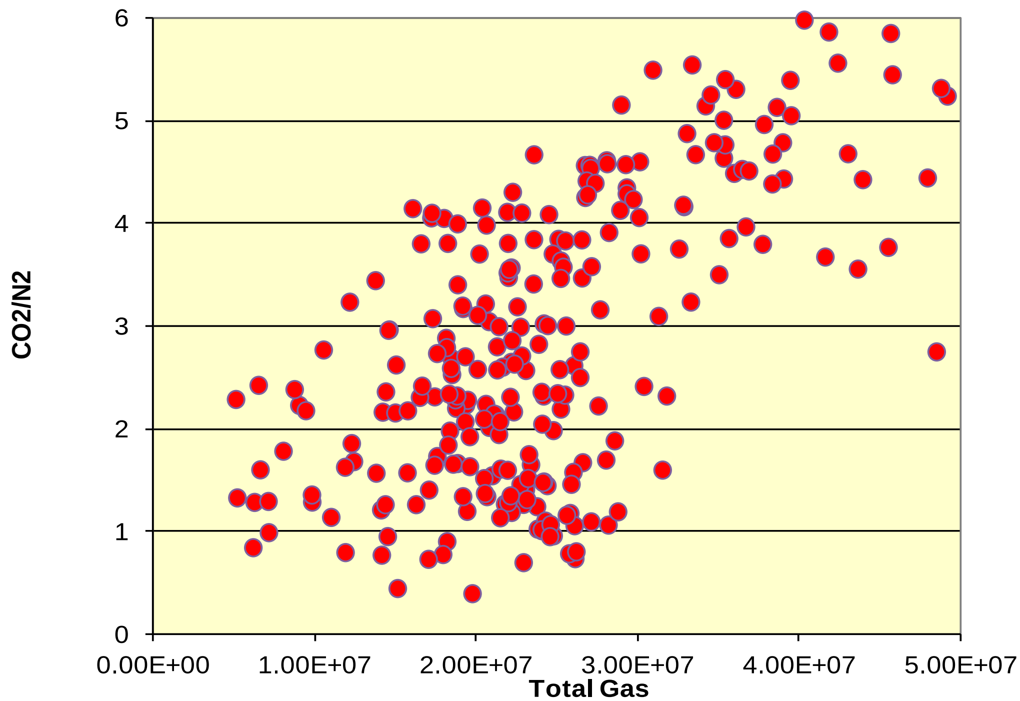
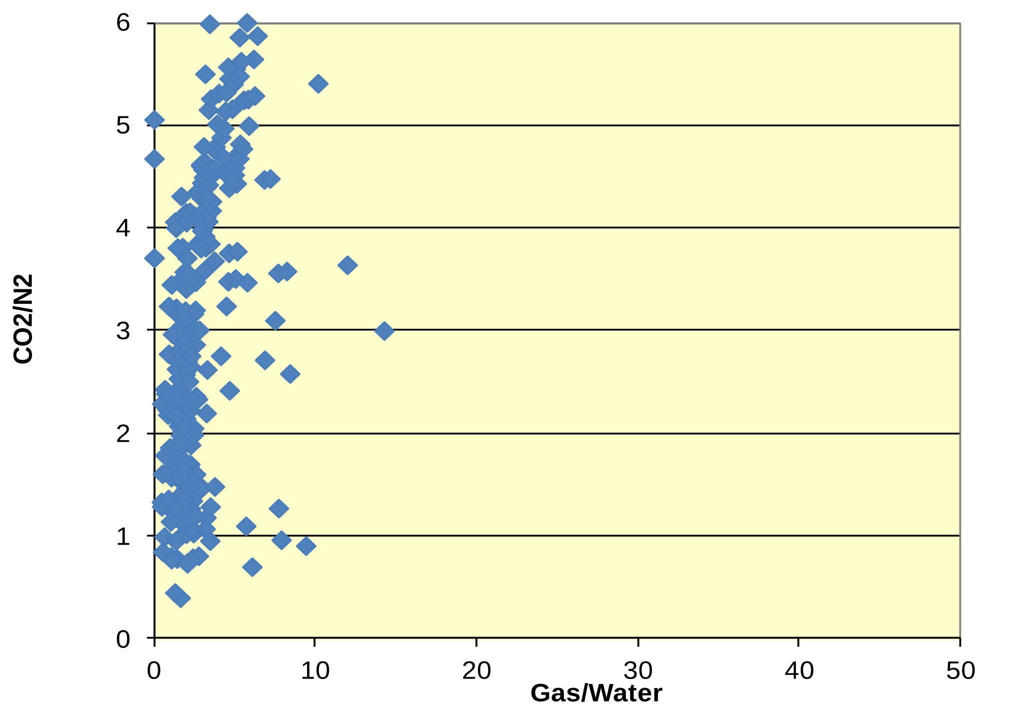
Figure F53

Coso Well 34-9RD2





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Coso Well 15A-17
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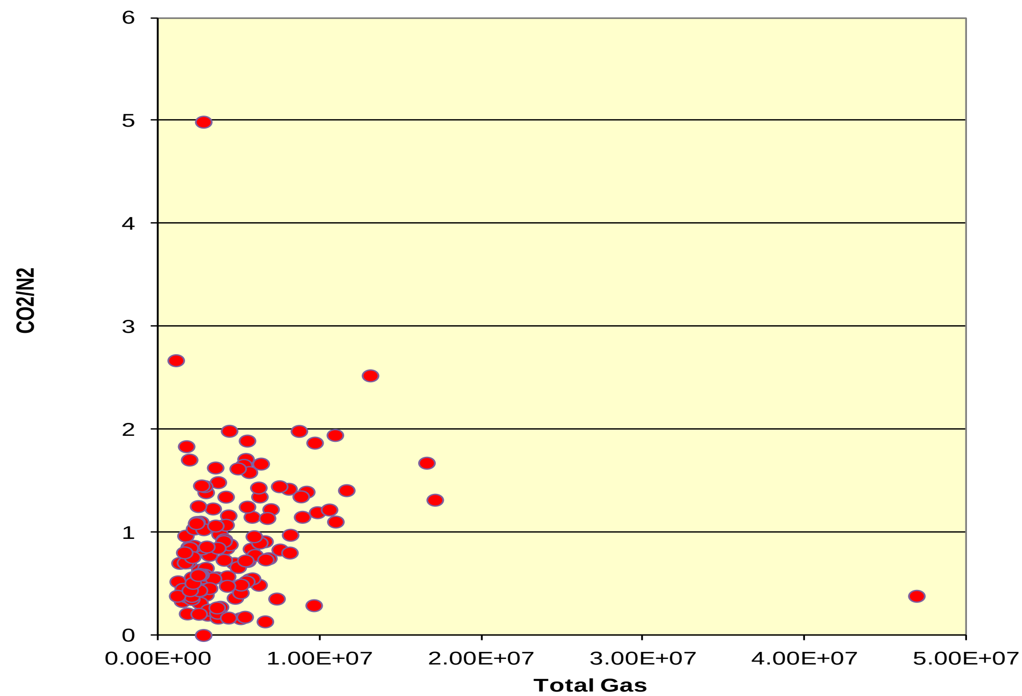
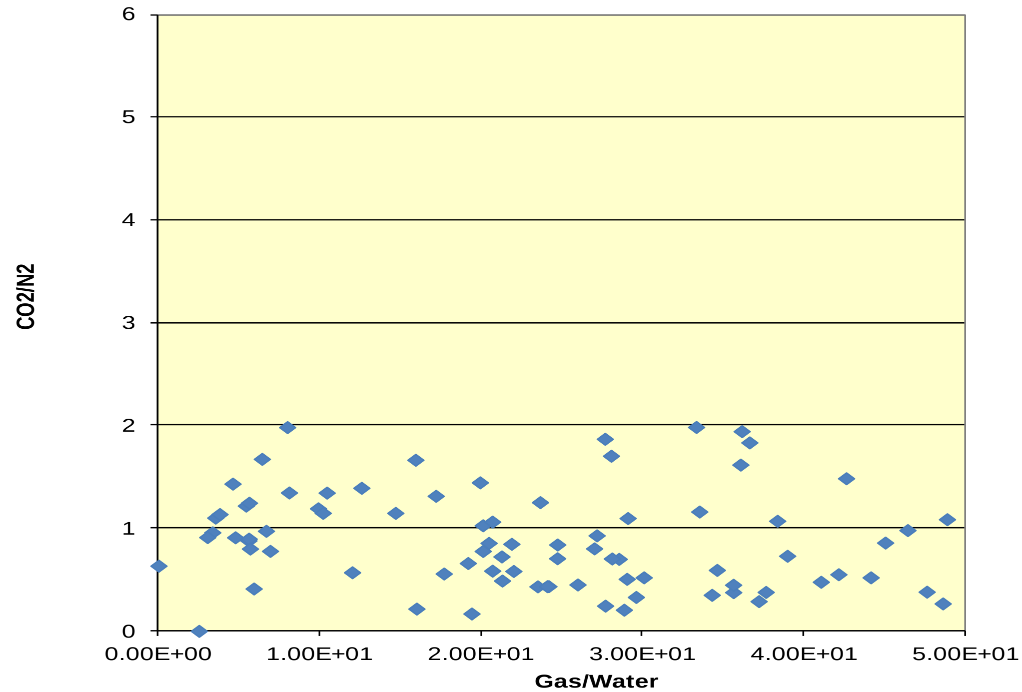
Figure F54

Hawaii Well SOH1





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Hawaii Well SOH1

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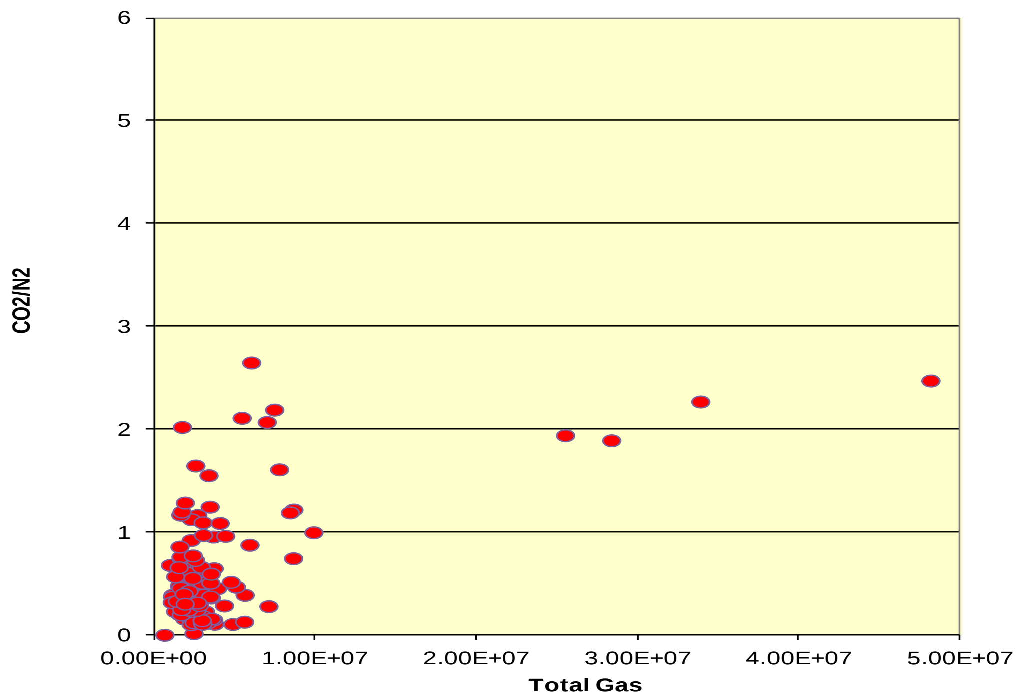
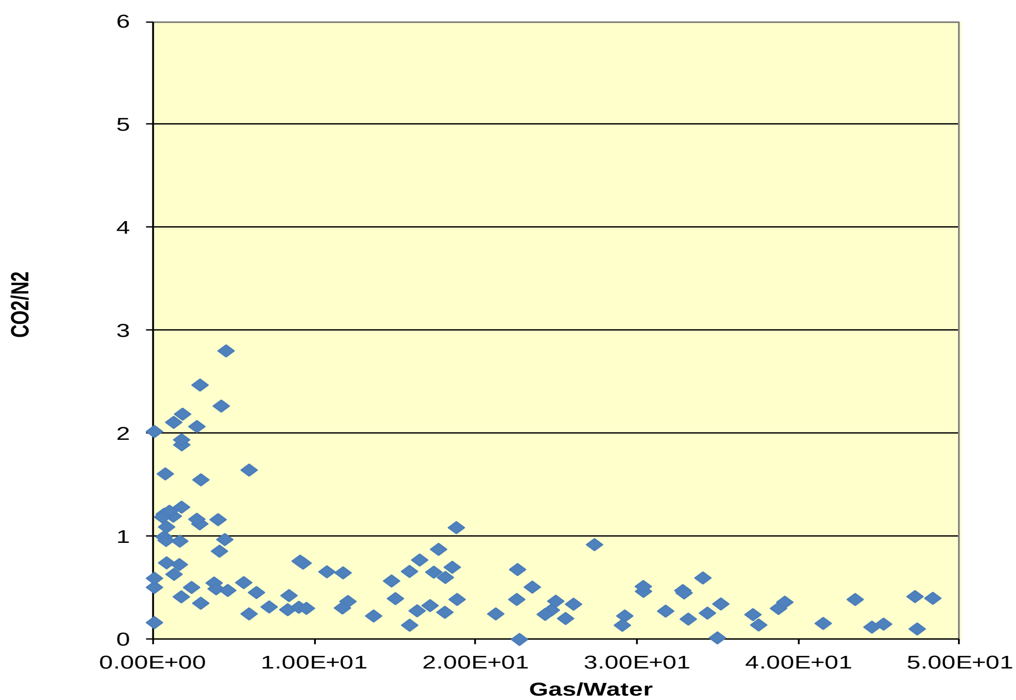
Figure F55

Hawaii Well SOH2





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Hawaii Well SOH2

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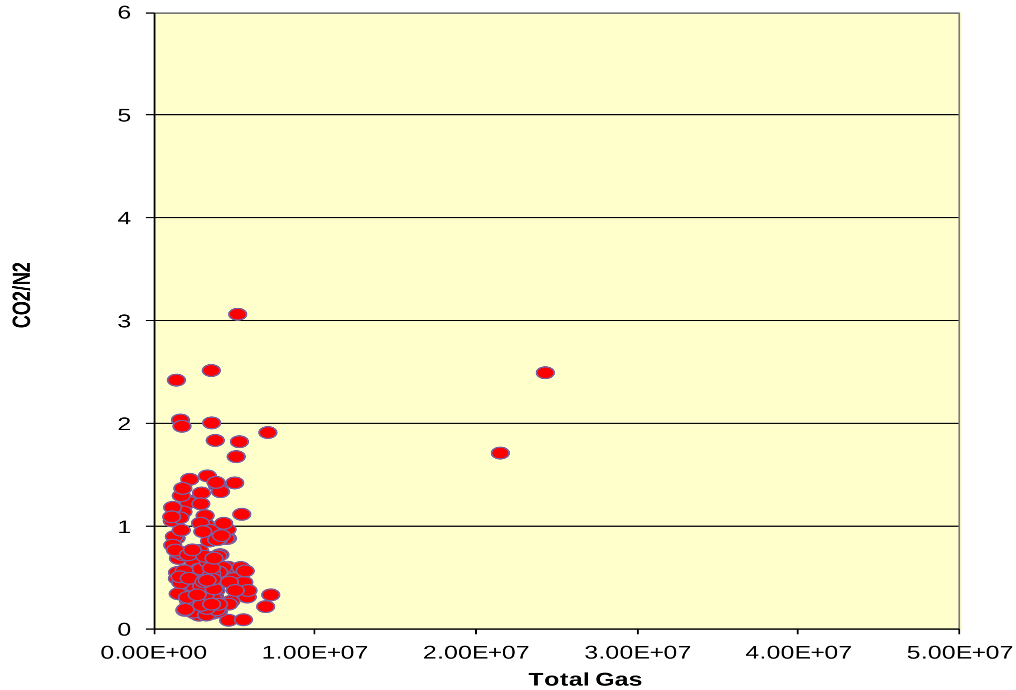
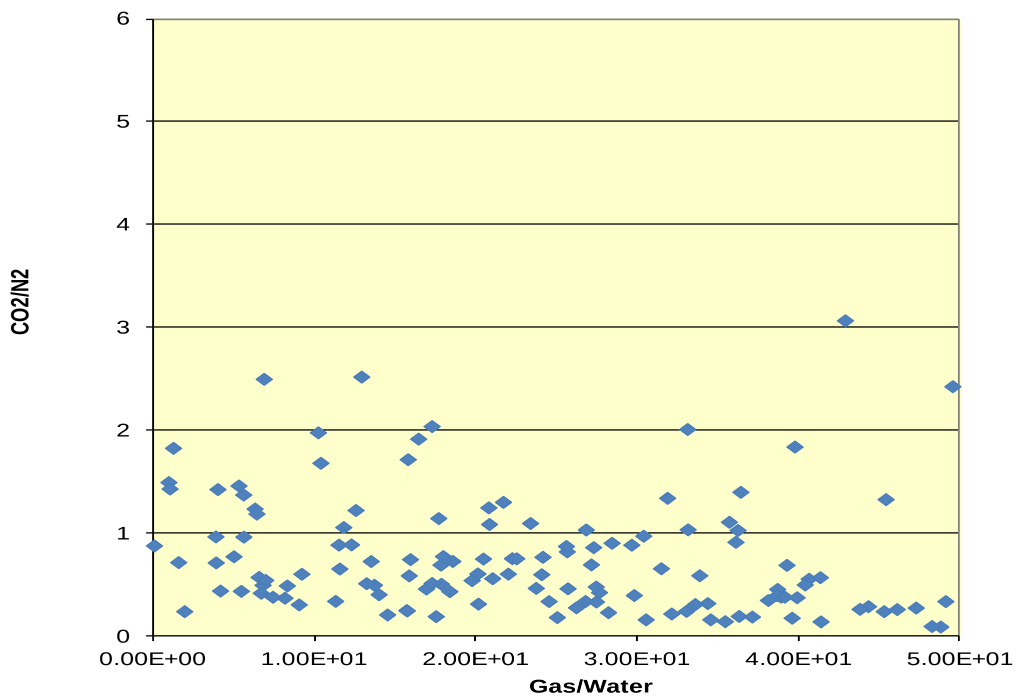
Figure F56

Hawaii Well SOH4





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Hawaii Well SOH4

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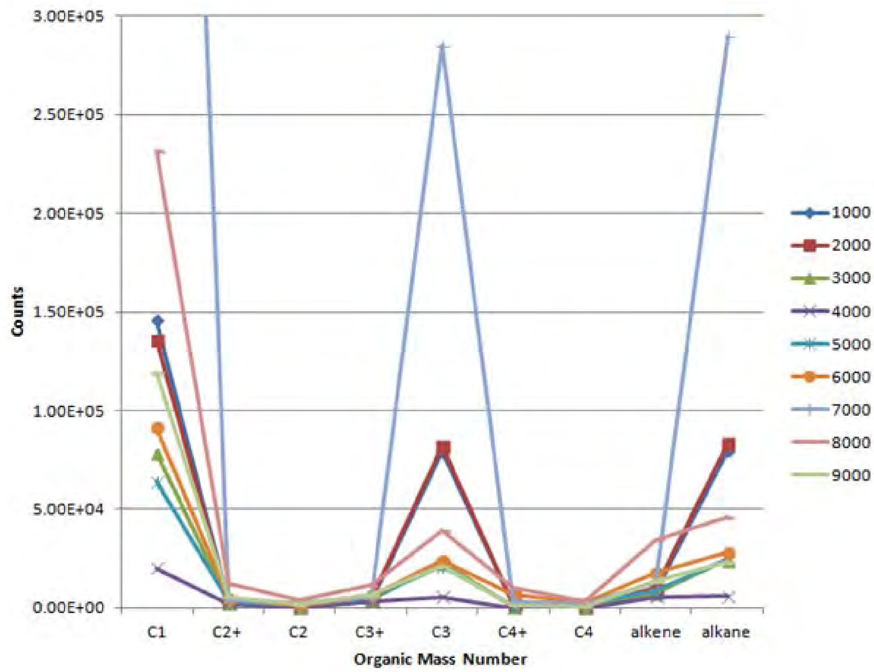
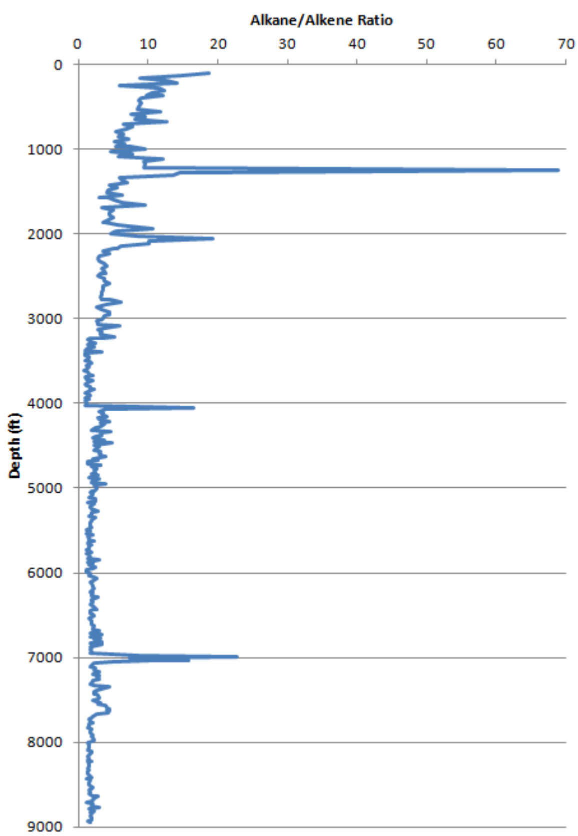
Figure F57

APPENDIX G
SHULTZ-FLORY DIAGRAMS

Fallon Well FOH#3





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Shultz-Flory Diagrams for Fallon Well FH0#3
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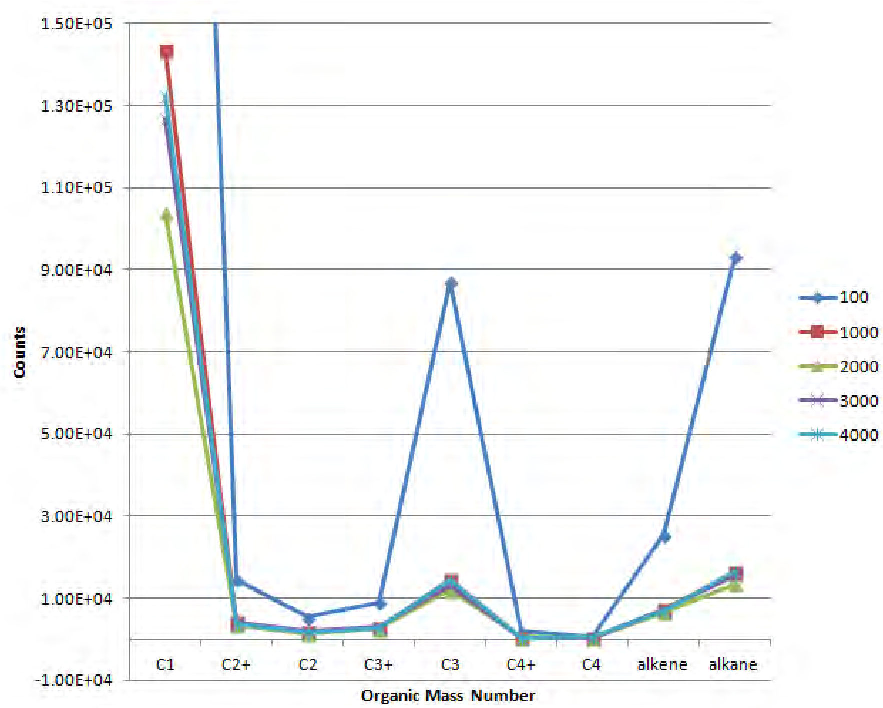
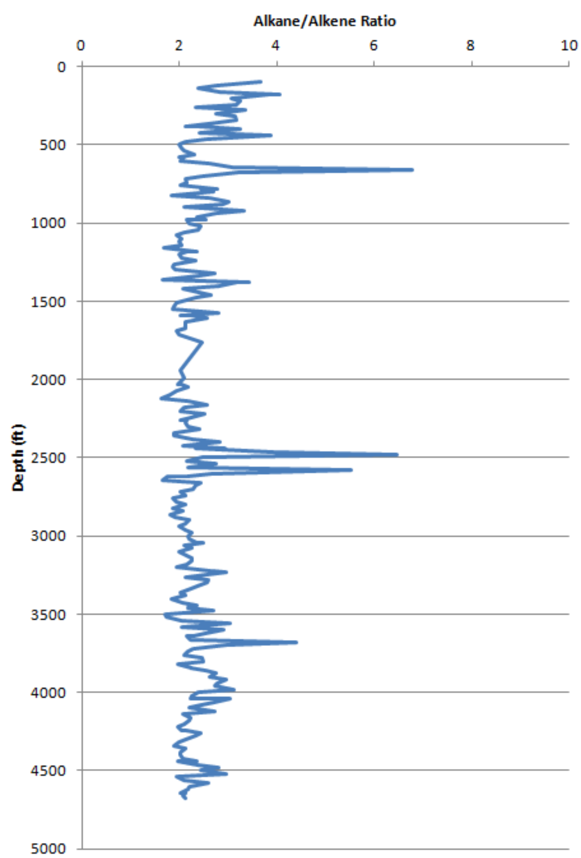
Figure G1

Hawthorne Well HWAAD#2





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Shultz-Flory Diagrams for Hawthorne Well HWAAD#2

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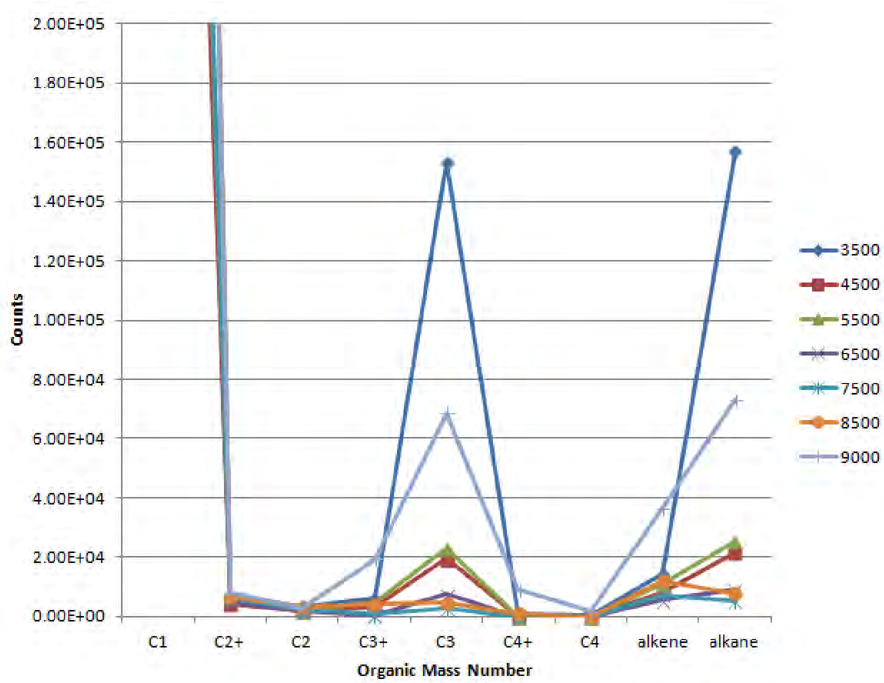
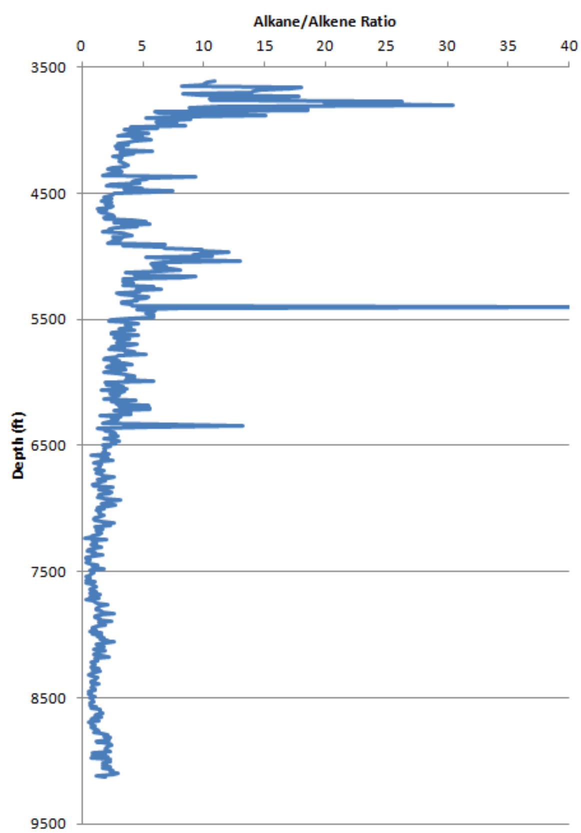
Figure G2

Salton Sea Well Elmore 16





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Shultz-Flory Diagrams for Salton Sea Well Elmore 16

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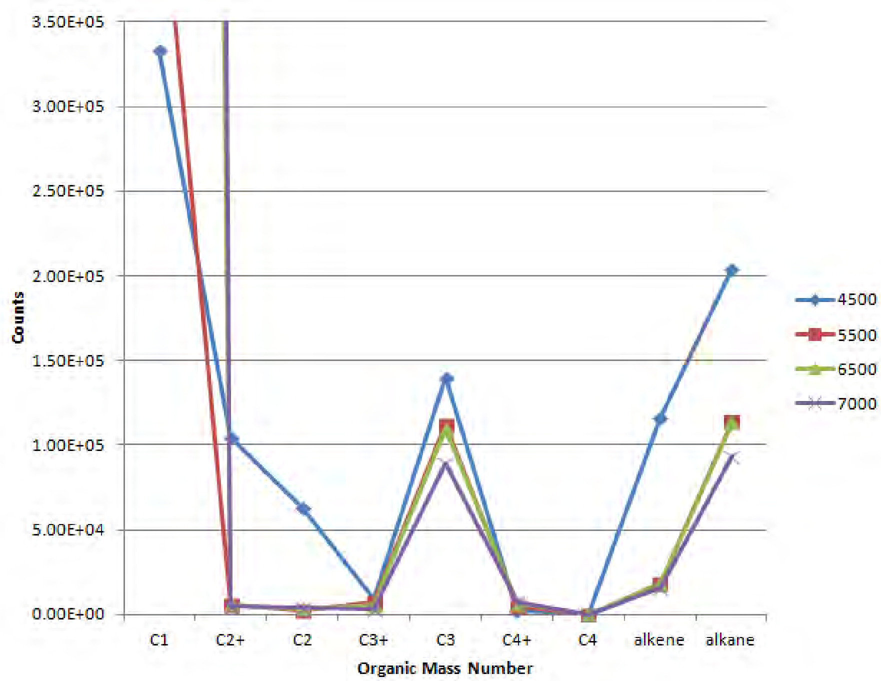
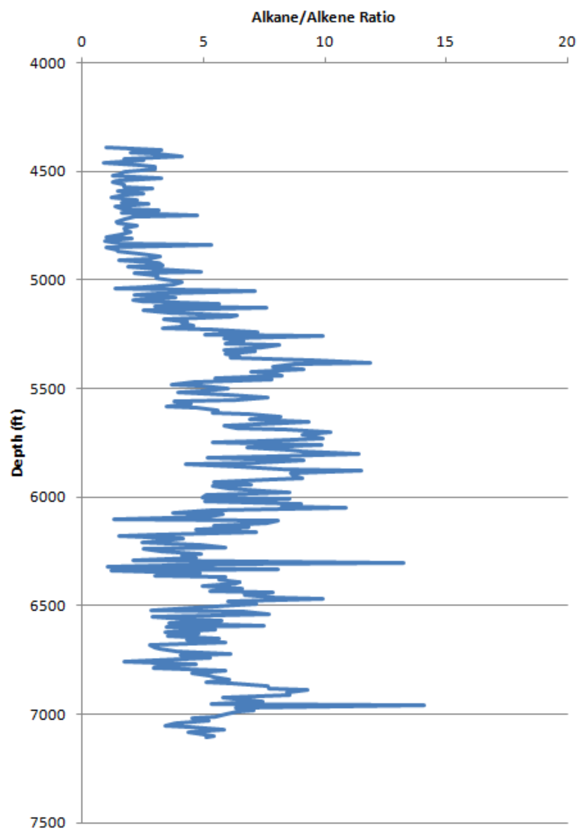
Figure G3

Salton Sea Well Sinclair 24





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Methodologies for Reservoir Characterizations Using Fluid Inclusion Gas Chemistry

Shultz-Flory Diagrams for Salton Sea Well Sinclair 24

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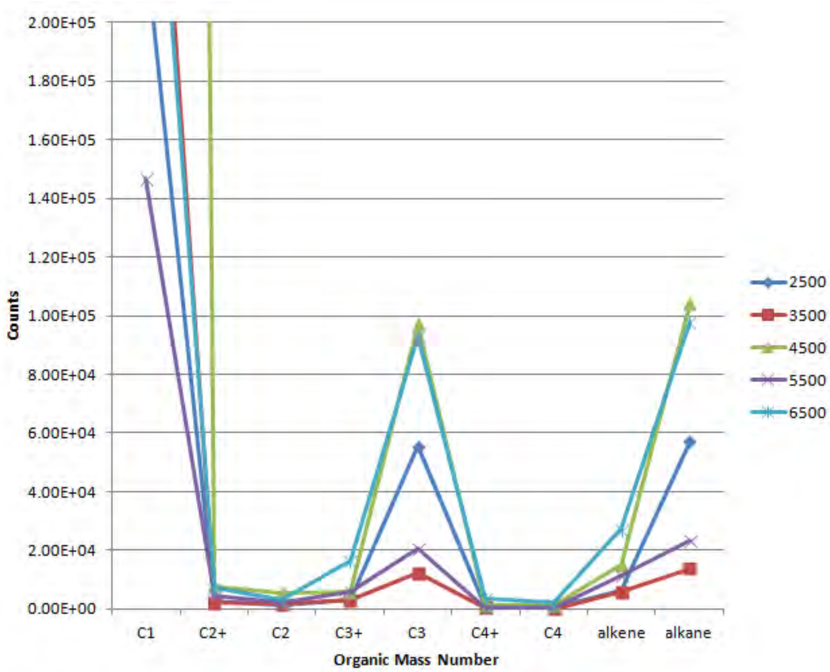
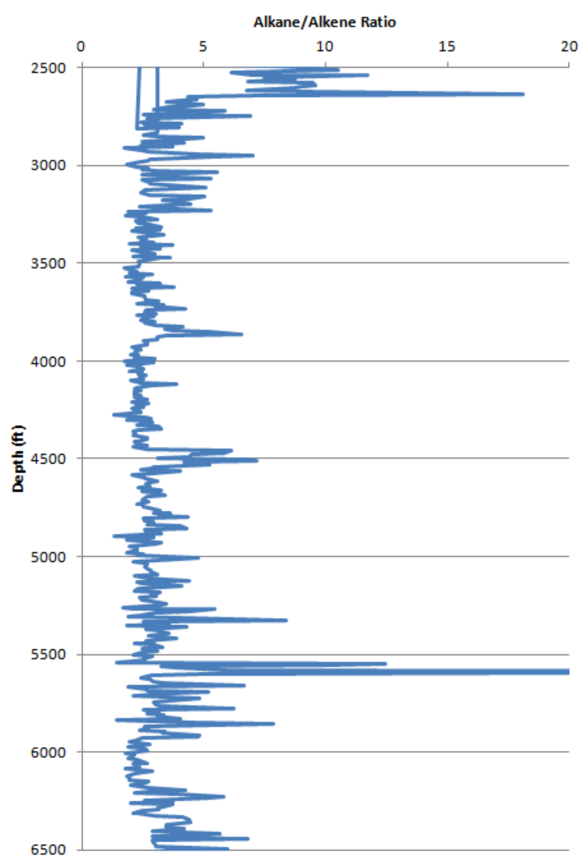
Figure G4

Kahara Well K33





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Shultz-Flory Diagrams for Kahara Well K33

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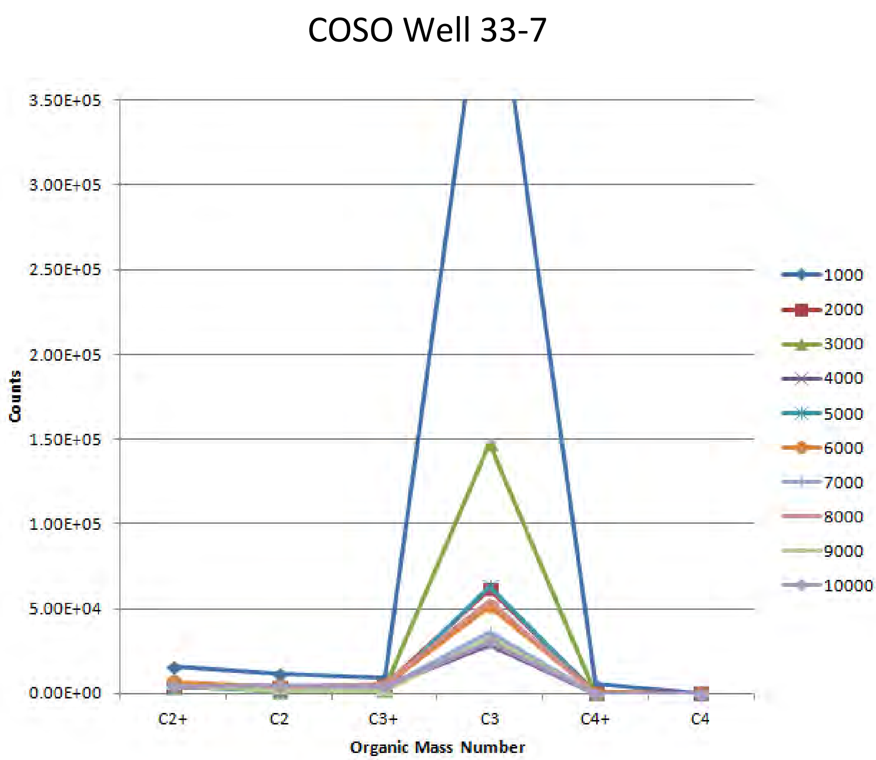
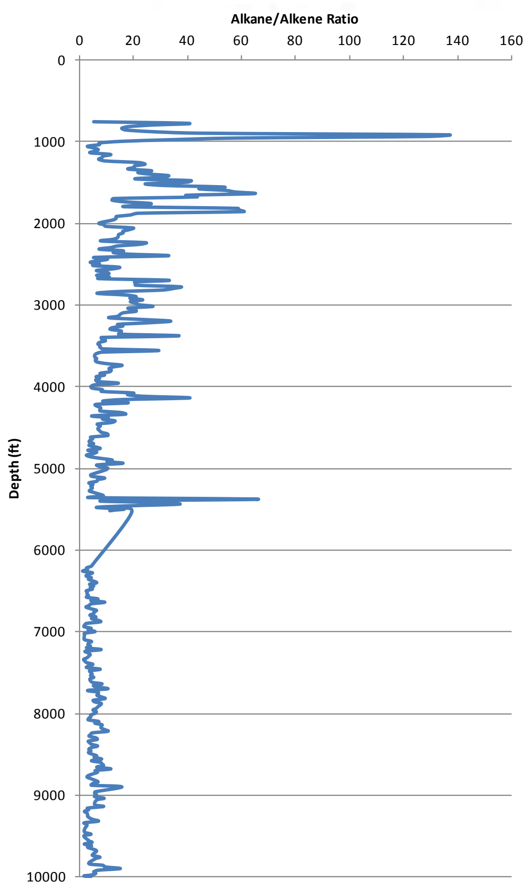
Figure G5





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Shultz-Flory Diagrams for COSO Well 33-7
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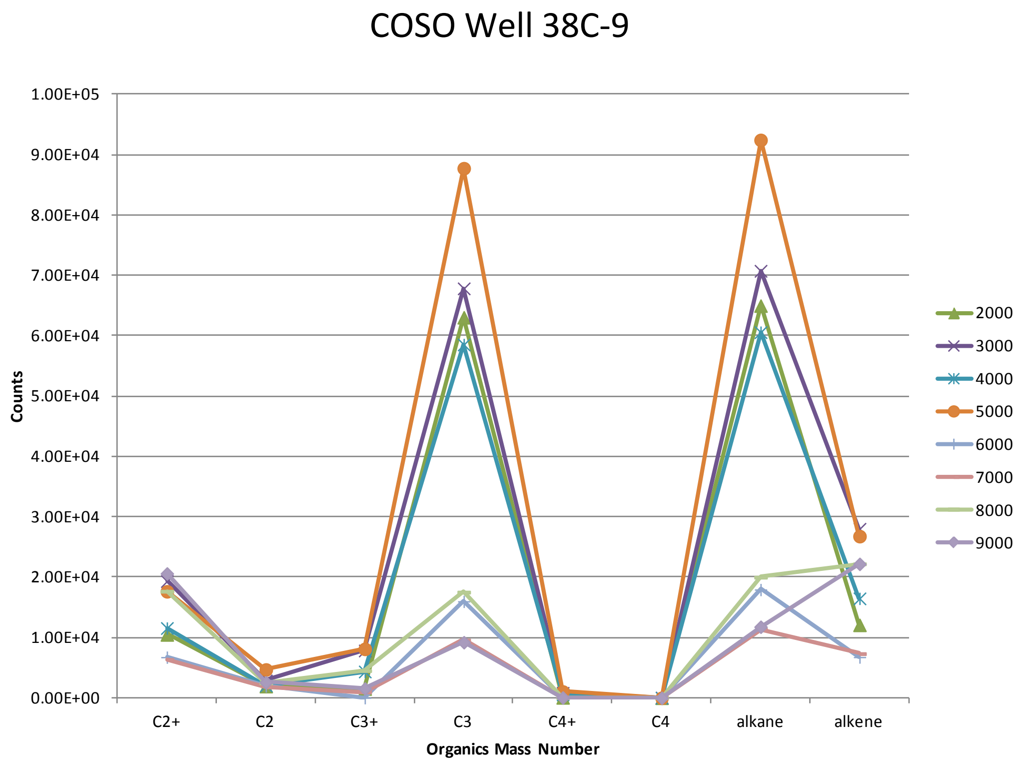
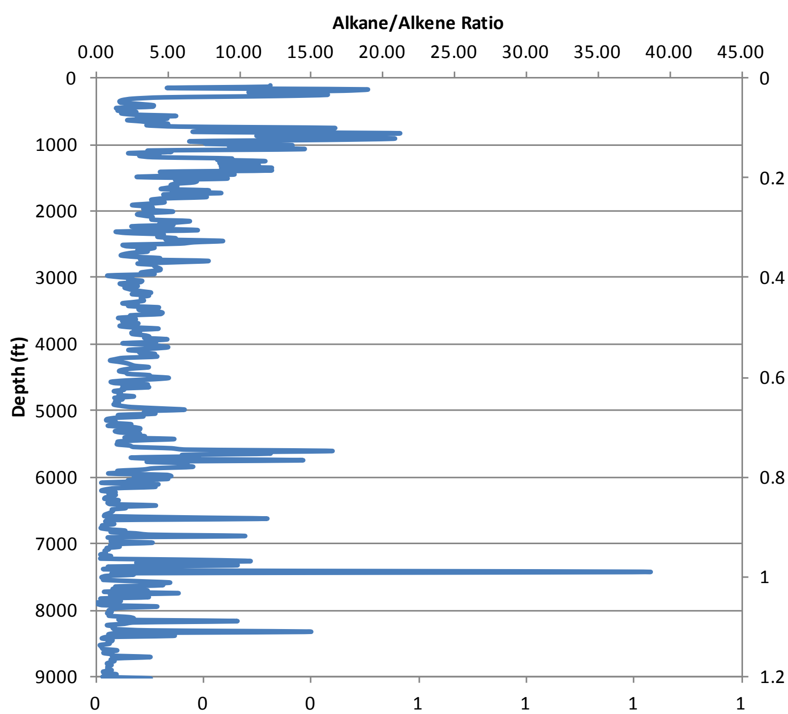
Figure G6





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Shultz-Flory Diagrams for COSO Well 38C-9

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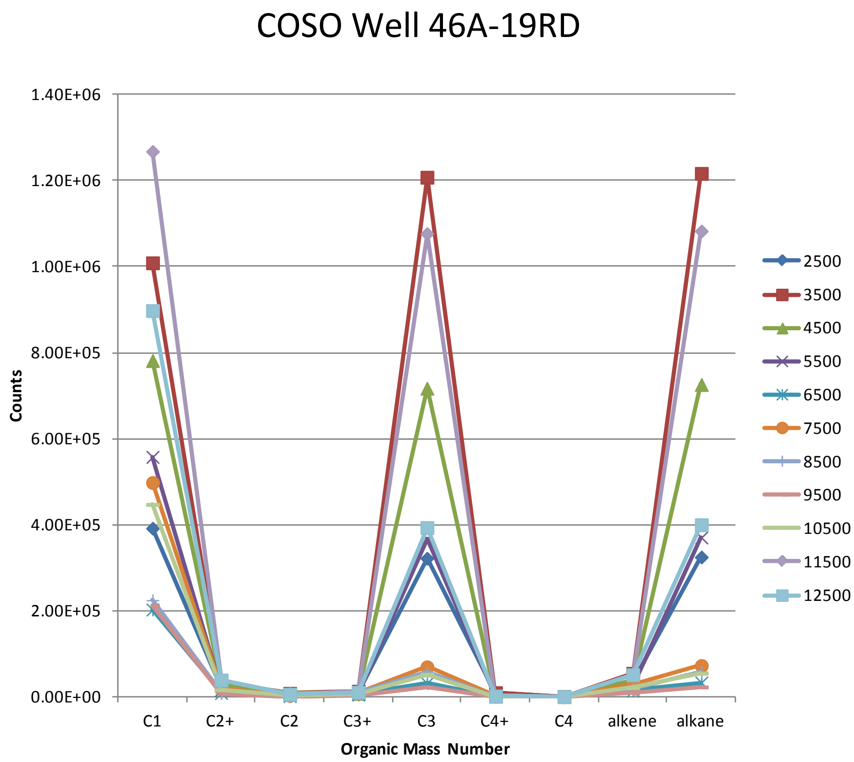
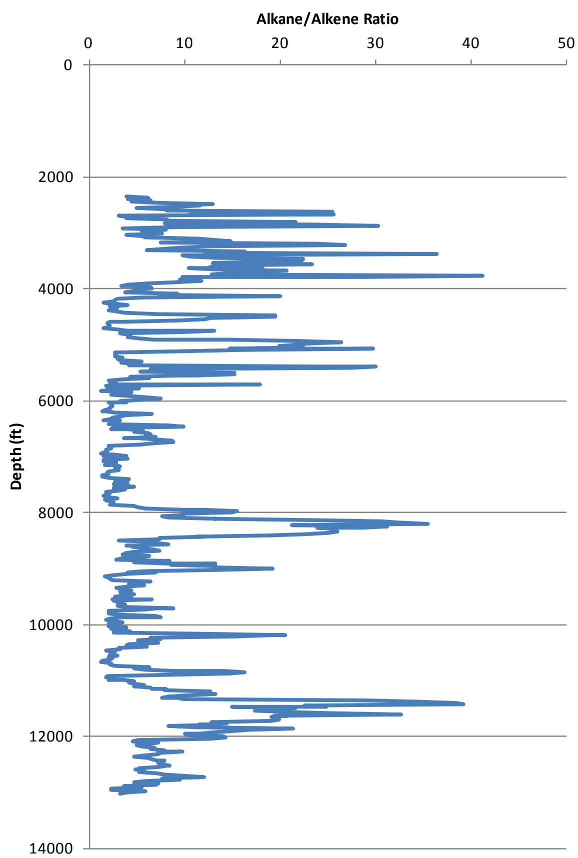
Figure G7





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Shultz-Flory Diagrams for COSO Well 46A-19RD

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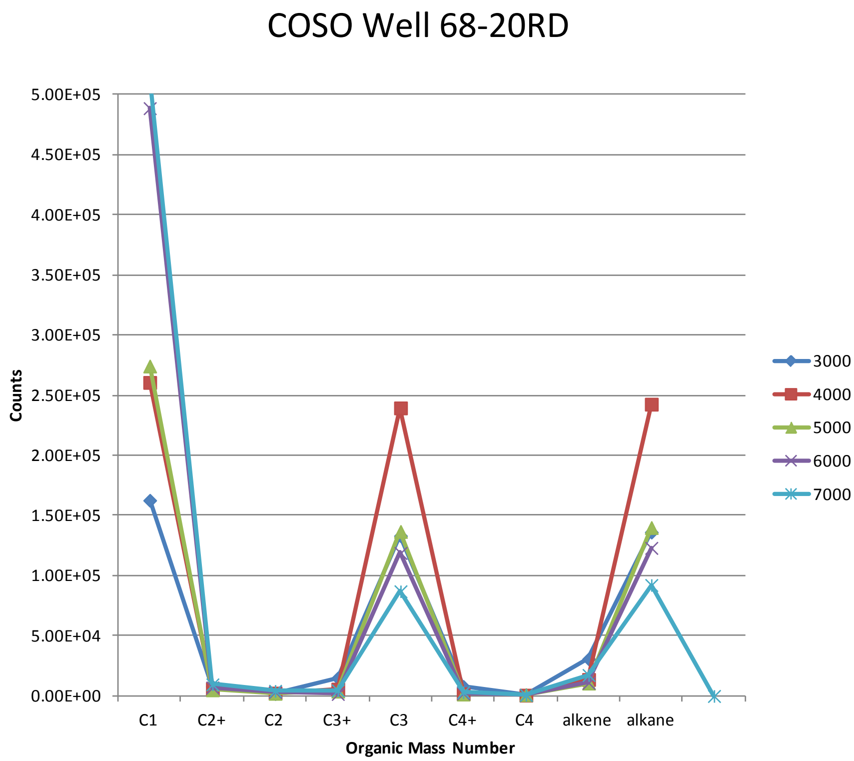
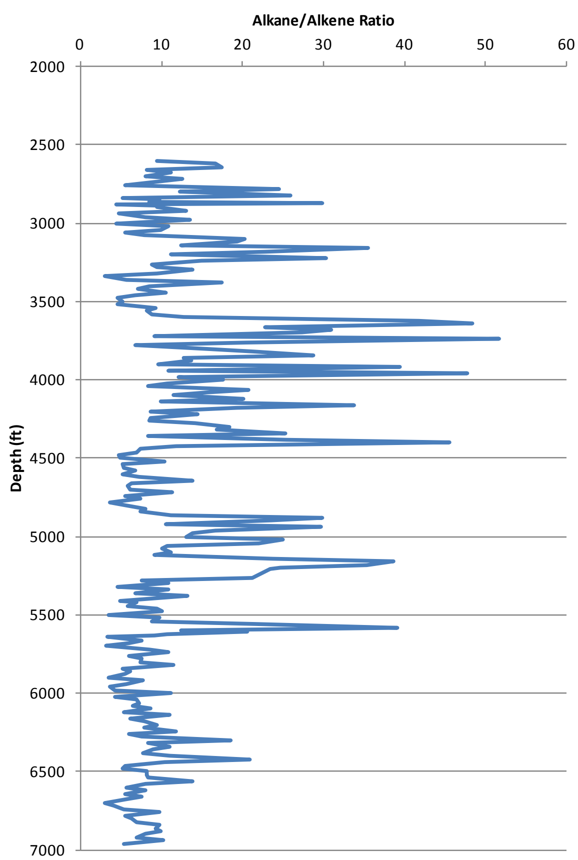
Figure G8





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Shultz-Flory Diagrams for COSO Well 68-20RD
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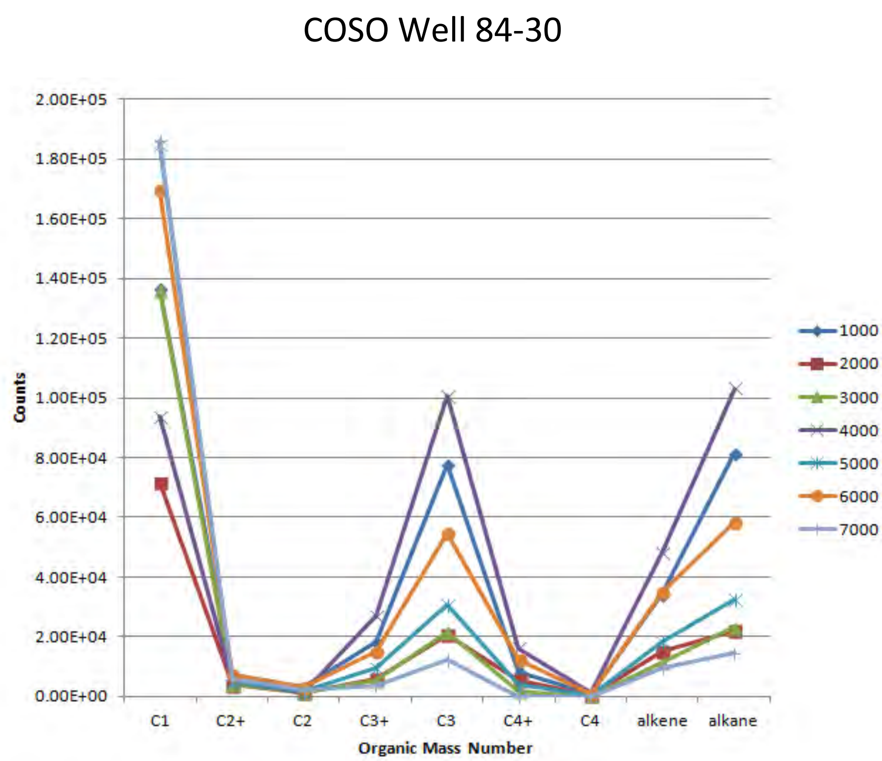
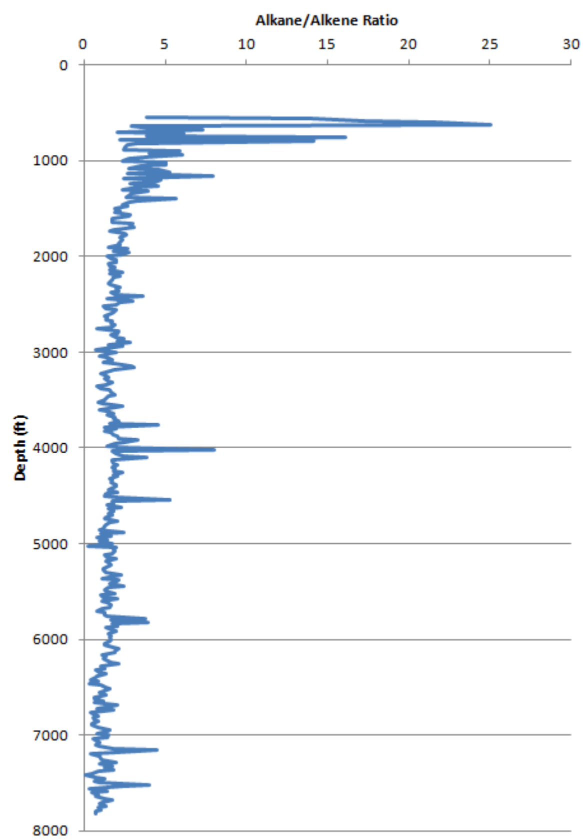
Figure G9





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Shultz-Flory Diagrams for COSO Well 84-30

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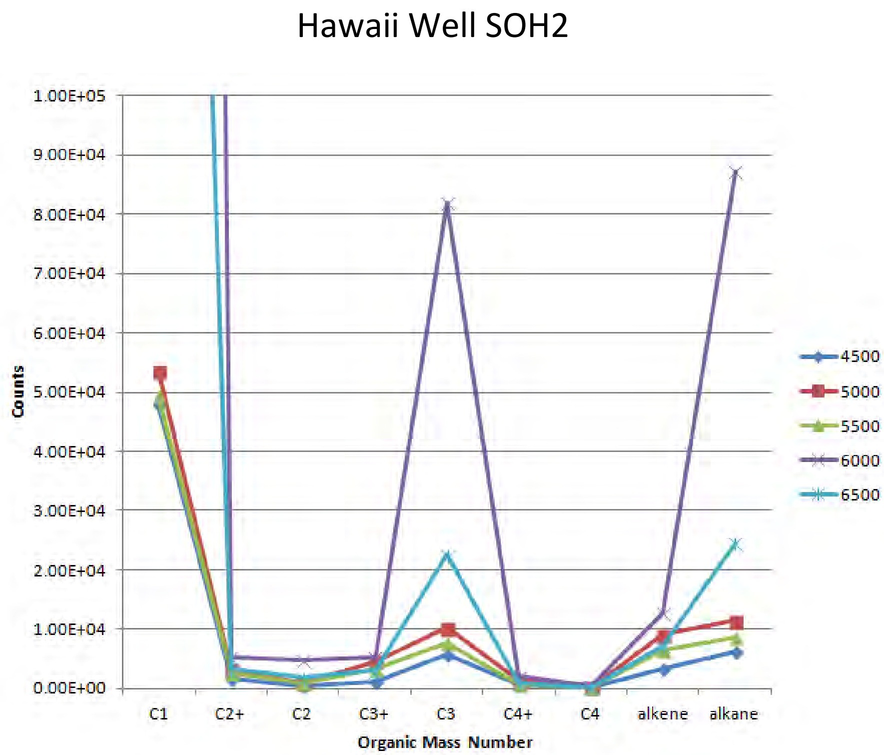
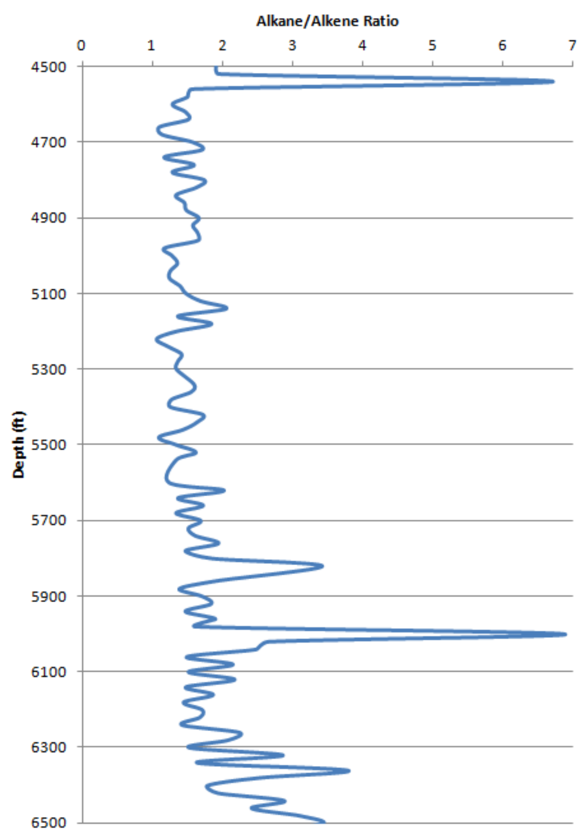
Figure G10





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Shultz-Flory Diagrams for Hawaii Well SOH2

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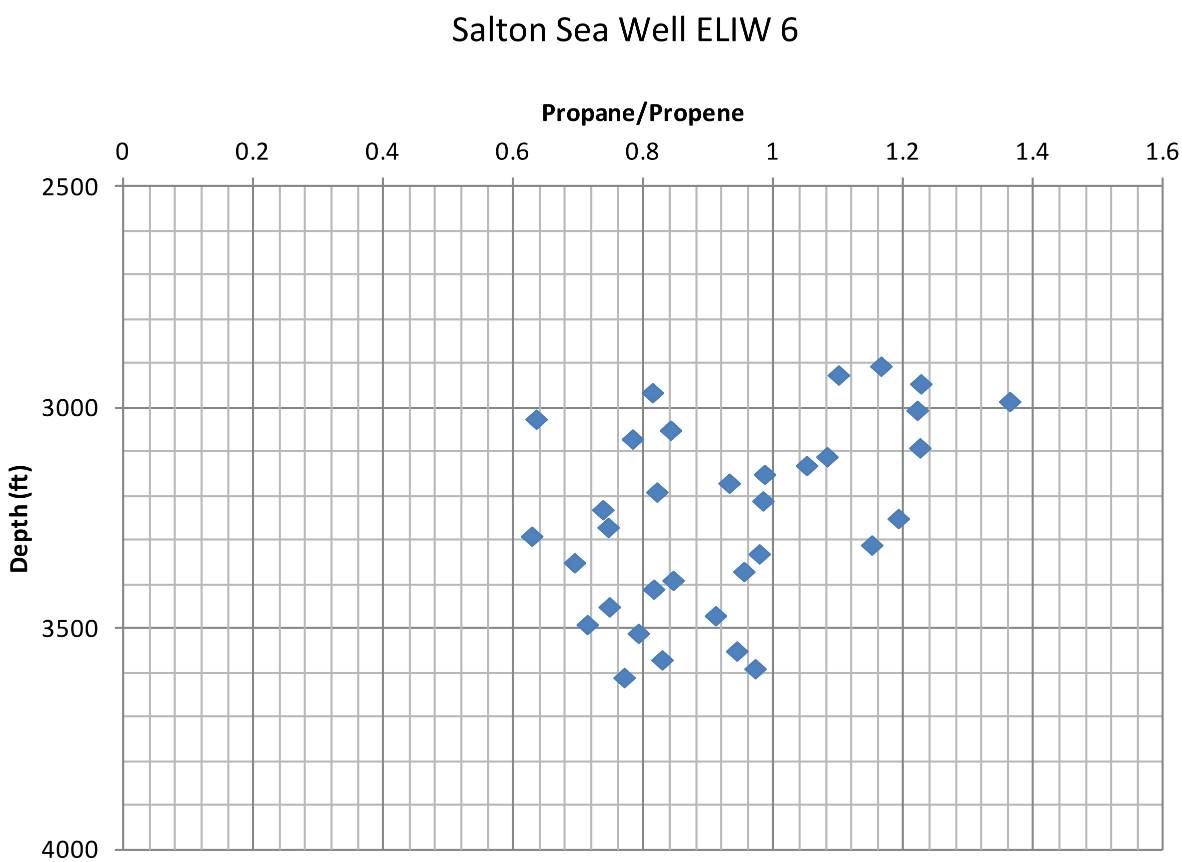
Figure G11

APPENDIX H
SALTON SEA ORGANIC PLOTS



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Salton Sea Well ELIW 6

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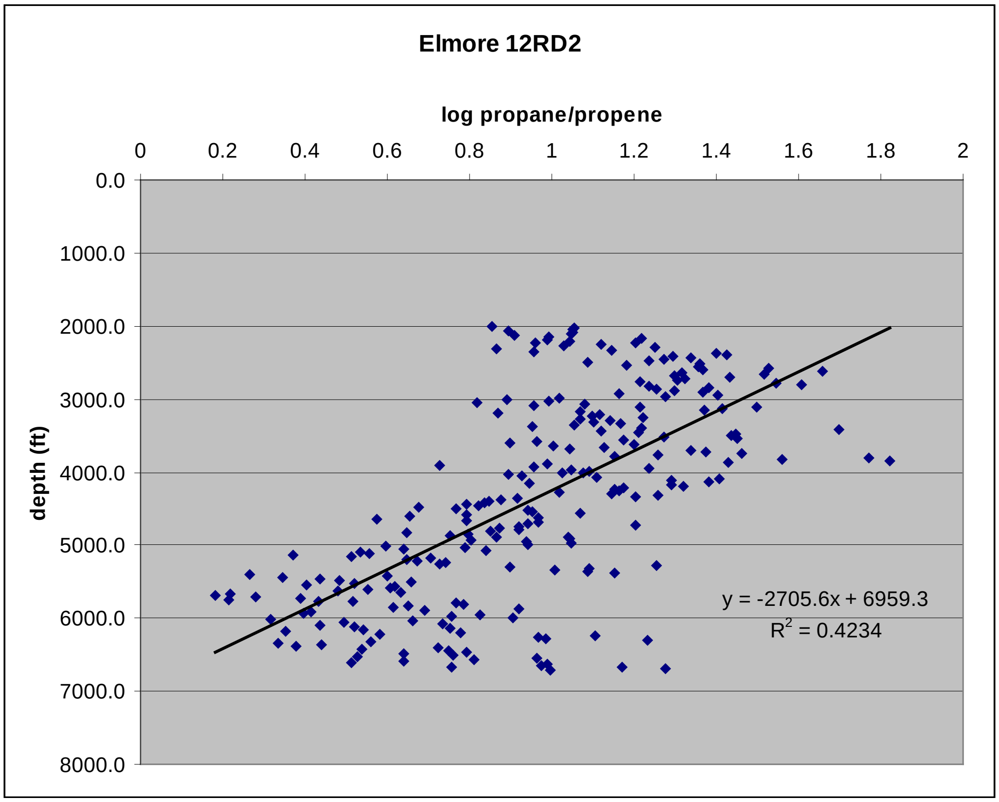
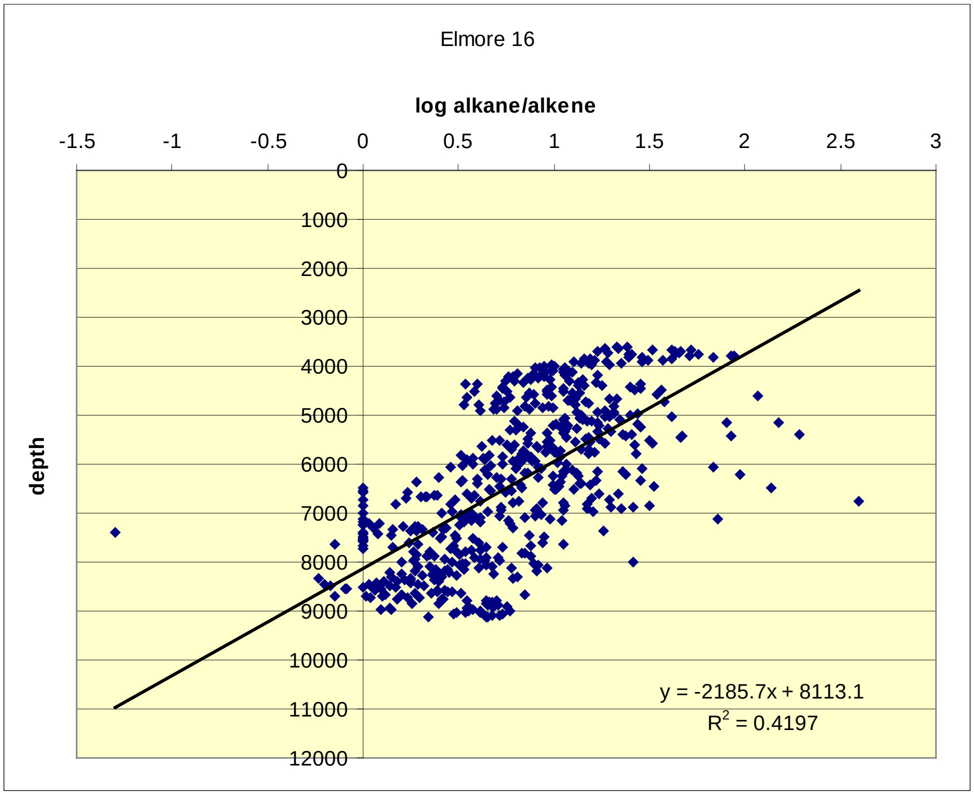
Figure H1

Salton Sea Well Elmore 12



Salton Sea Well Elmore 16



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Salton Sea Well Elmore 16

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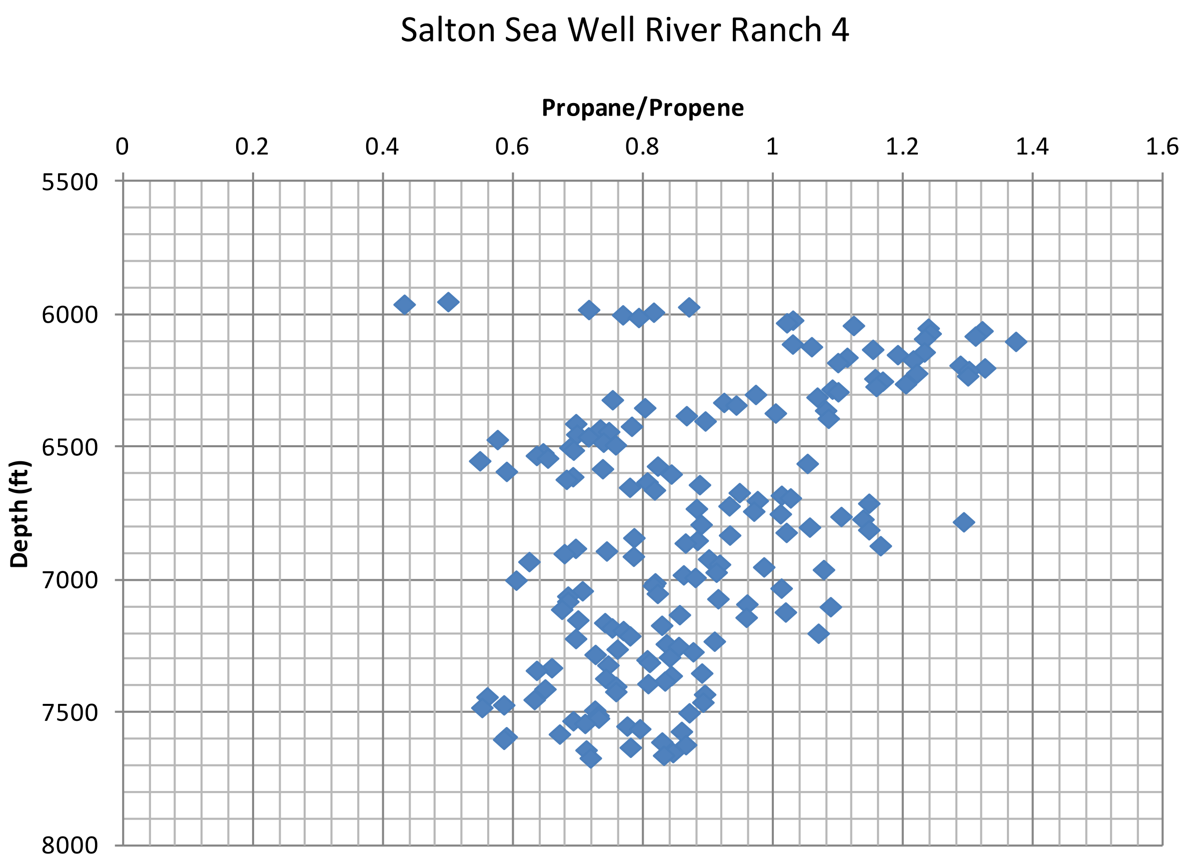
Figure H3



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Salton Sea Well River Ranch 4
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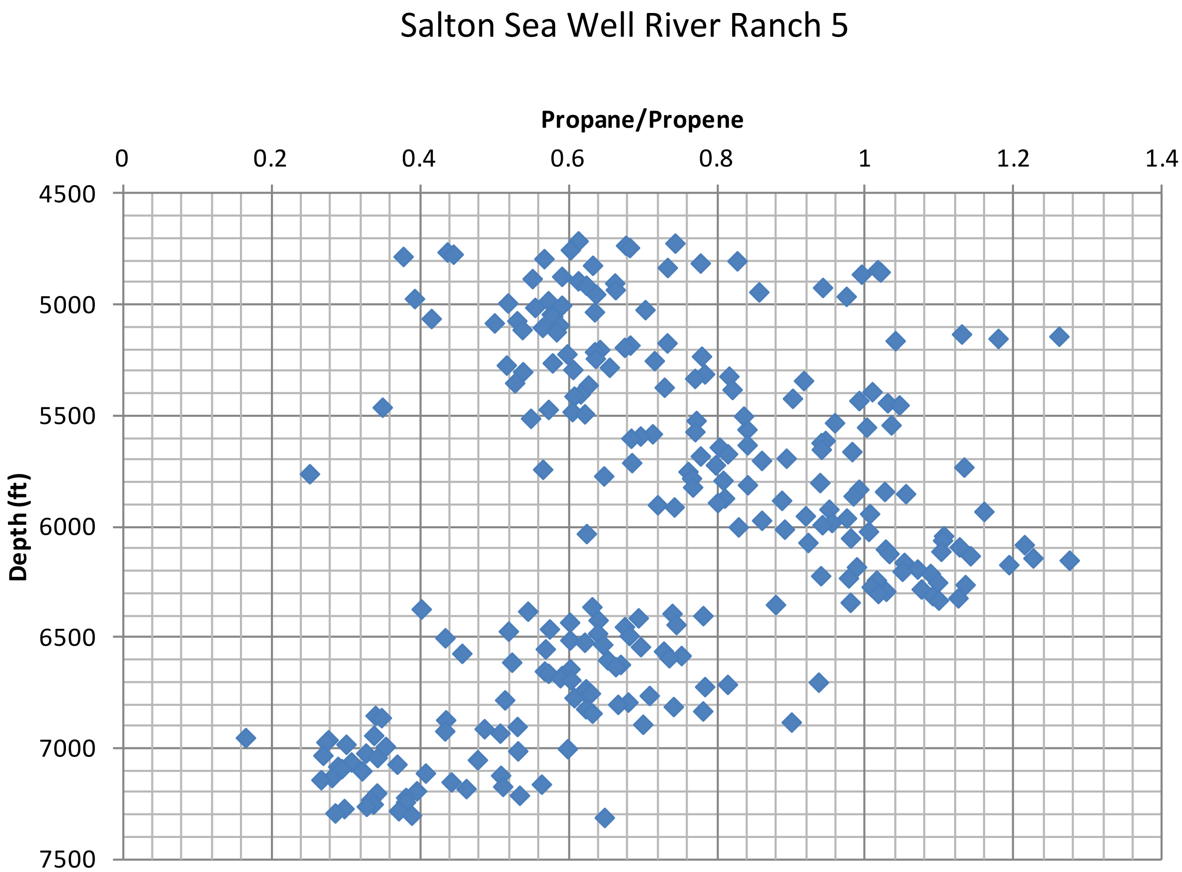
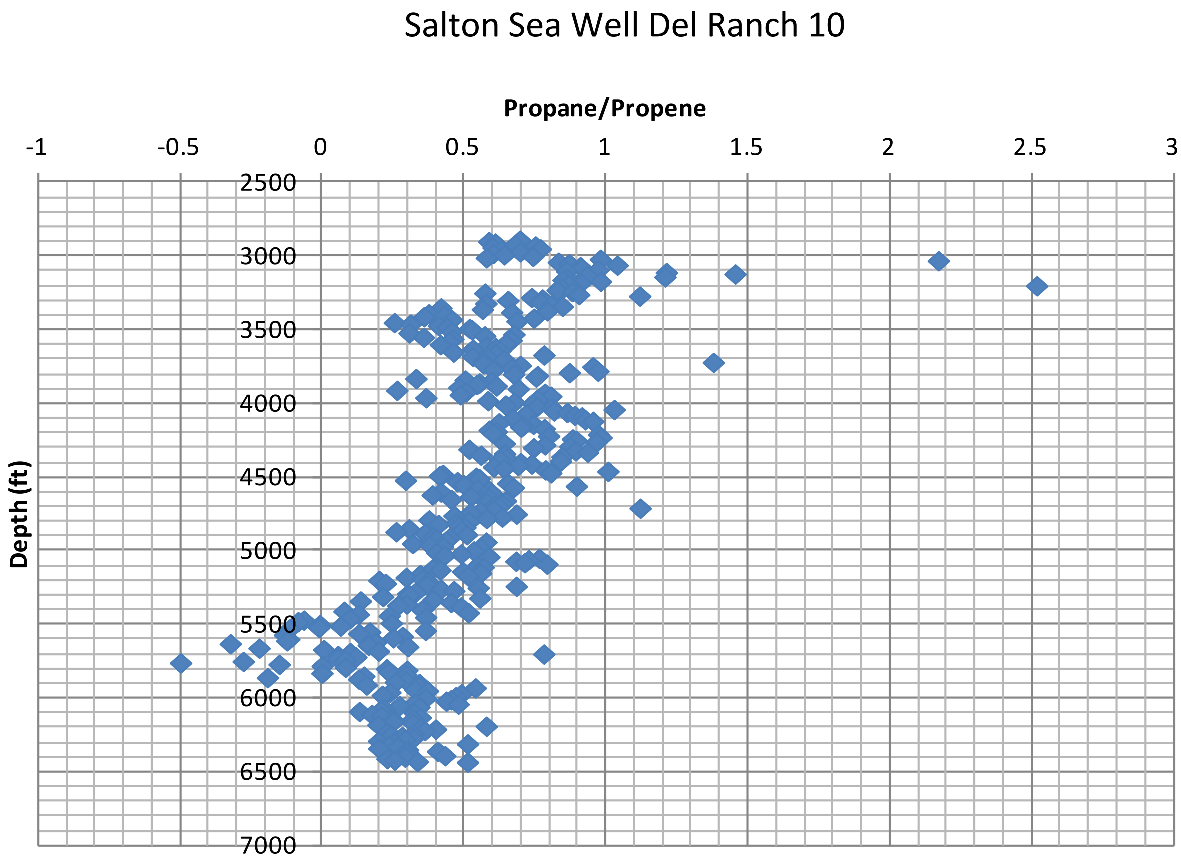
Figure H4



Salton Sea Well River Ranch 5
Propane/Propene
0
0.2
0.4
0.6
0.8
1
1.2
1.4
4500
5000
5500
6000
6500
7000
7500
Depth (ft)



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Salton Sea Well Del Ranch 10
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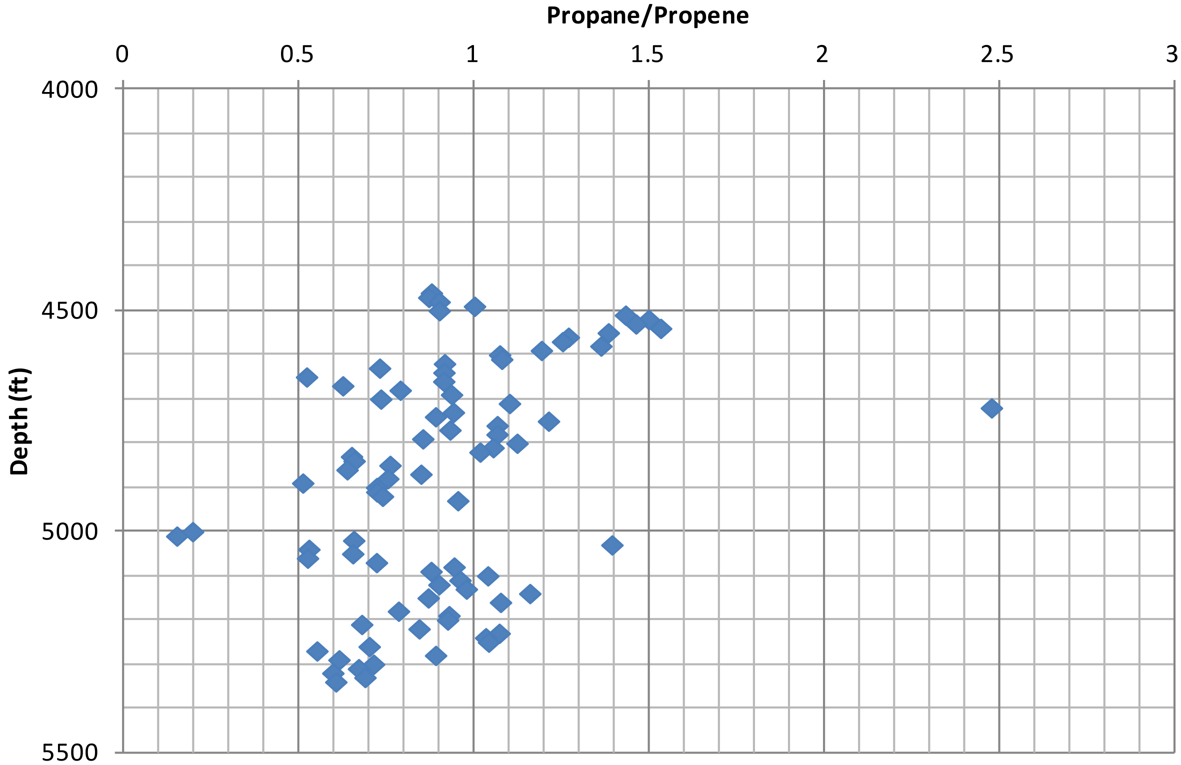
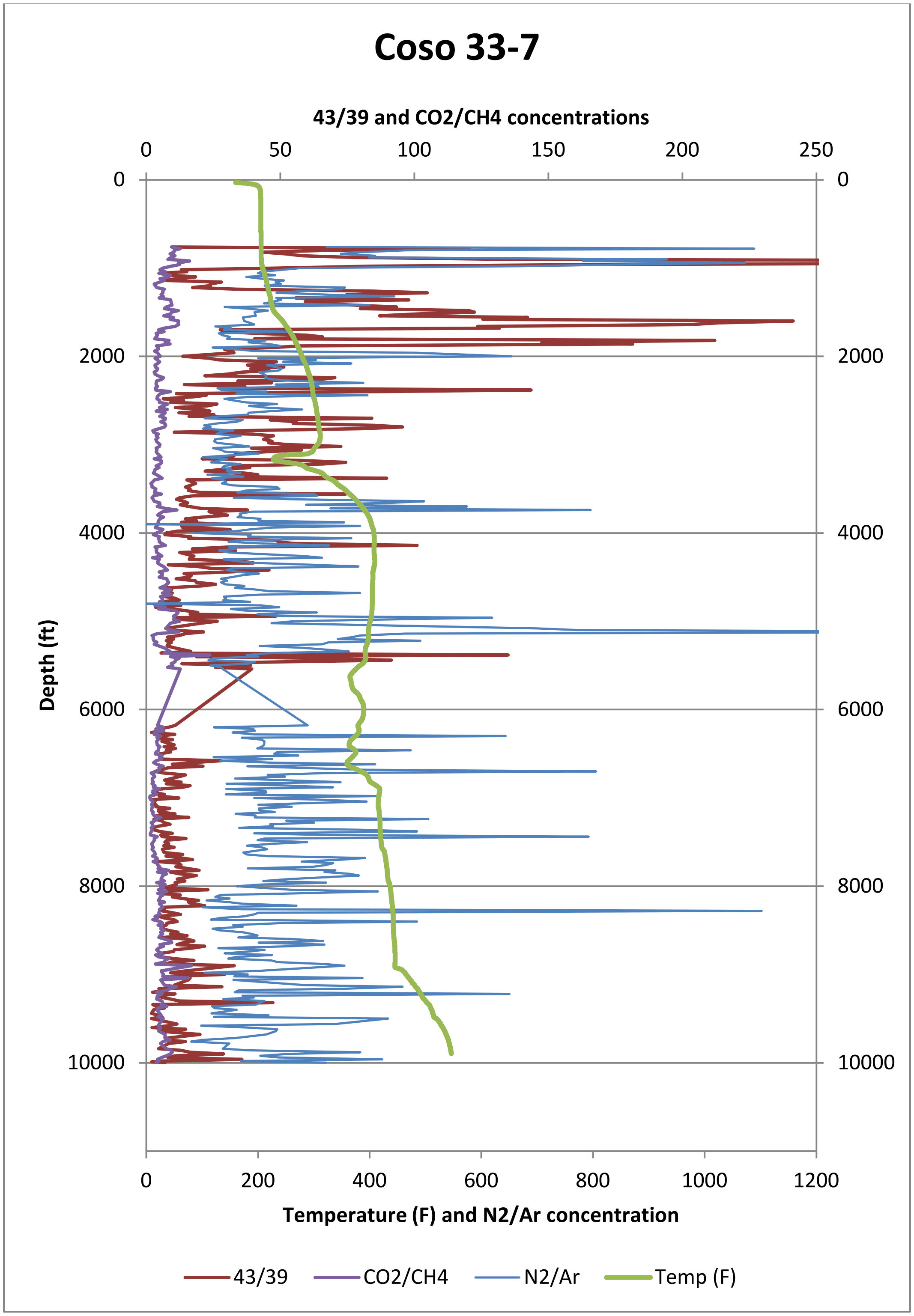
Figure H6

Salton Sea Well Vulcan M10

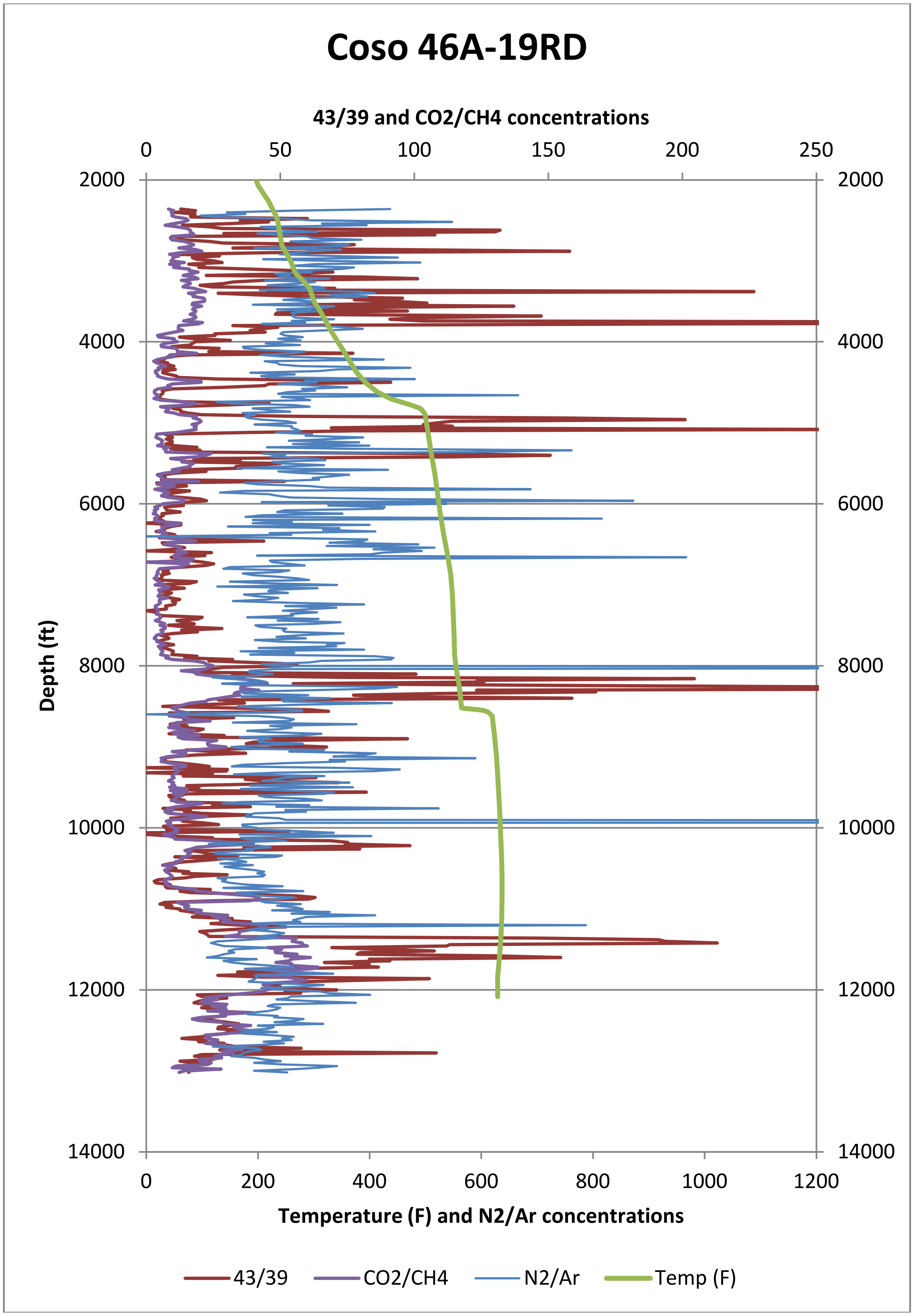


APPENDIX I

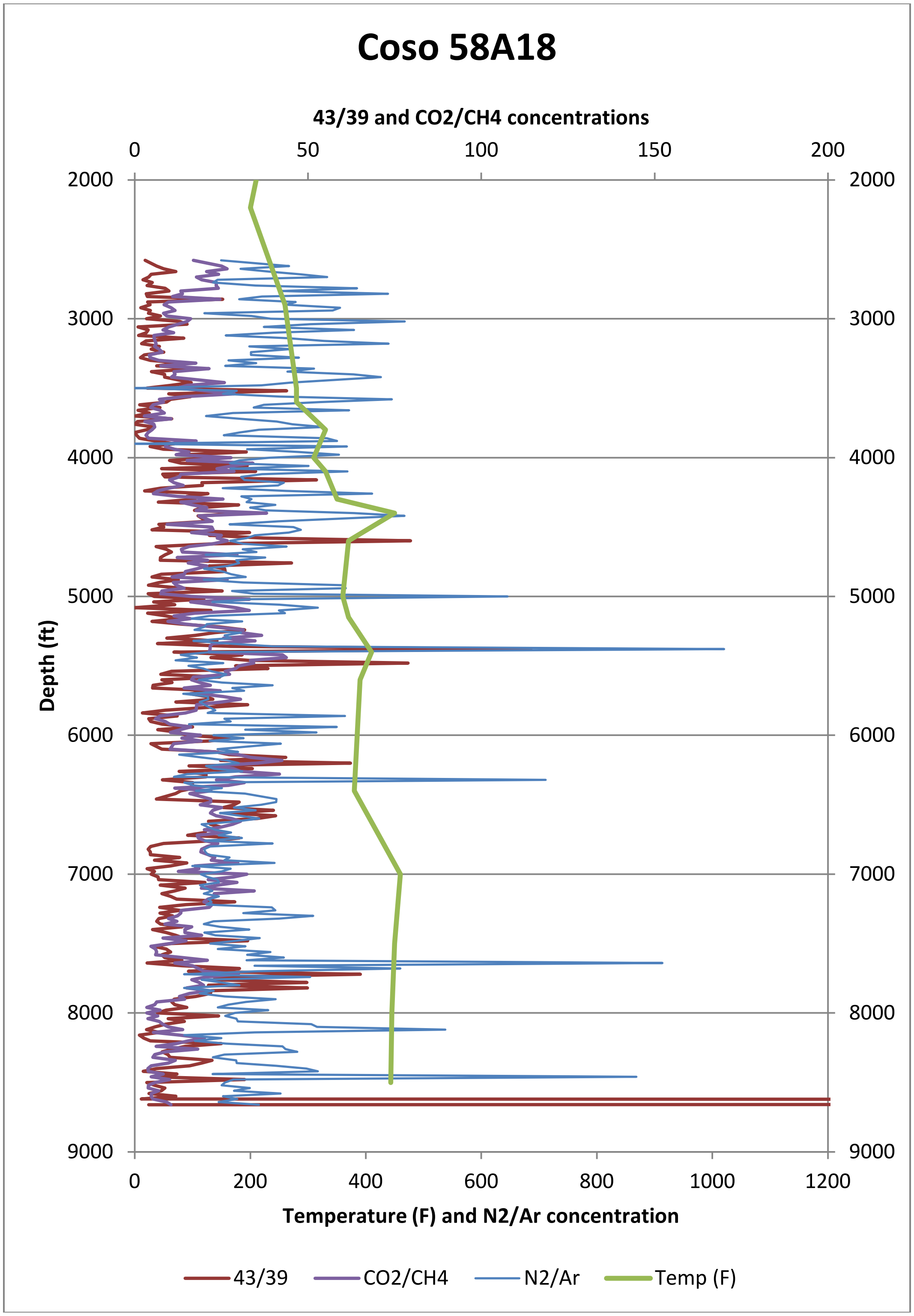
TEMPERATURE VERSUS GAS RATIOS

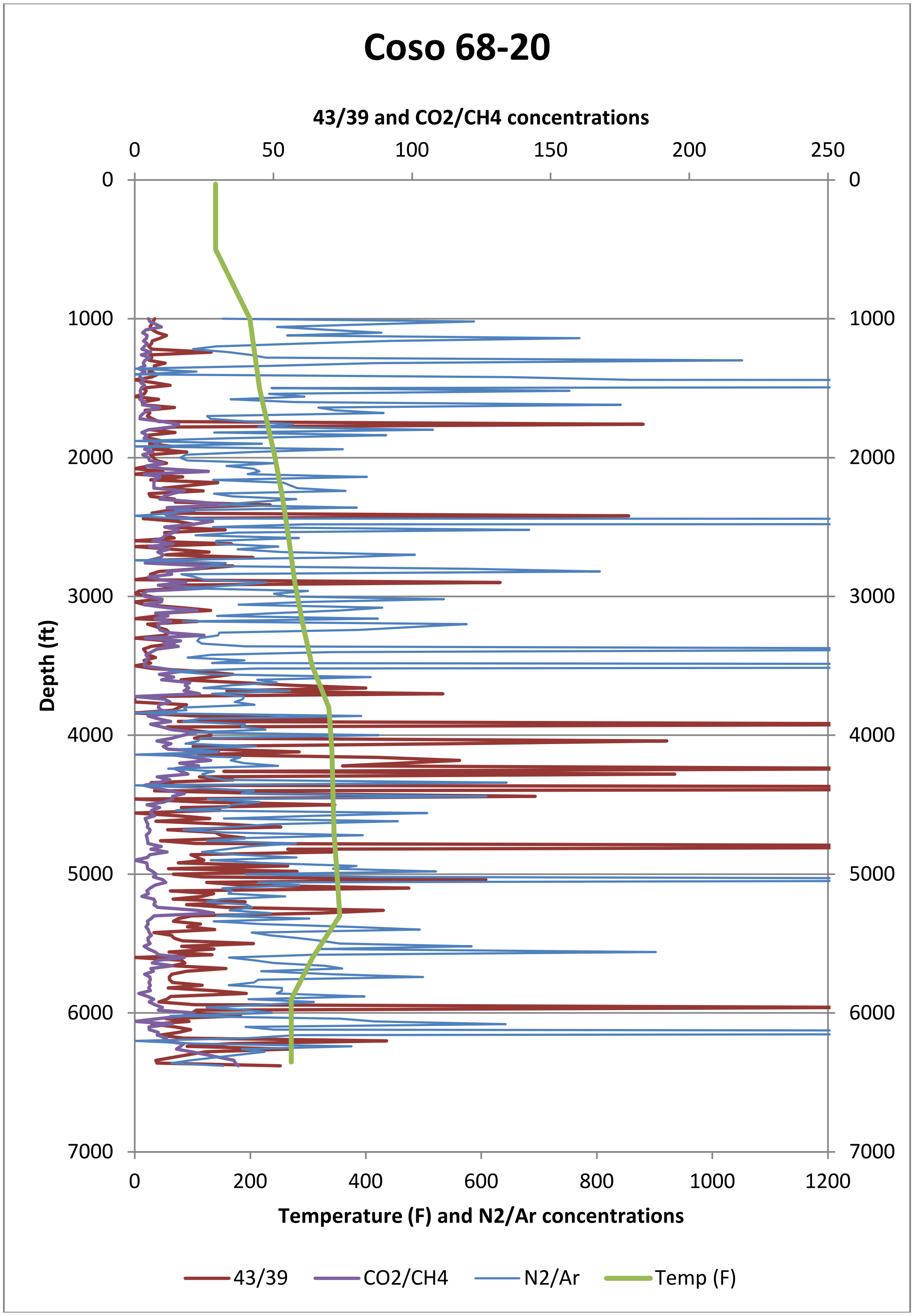


Coso 33-7
43/39 and CO2/CH4 concentrations
0
50
100
150
200
250
0
2000
4000
6000
8000
10000
0
2000
4000
6000
8000
10000
Depth (ft)
0
200
400
600
800
1000
1200
Temperature (F) and N2/Ar concentration
43/39
CO2/CH4
N2/Ar
Temp (F)

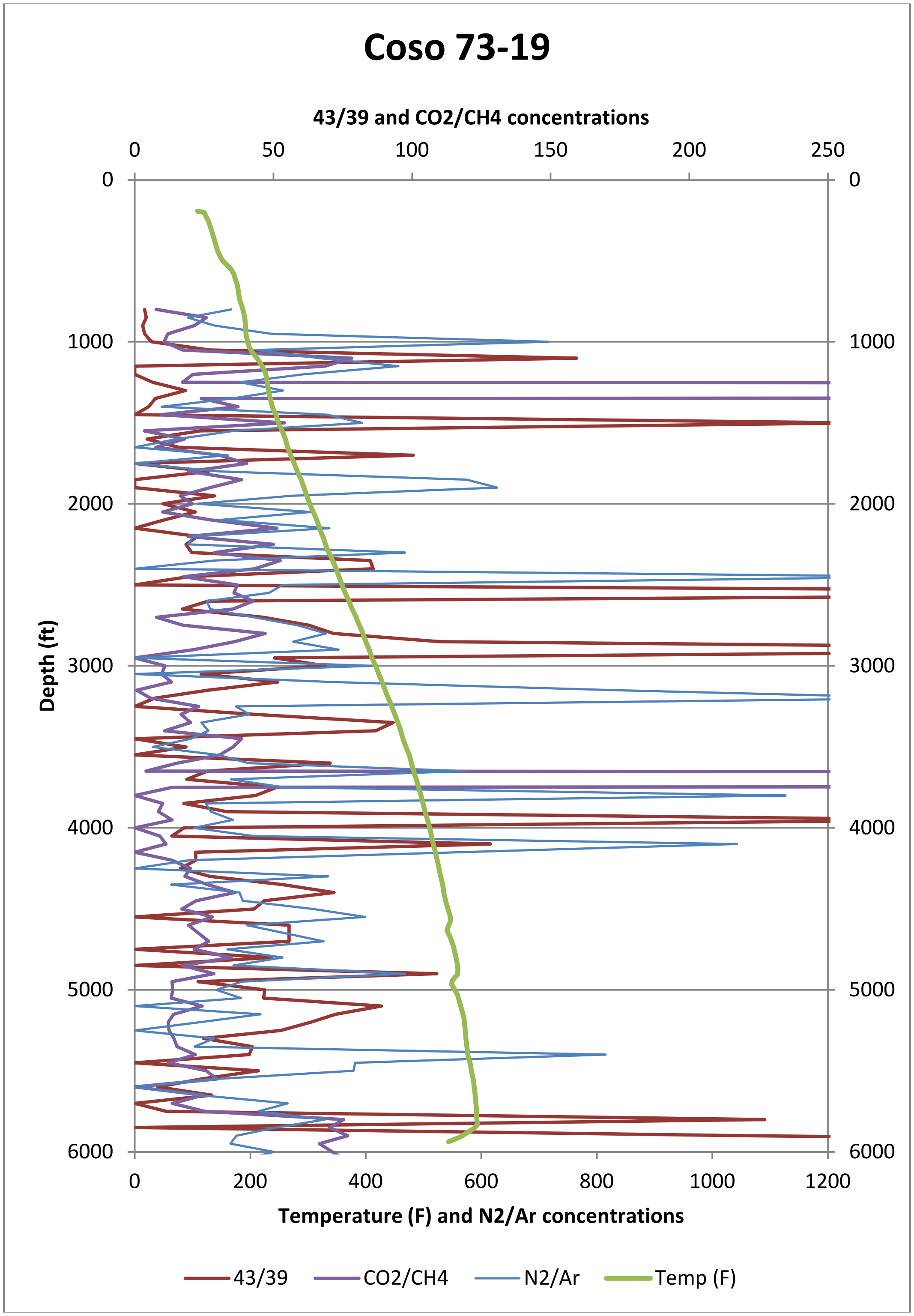


Coso 46A-19RD
43/39 and CO2/CH4 concentrations
0
50
100
150
200
250
2000
4000
6000
8000
10000
12000
14000
Depth (ft)
200
400
600
800
1000
1200
Temperature (F) and N2/Ar concentrations
43/39
CO2/CH4
N2/Ar
Temp (F)

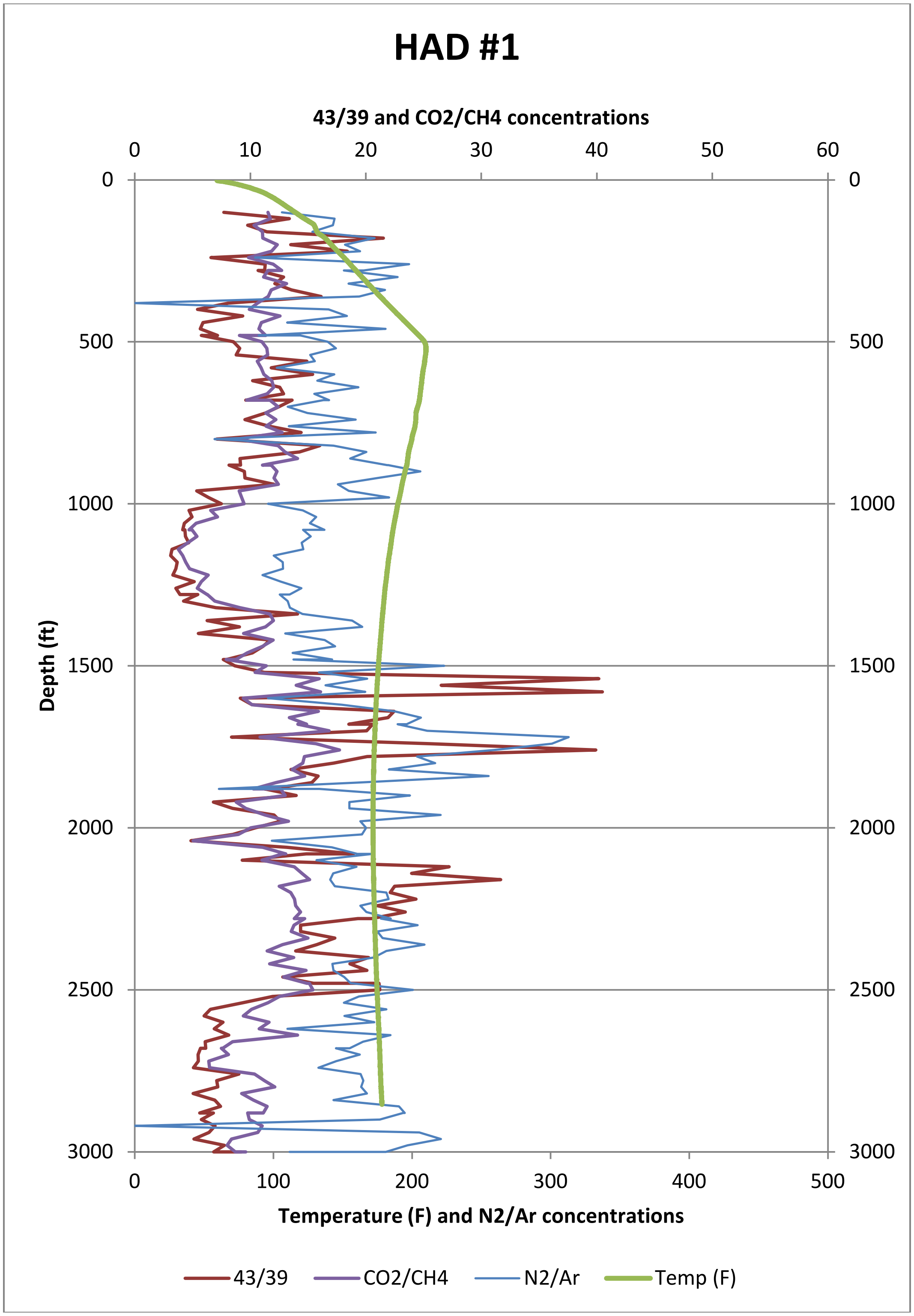

Coso 58A18
43/39 and CO2/CH4 concentrations
0
50
100
150
200
2000
3000
4000
5000
6000
7000
8000
9000
Depth (ft)
0
200
400
600
800
1000
1200
Temperature (F) and N2/Ar concentration
43/39
CO2/CH4
N2/Ar
Temp (F)



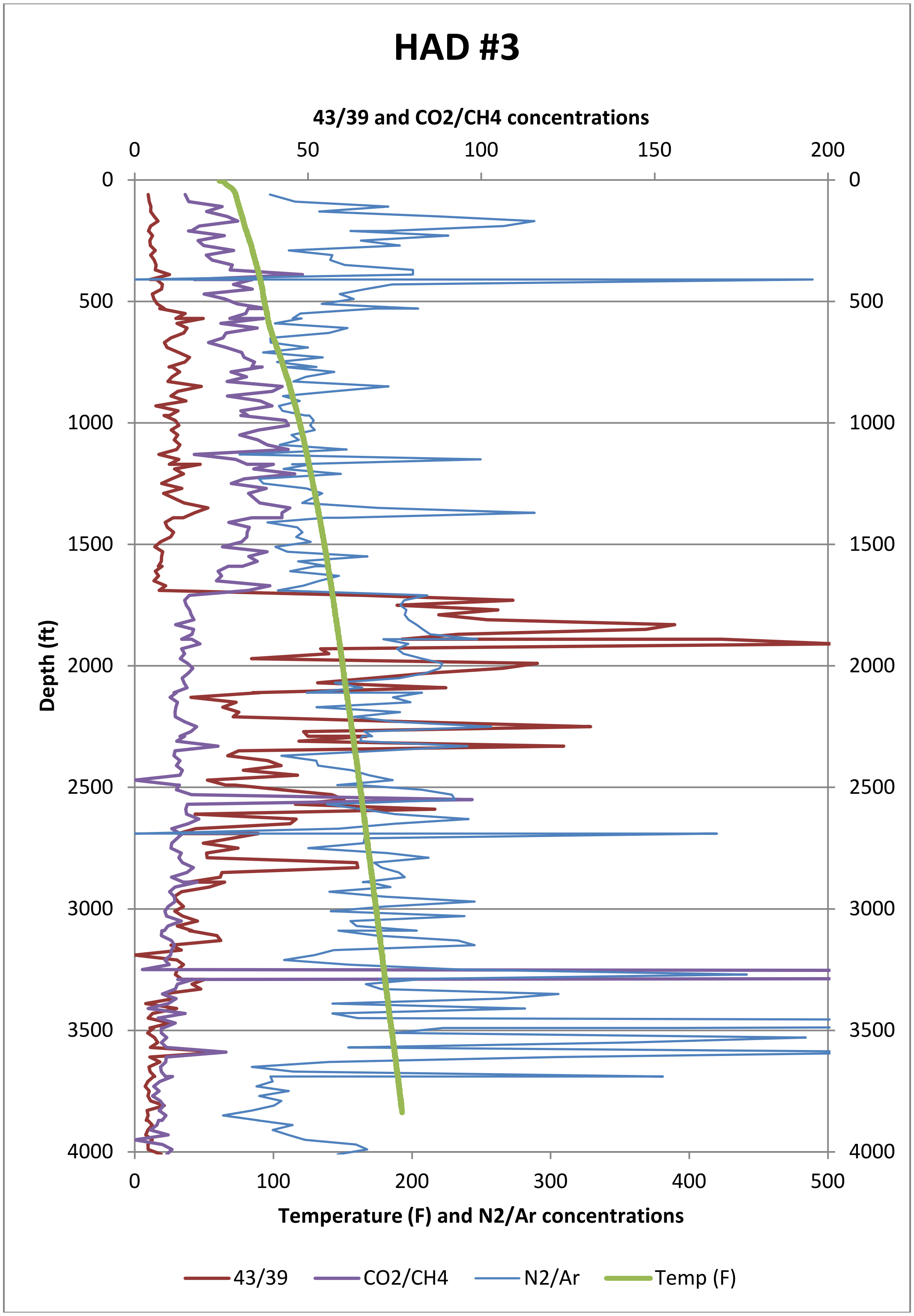
Coso 68-20
43/39 and CO2/CH4 concentrations
0
50
100
150
200
250
Depth (ft)
0
1000
2000
3000
4000
5000
6000
7000
0
200
400
600
800
1000
1200
Temperature (F) and N2/Ar concentrations
43/39
CO2/CH4
N2/Ar
Temp (F)



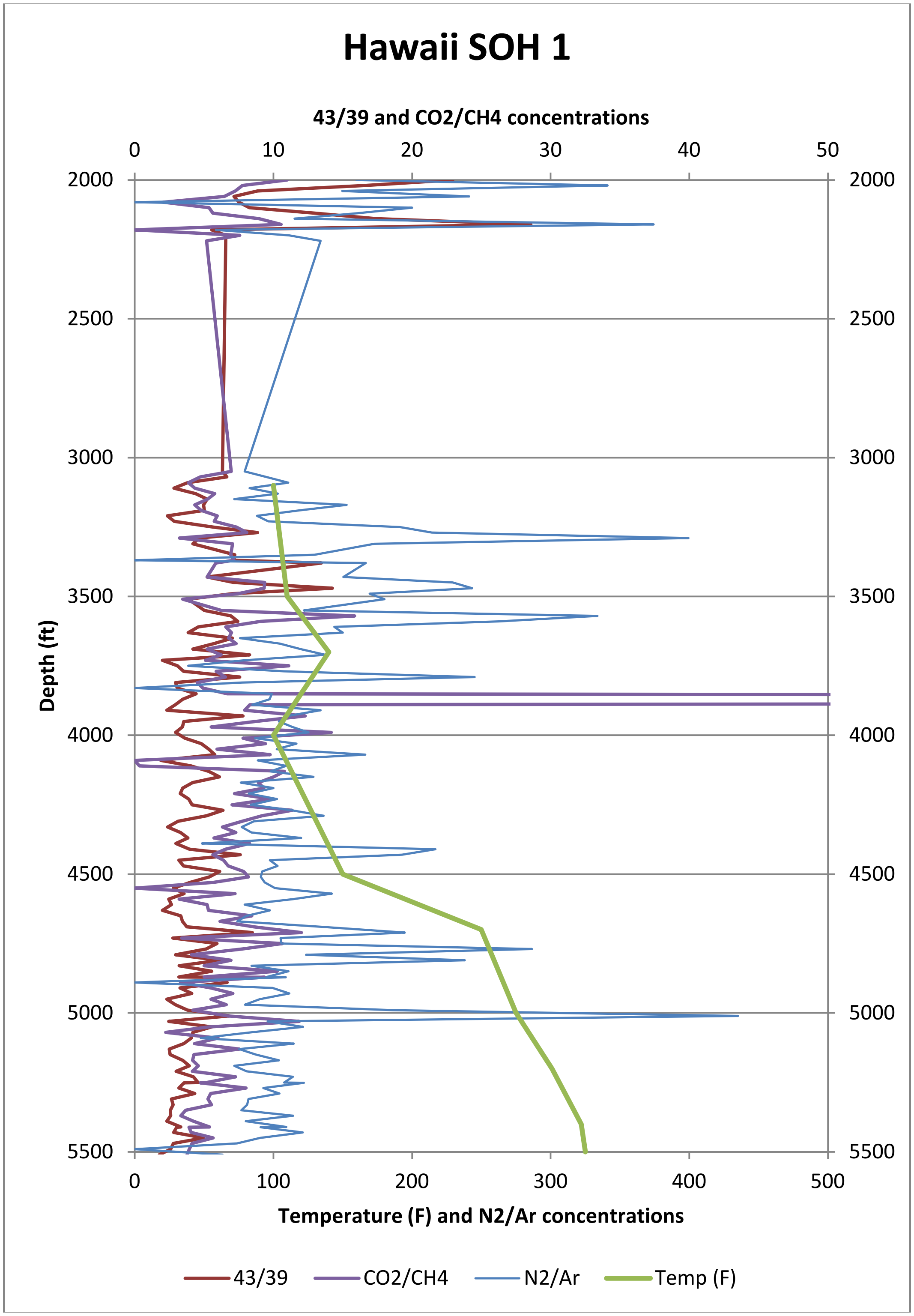
Coso 73-19
43/39 and CO2/CH4 concentrations
0
50
100
150
200
250
0
1000
2000
3000
4000
5000
6000
Depth (ft)
0
200
400
600
800
1000
1200
Temperature (F) and N2/Ar concentrations
43/39
CO2/CH4
N2/Ar
Temp (F)



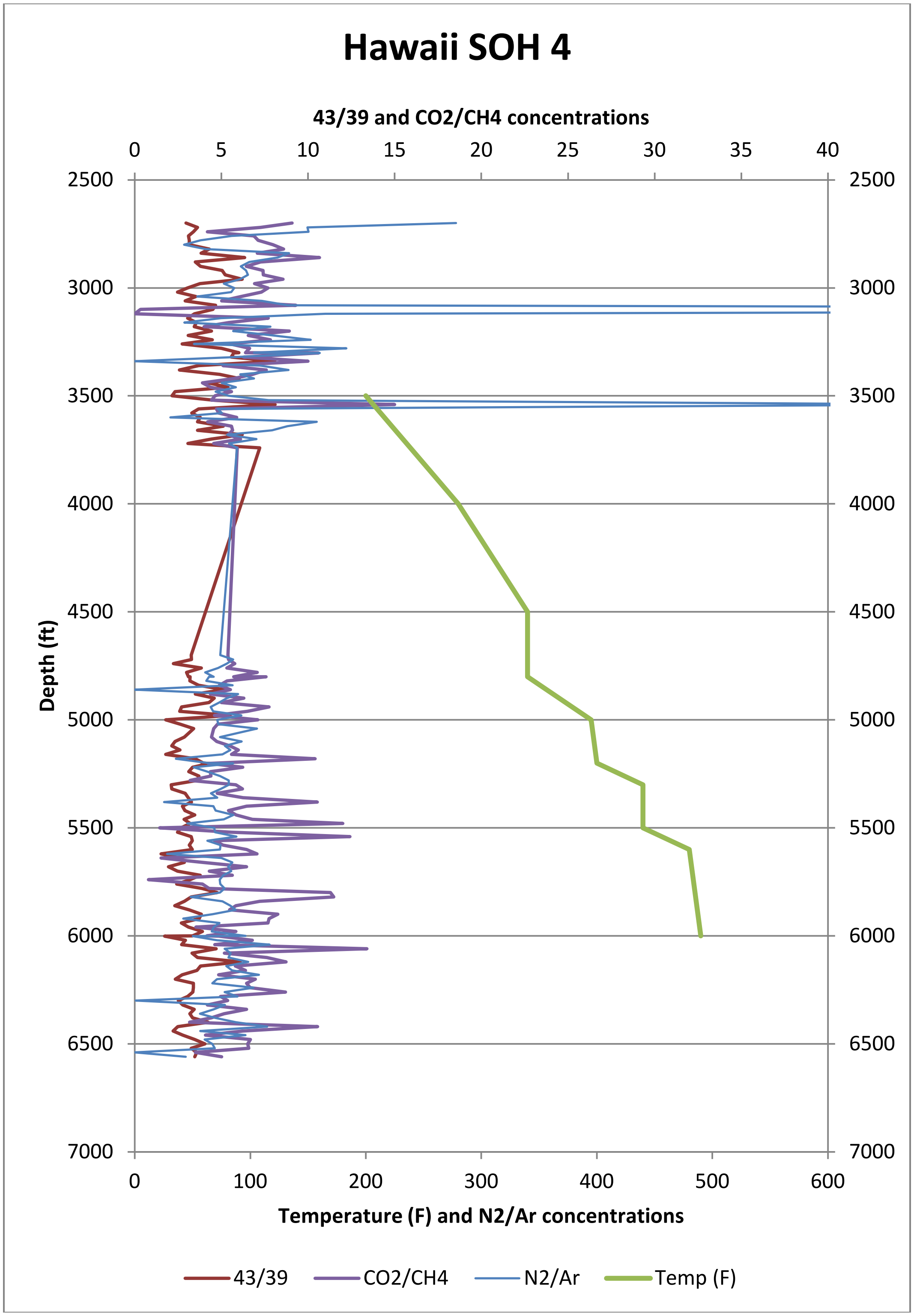
HAD #1
43/39 and CO2/CH4 concentrations
0
10
20
30
40
50
60
0
500
1000
1500
2000
2500
3000
Depth (ft)
0
100
200
300
400
500
Temperature (F) and N2/Ar concentrations
43/39
CO2/CH4
N2/Ar
Temp (F)



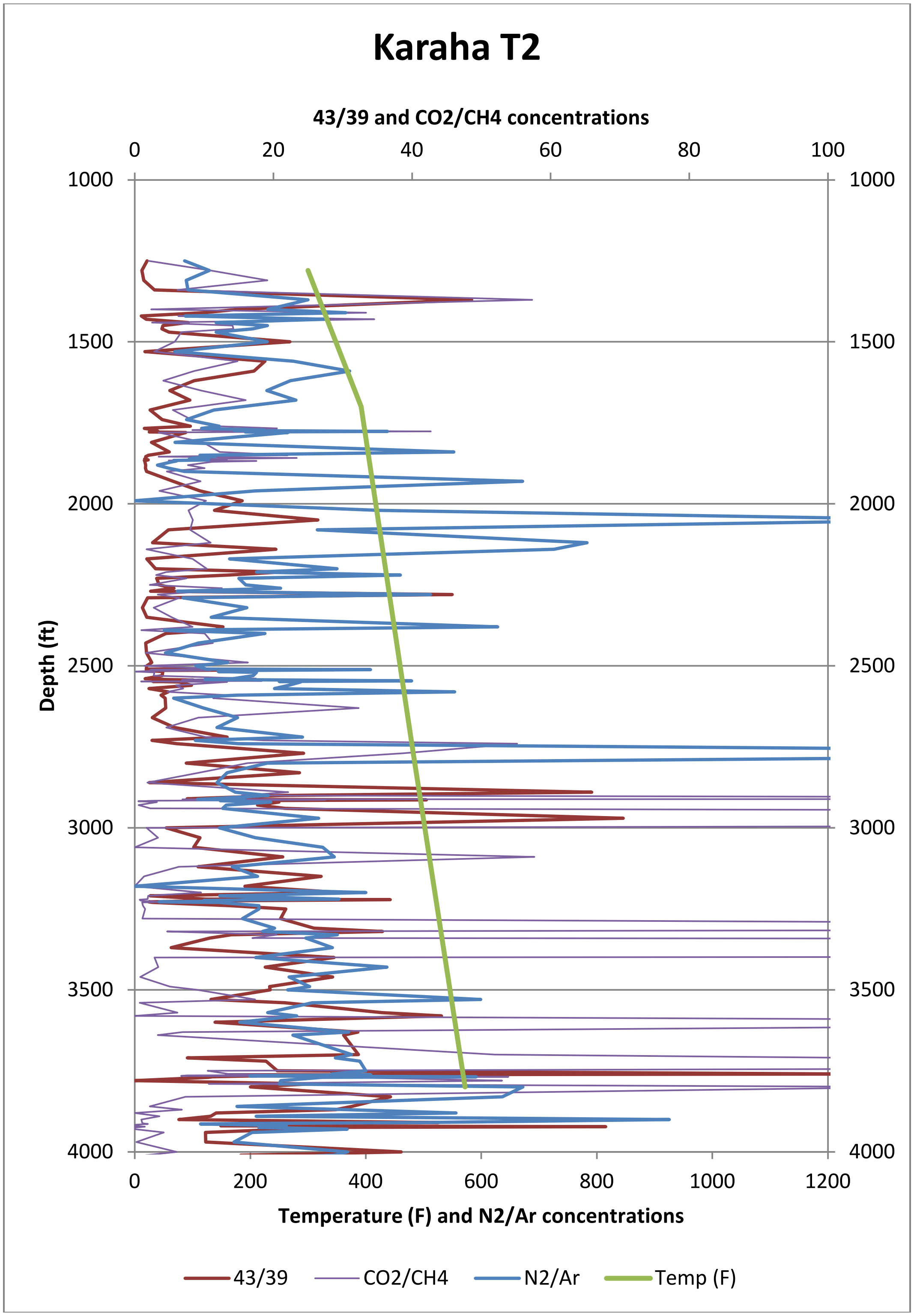
HAD #3
43/39 and CO2/CH4 concentrations
0
50
100
150
200
0
500
1000
1500
2000
2500
3000
3500
4000
Depth (ft)
0
100
200
300
400
500
Temperature (F) and N2/Ar concentrations
43/39
CO2/CH4
N2/Ar
Temp (F)

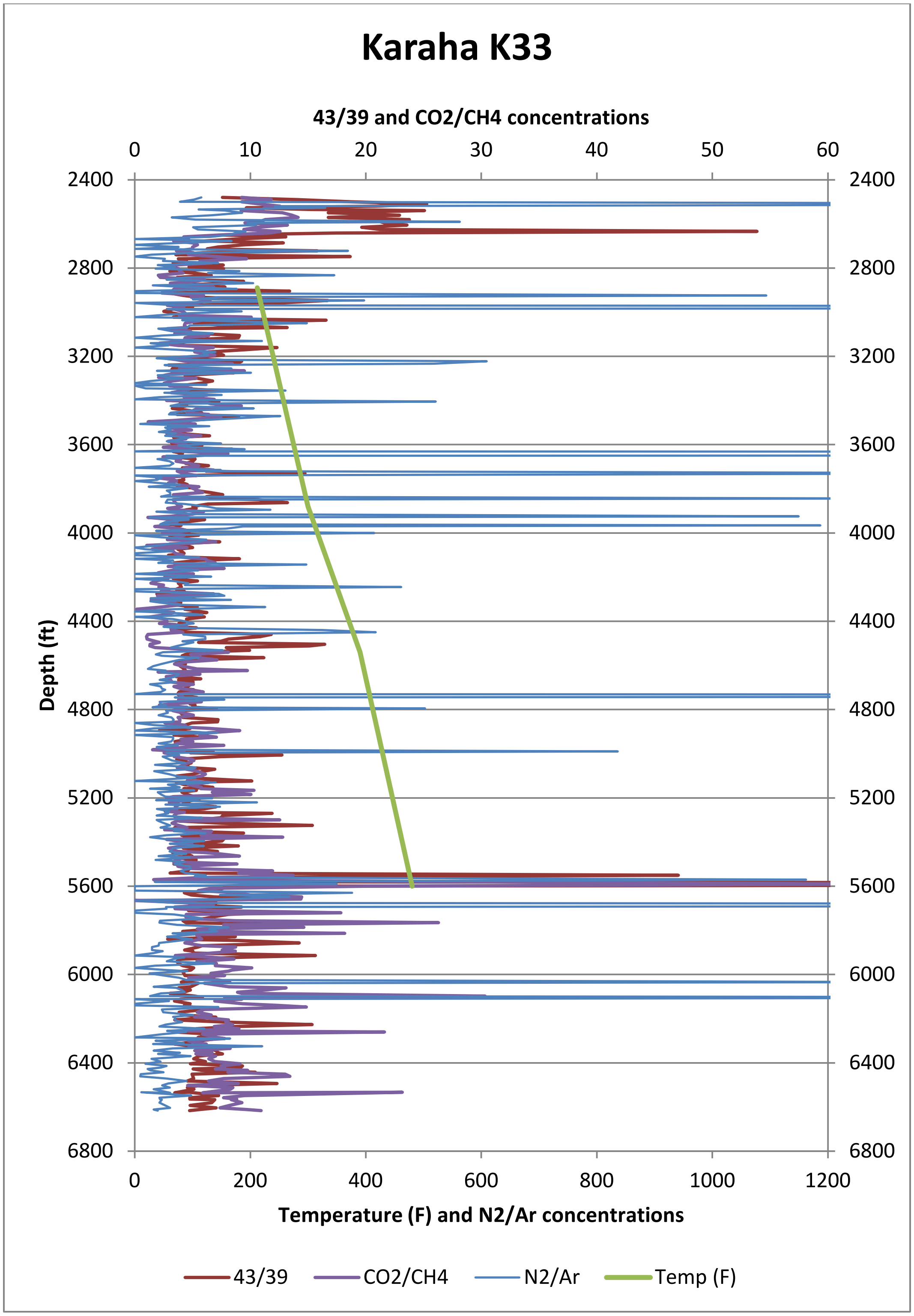


Hawaii SOH 1
43/39 and CO2/CH4 concentrations
0
10
20
30
40
50
2000
2500
3000
3500
4000
4500
5000
5500
Depth (ft)
0
100
200
300
400
500
Temperature (F) and N2/Ar concentrations
43/39
CO2/CH4
N2/Ar
Temp (F)



Hawaii SOH 4
43/39 and CO2/CH4 concentrations
0
5
10
15
20
25
30
35
40
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
Depth (ft)
0
100
200
300
400
500
600
Temperature (F) and N2/Ar concentrations
43/39
CO2/CH4
N2/Ar
Temp (F)

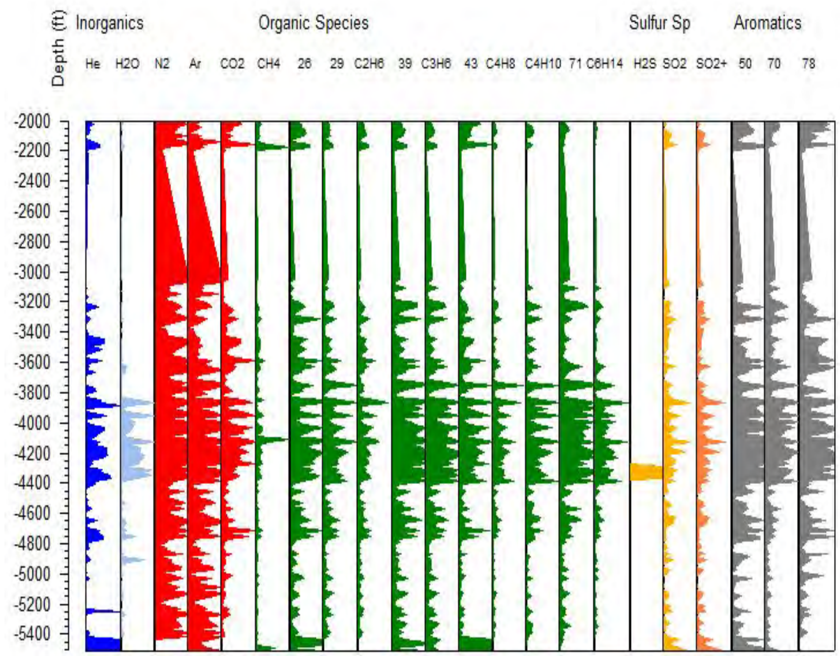

Karaha T2
43/39 and CO2/CH4 concentrations
0
20
40
60
80
100
1000
1500
2000
2500
3000
3500
4000
Depth (ft)
0
200
400
600
800
1000
1200
Temperature (F) and N2/Ar concentrations
43/39
CO2/CH4
N2/Ar
Temp (F)

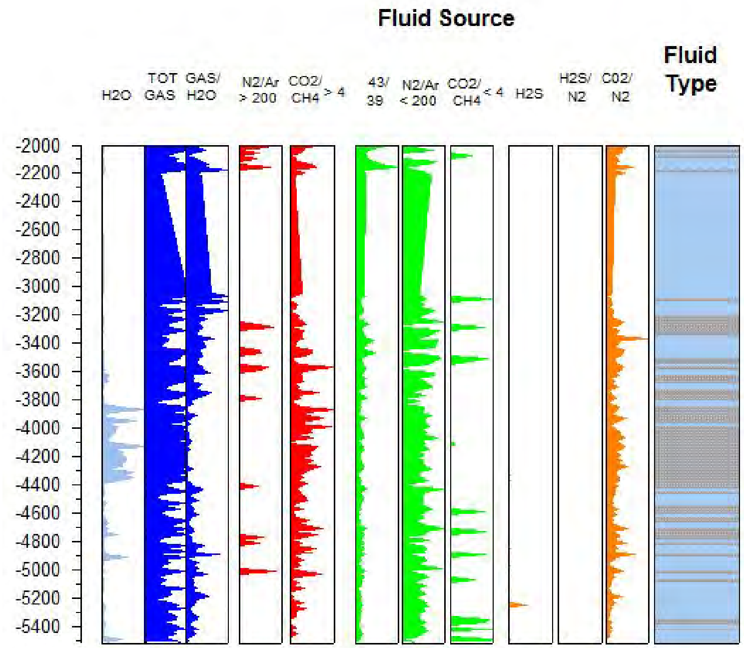

Karaha K33
43/39 and CO2/CH4 concentrations
0
10
20
30
40
50
60
Depth (ft)
2400
2800
3200
3600
4000
4400
4800
5200
5600
6000
6400
6800
0
200
400
600
800
1000
1200
Temperature (F) and N2/Ar concentrations
43/39
CO2/CH4
N2/Ar
Temp (F)

APPENDIX J

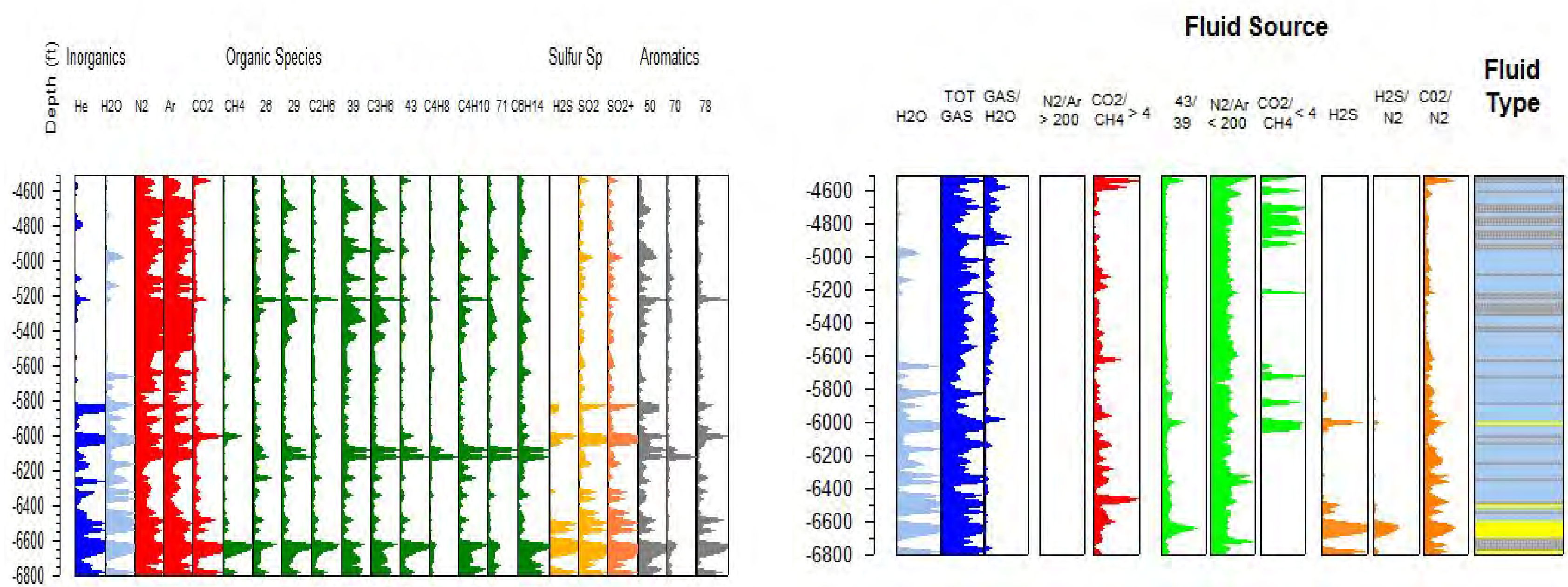
FIS LOGS

Puna Geothermal System

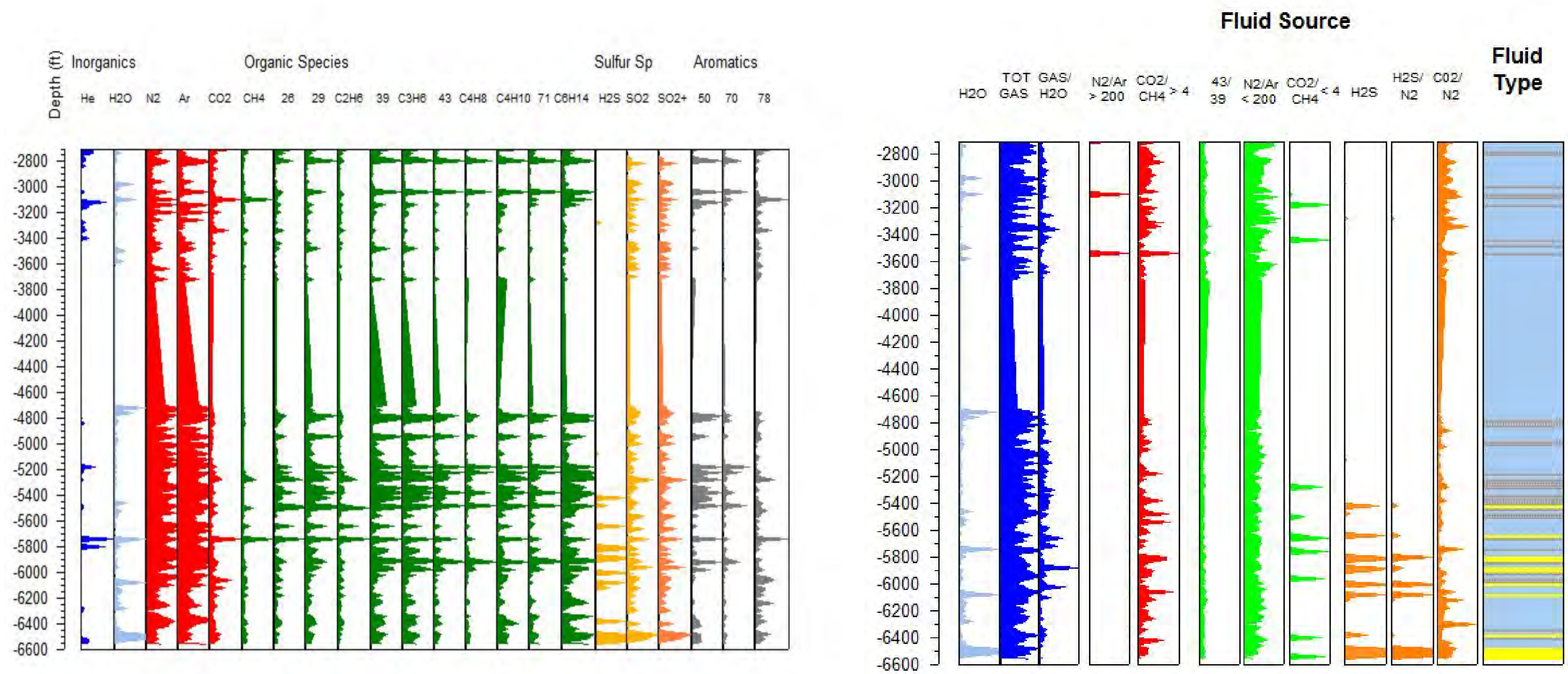




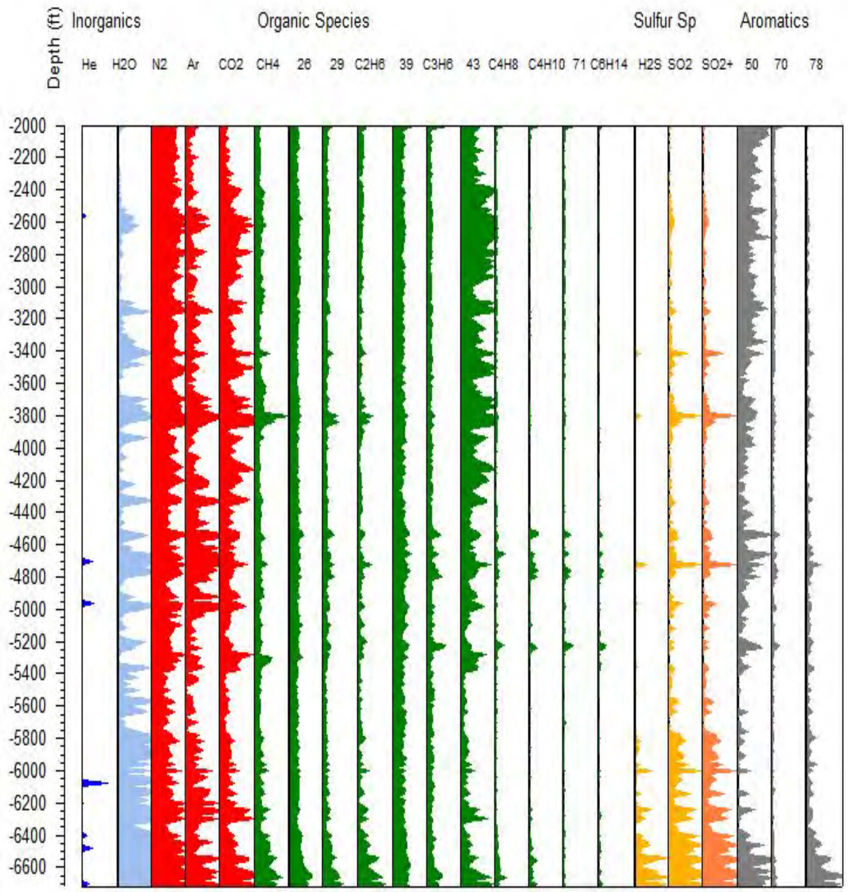
Fluid well logs for Hawaiian SOH 1. Note from approximately 3,800 feet to 4,400 feet the increase in H_2O, the organic species, and N_2, and argon species. This zone is interpreted as background fluid however it is different than the fluids above and below this zone.

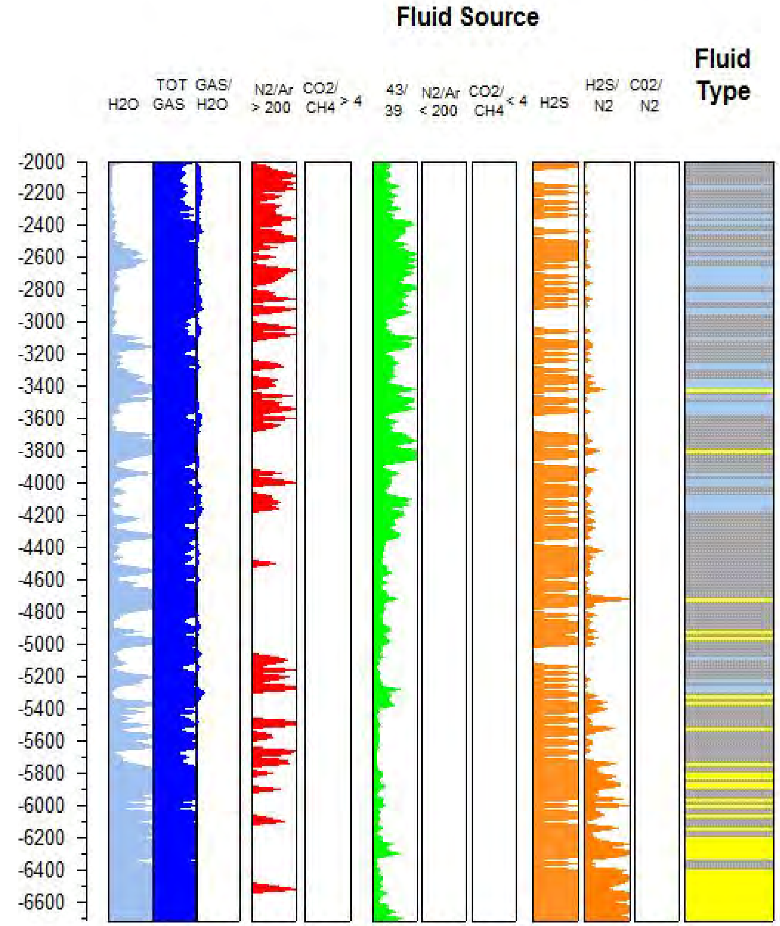


Fluid well logs for Hawaiian Well SOH 2. Note the increase in H_2O and several species below about 5,600 feet. A zone labeled as condensate is suggested by the fluid inclusion gas chemistry at approximately 6,600 feet.

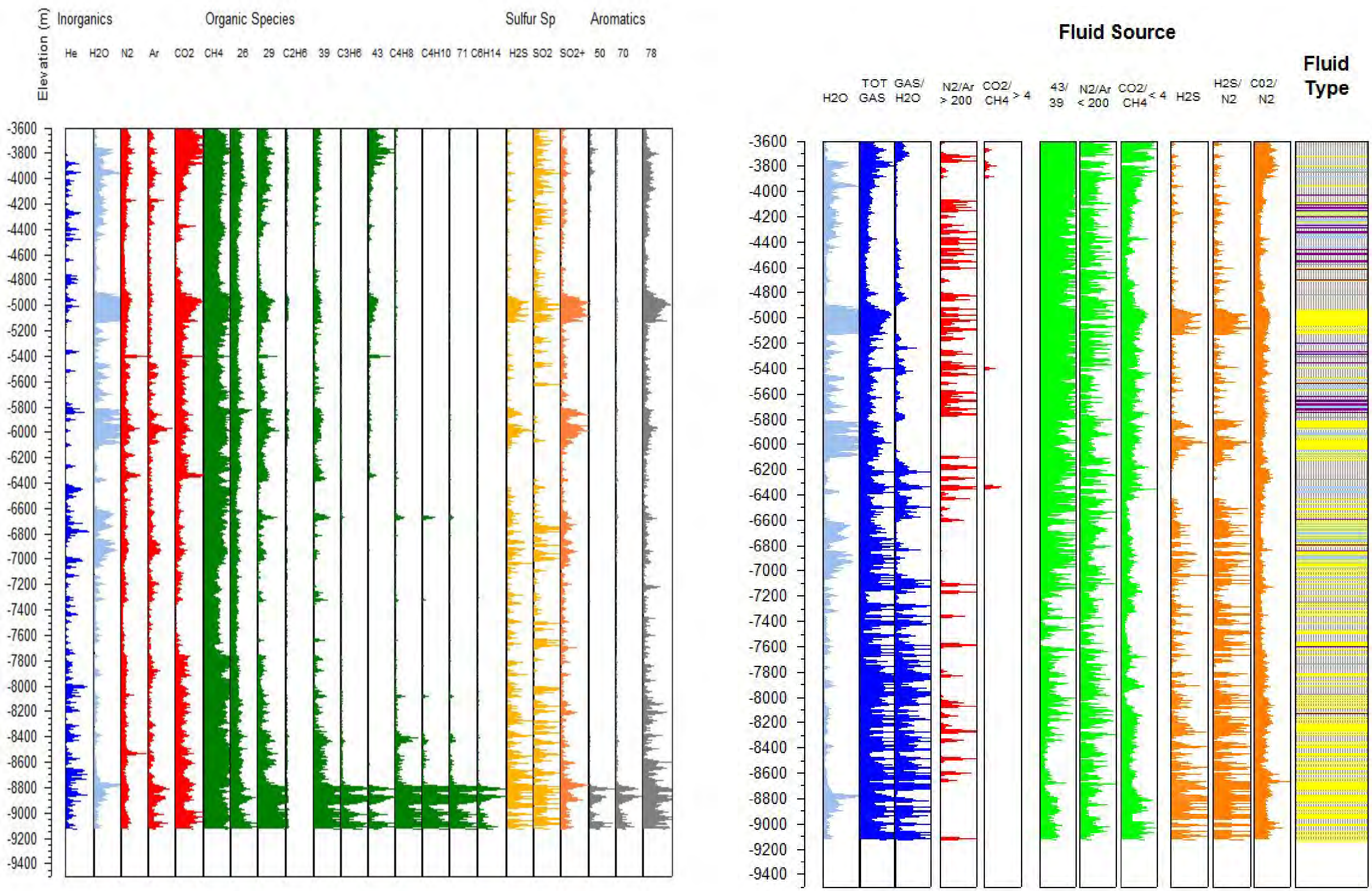


Fluid well logs for Hawaiian Well SOH 4. This is the hottest well of the three analyzed for this field. Note the general lack of water and more gaseous inclusions. Several peaks occur in the H_2S concentration indicating possible condensate fluids at these depths (yellow).

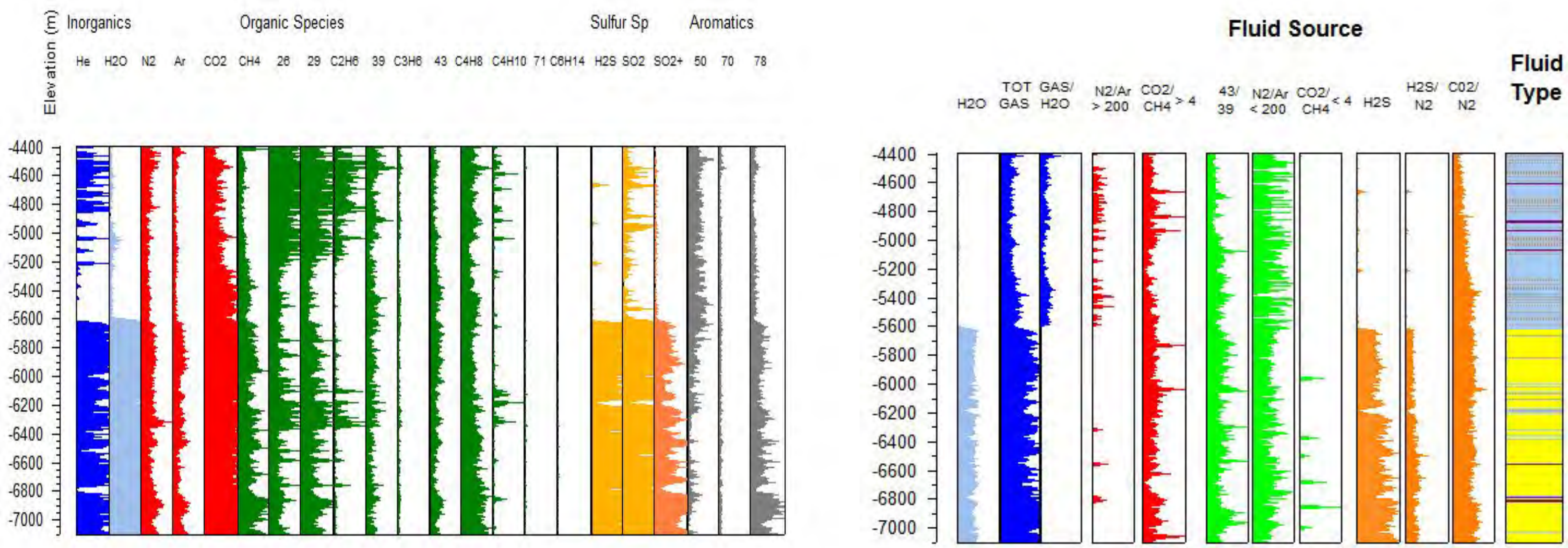




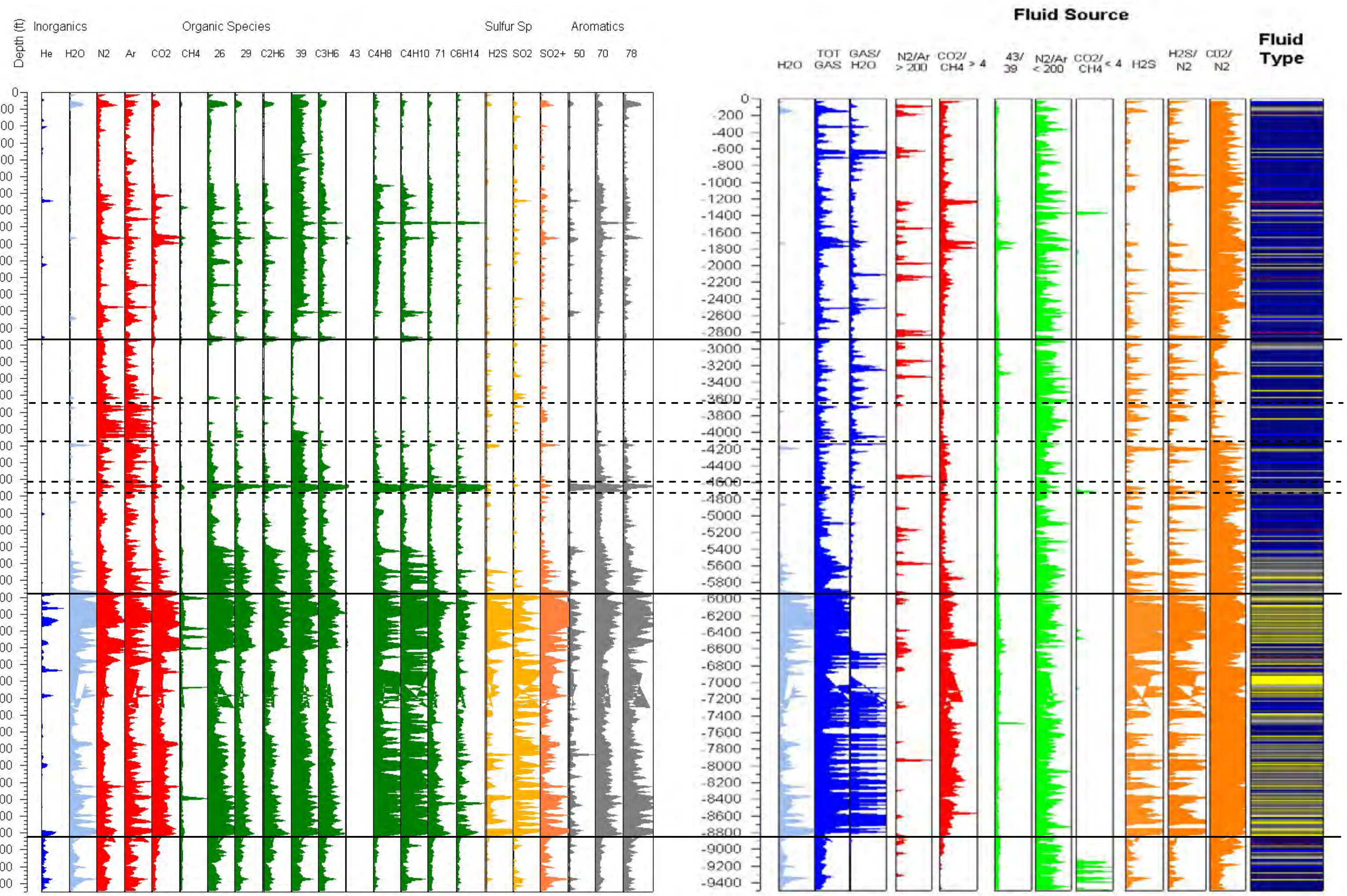
Fluid well logs for Salton Sea Elmore 12. There is a package of fluids below 5,800 feet which are typed as condensate however condensate does not occur in the Salton Sea geothermal field. These fluids are sulfide rich fluids and may be from petroleum related fluids.



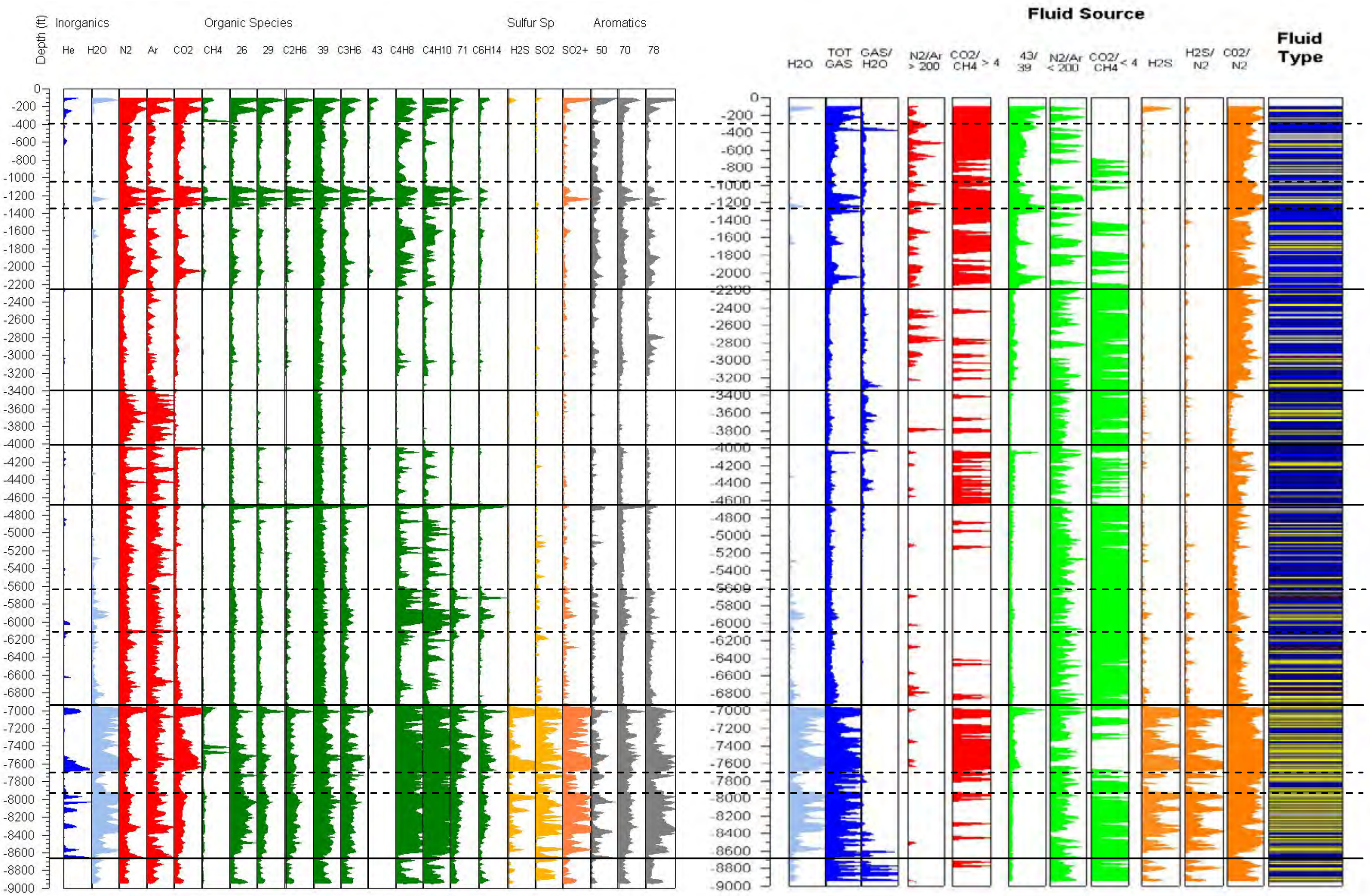
Fluid well logs for Salton Sea Elmore 16. The yellow designated fluids are sulfide rich fluids that are most likely derived or interacted with the petroleum fluids that occur in the field. Organics, H_2S, and aromatics are all high in this zone from 8,800 feet to the depth of the well. In addition, the high H_2O zones most likely represent the rhyolitic dikes that occur in Elmore 16.



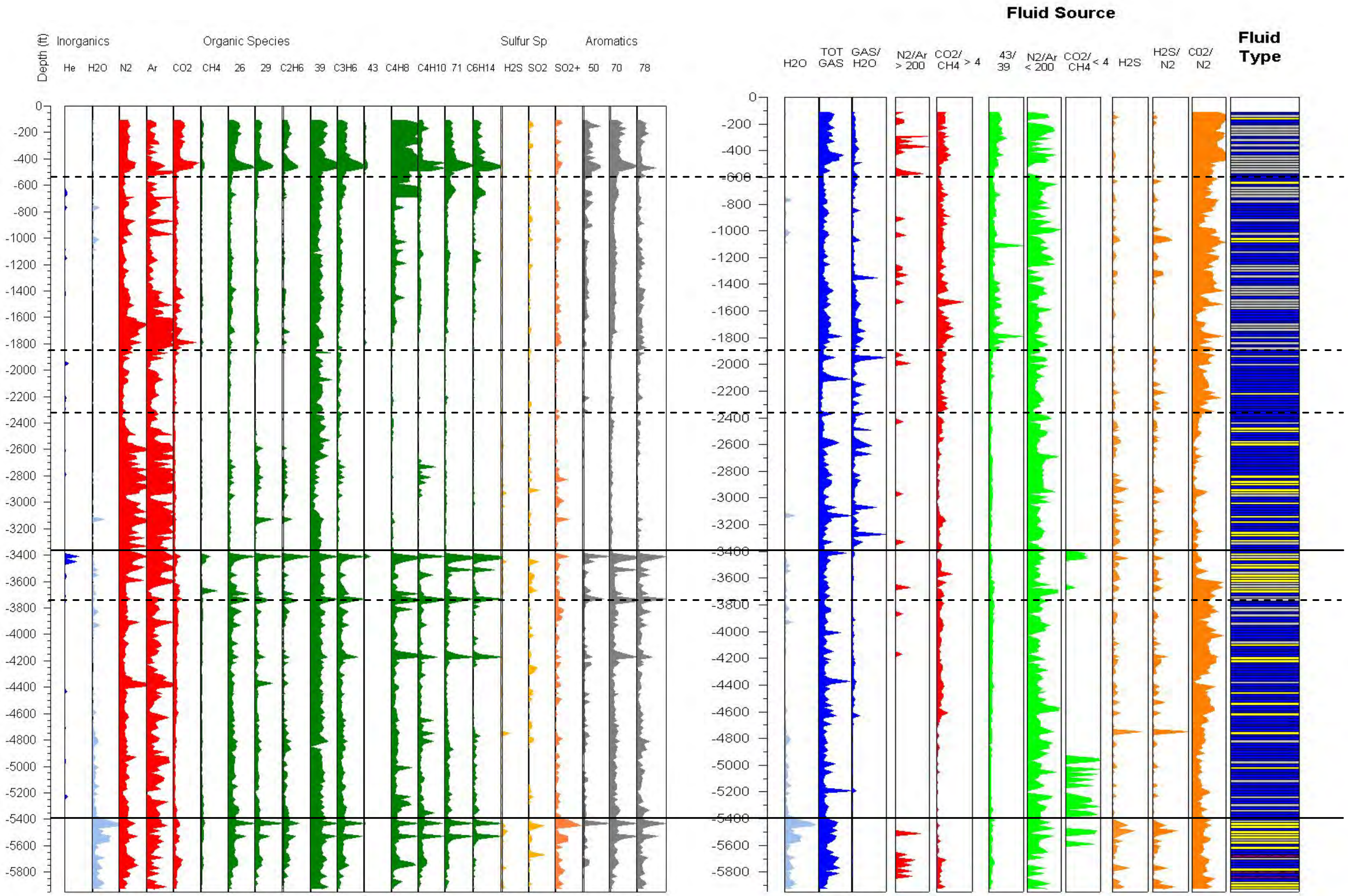
Fluid well log for Salton Sea Sinclair 24. There is a distinct break in the fluid inclusion gas chemistry at approximately 5,600 feet. Below this depth, these fluids are sulfide rich and most likely a result of or interaction with the petroleum components of the field.



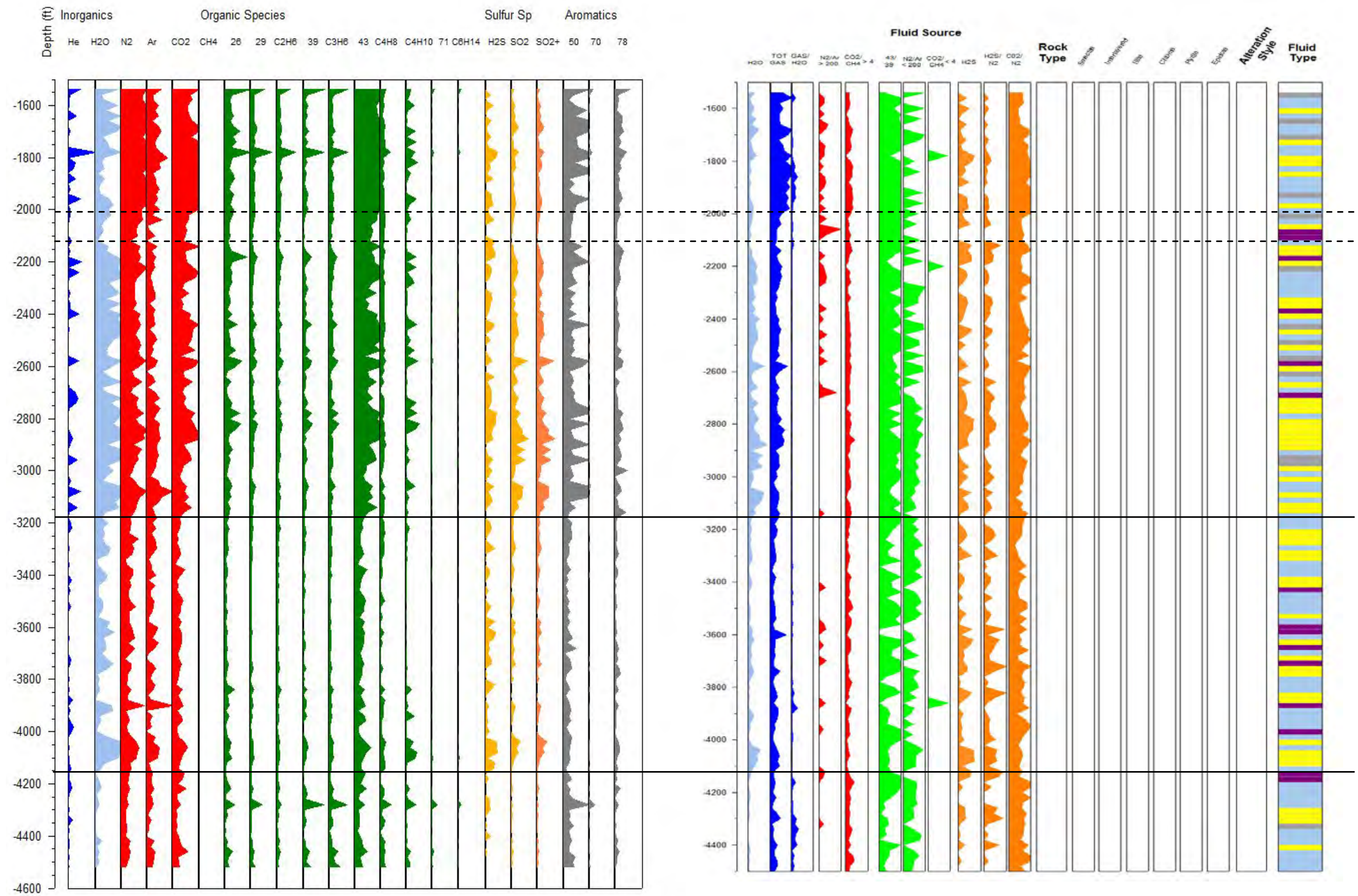
FIS logs and fluid interpretation for Well CL82-36.



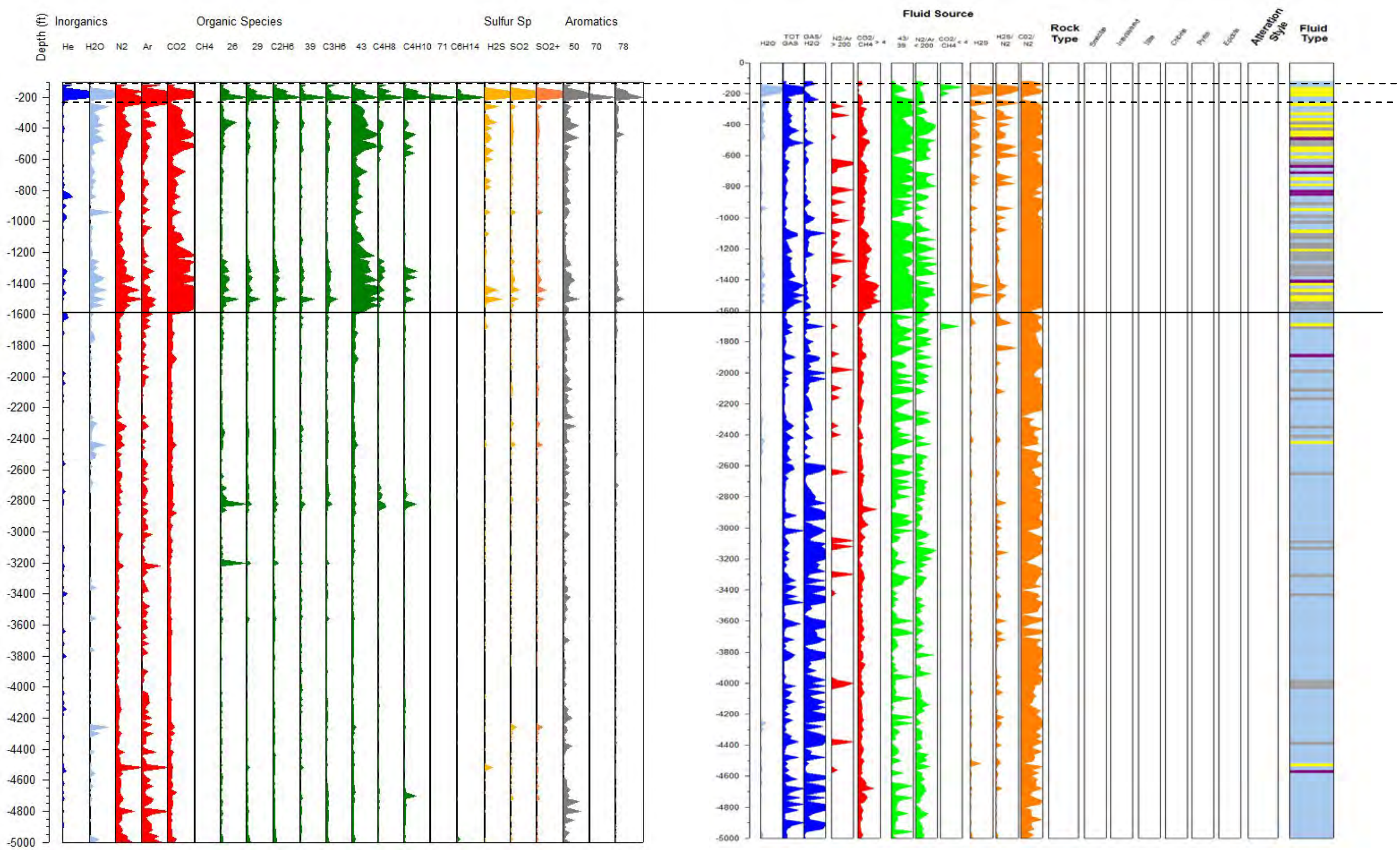
FIS logs and fluid interpretation for Well FOH3.



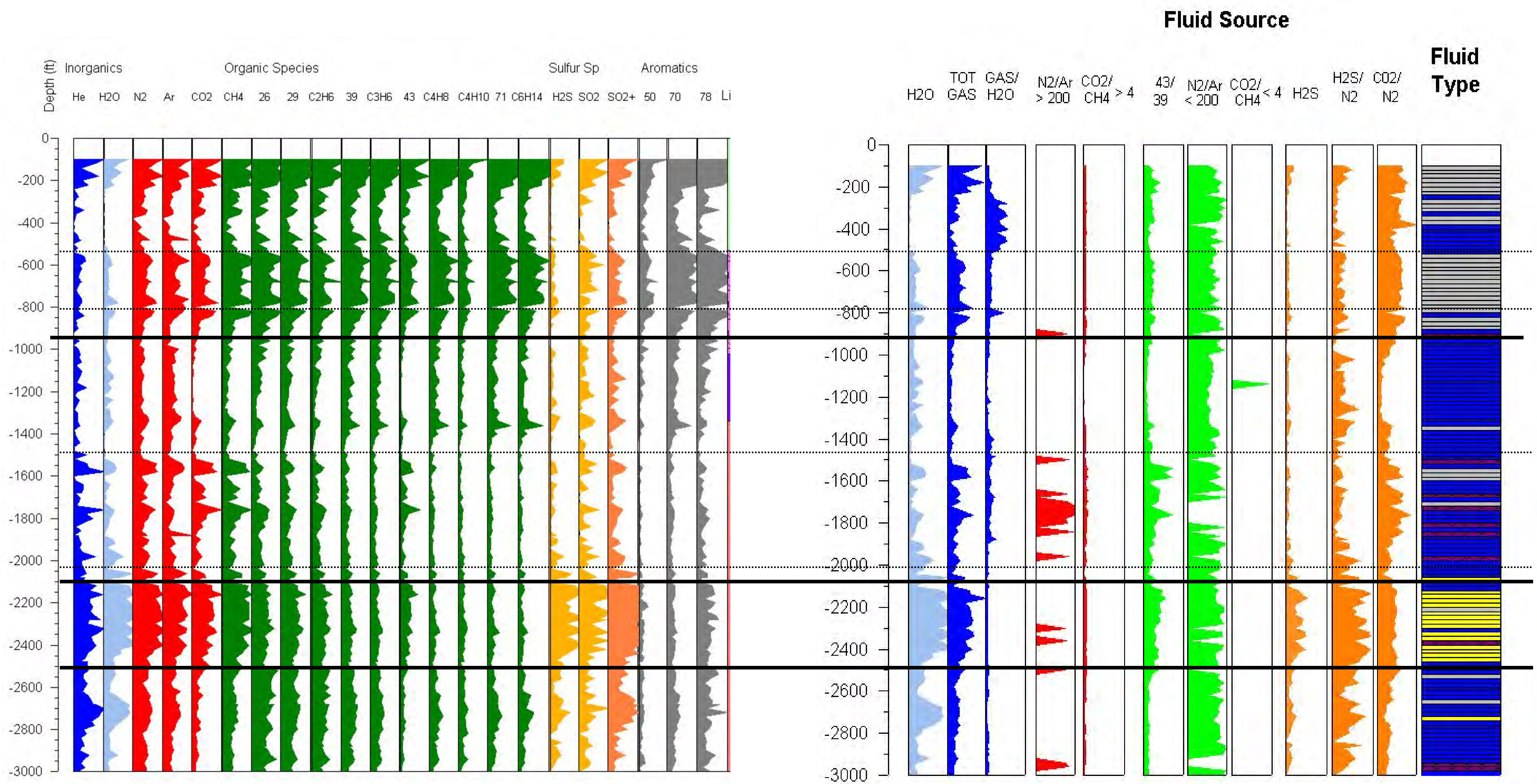
FIS logs and fluid interpretation for Well CL84-31.



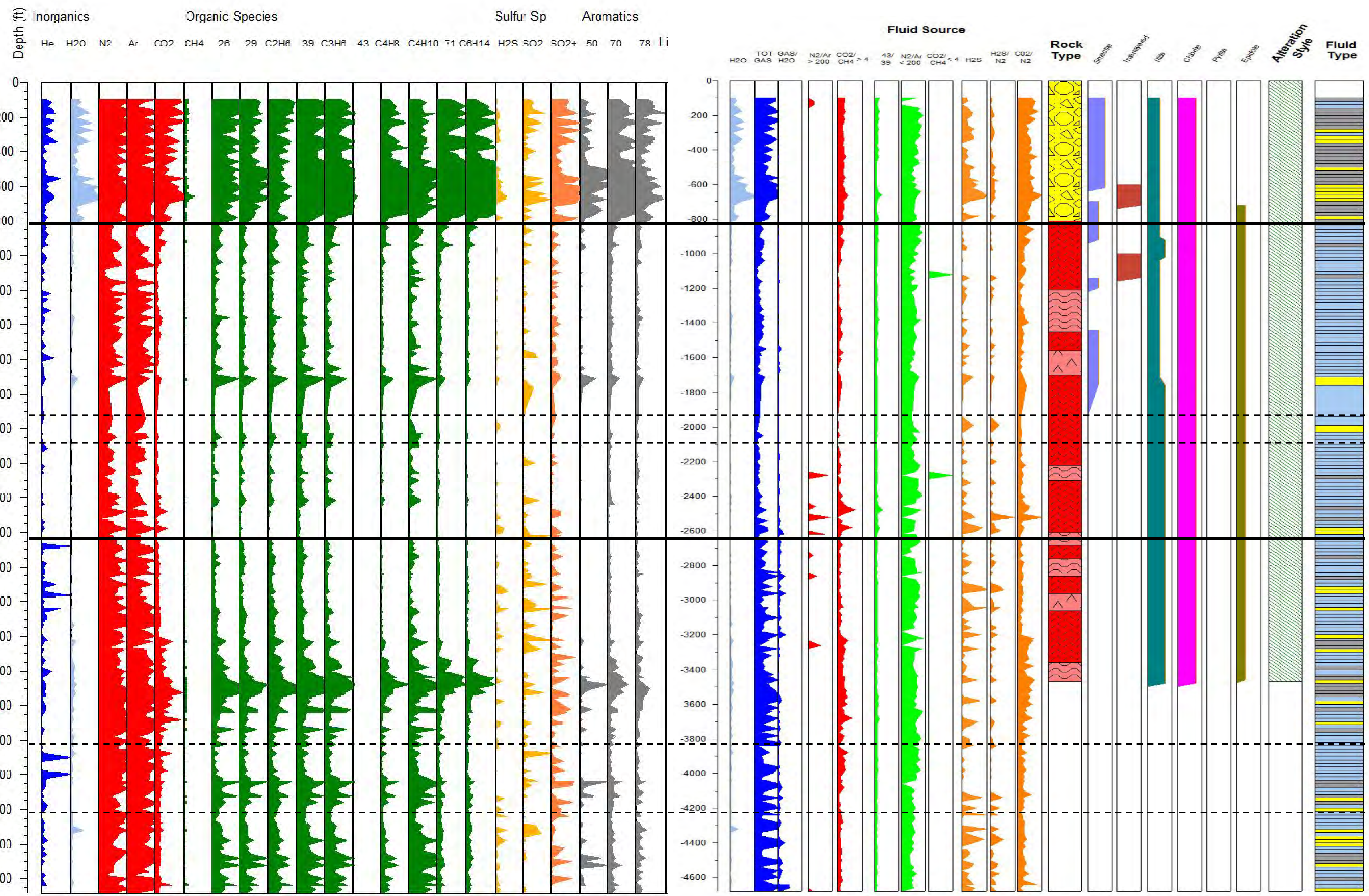
FIS logs and fluid interpretation for Well FDU-2D.



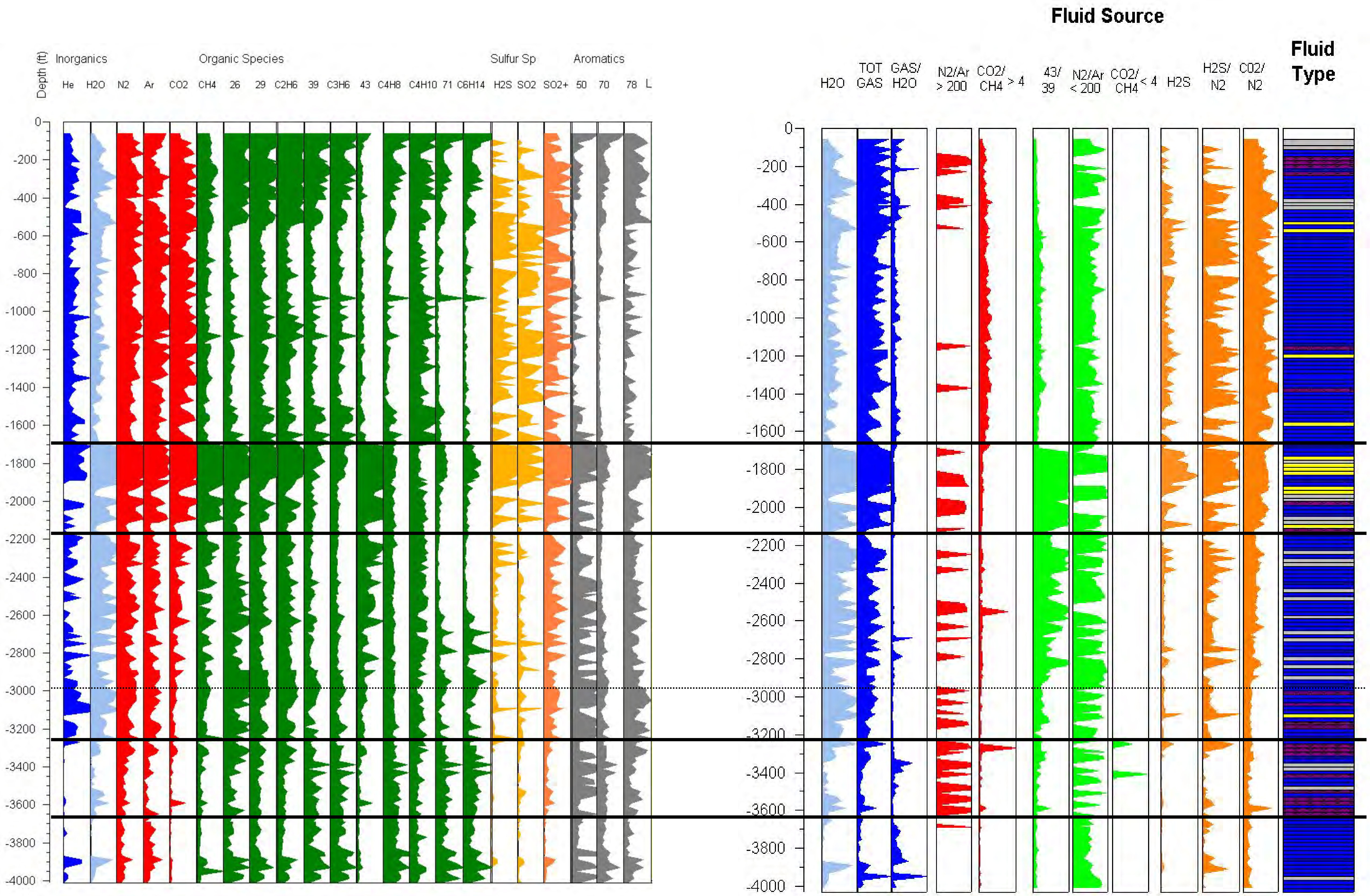
FIS logs and fluid interpretation for Well FLTH 88-24.



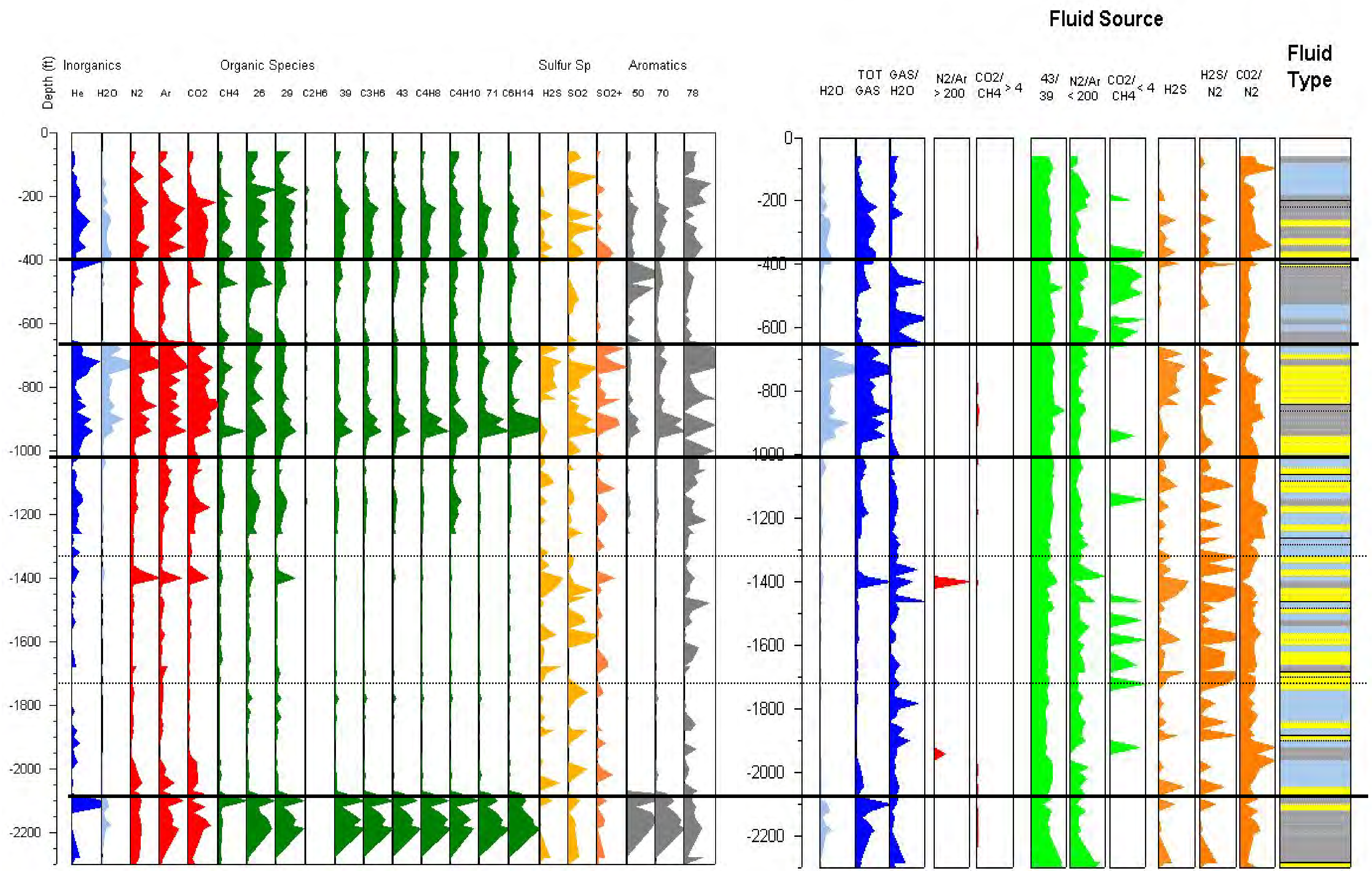
FIS logs for HAD #1



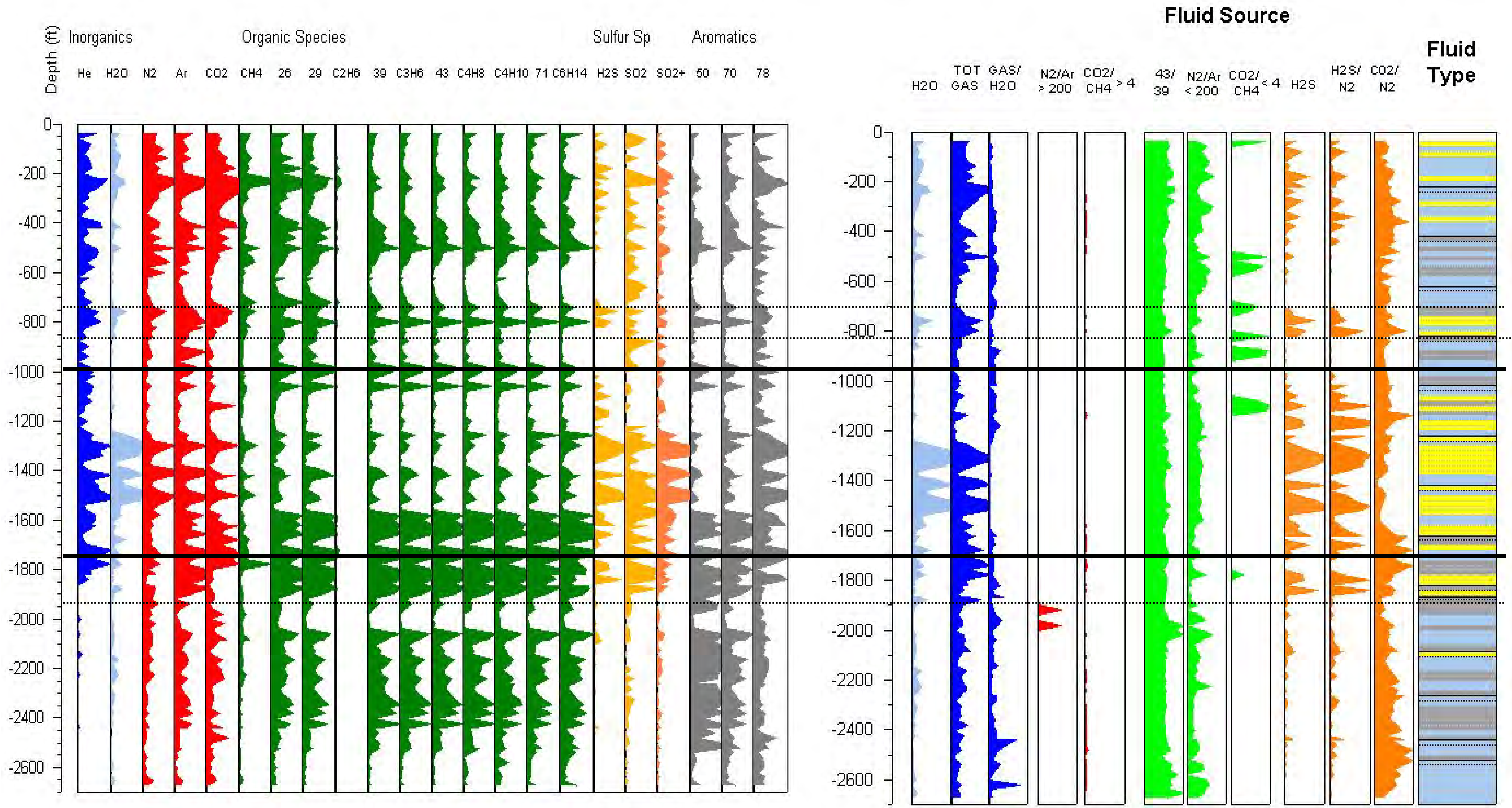
FIS log and lithology for Well HAD#2.



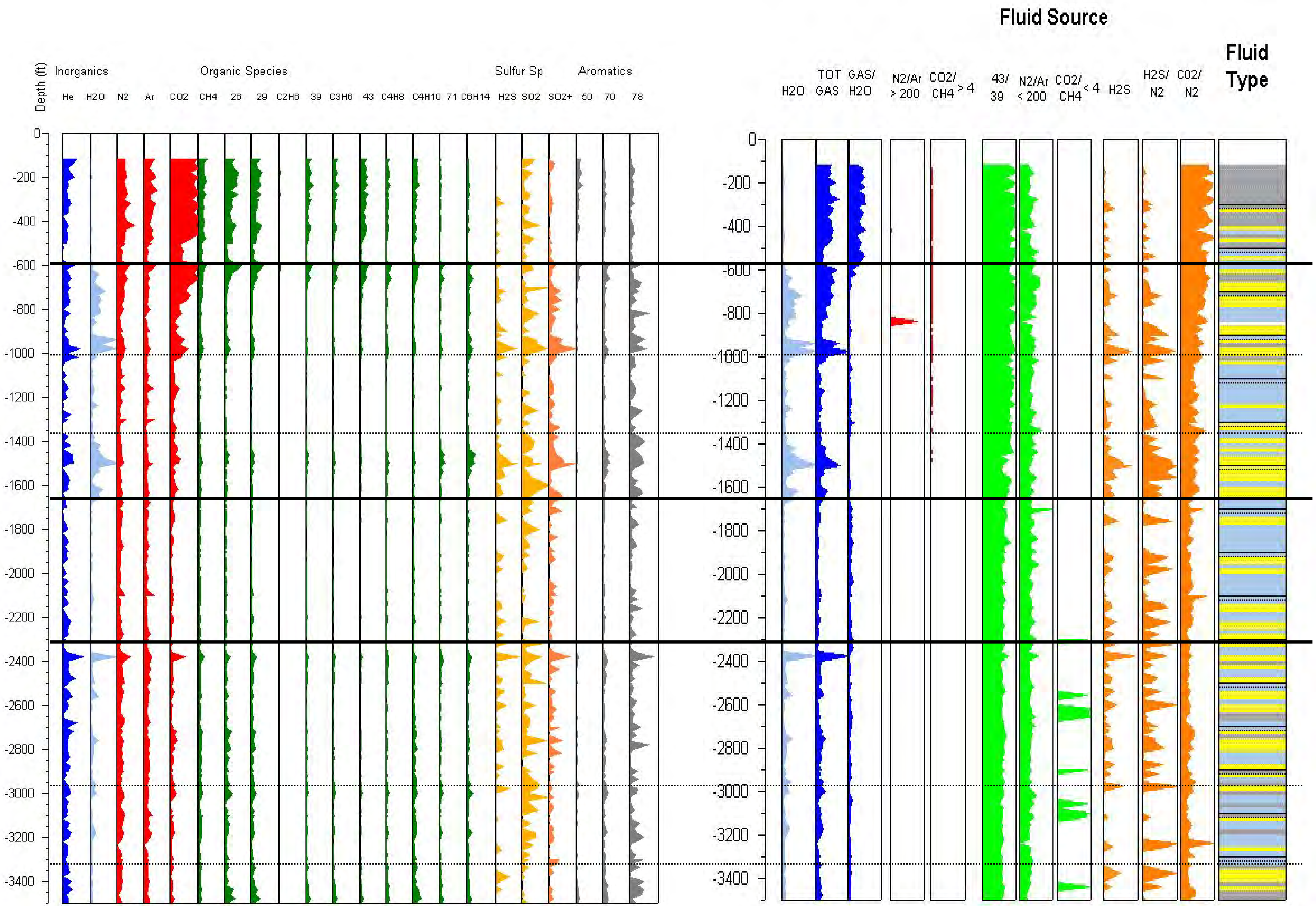
FIS logs for HAD #3



FIS logs for Well NAFEC 1



FIS logs for Well NAFEC 2.



FIS logs for Well NAFEC 3