SUBSURFACE GEOCHEMICAL ASSESSMENT OF METHANE GAS OCCURRENCES

PLAYA VISTA DEVELOPMENT
First Phase Project
Los Angeles, California

Prepared for:
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EXECUTIVE SUMMARY

Exploration Technologies, Inc. (ETI) was retained in May 1999 by the City of Los Angeles, Department of Building and Safety (LADBS), and Playa Capital to serve as Peer Reviewer regarding subsurface methane gas issues in the proposed Playa Vista Development in Los Angeles, California. In order to provide adequate methane data for evaluation, ETI designed and supervised the collection and analysis of two shallow soil vapor surveys consisting of 812 sites placed on a 100 foot staggered grid over the First Phase of the Playa Vista Development. The soil gas samples were collected by Scientific Geochemical Services in Casper, Wyoming and analyzed by Microseeps in Pittsburgh, Pennsylvania. Using the soil gas data as a guide, 32 monitor wells were installed by Camp, Dresser and McKee and sampled for their free and dissolved gases. Gas analysis for these samples were also conducted by Microseeps. Stable carbon isotopes for the free gases in the ground water were analyzed by Isotech Labs in Champaign, Illinois.

This soil gas and ground water data have defined two main areas of methane gas seepage, one very large thermogenic gas anomaly (the soil gas expression is over 1700 feet in length and 200 feet wide) in Tract 01 and another, slightly smaller thermogenic gas anomaly (slightly smaller in size, but not in concentrations) in the southern part of Tract 02. Anomalous levels of ethane, propane and butanes are coincident with methane in both anomalies, inferring that the methane is related to deeper thermogenic sources. The free gases and the dissolved gas anomalies in the ground water within the 50-foot gravel aquifer are also directly related to the soil gas anomalies indicating a vertical migration pathway from deeper sources. Methane isotopes completes this investigation, confirming a common, thermogenic source for the gases measured within these two anomalous areas.

The source of the thermogenic gas observed at the Site is most likely derived from shallow natural gas sands within the Upper Pliocene Pico Formation, probably sourced from the gross interval from 510 feet to 3434 feet, encountered in the non-commercial wells surrounding the Site. There is a north-south linear trend (1700 feet long and 200 feet wide) of very large to intermediate methane concentrations defined by soil gas, dissolved gas, free gas and isotopes measured in the aquifer, which lies to the east and parallel to Lincoln Boulevard. This anomaly has been interpreted as migration of thermogenic gases from depth from a proposed subsurface fault, herein named the Lincoln Boulevard Fault.

The position and attitude of the proposed Lincoln Boulevard Fault is based upon a combination of subsurface geologic data, surface topographic lineations, and a north-south trend of anomalous geochemical data. With respect to seismicity, this fault should be considered as a potentially active low potential fault. Geochemically, this fault is an active pathway for vertical natural gas migration. The proposed Lincoln Boulevard Fault provides a permeable vertical pathway for the natural gases at depth to migrate to the near-surface and have the observed distribution and concentrations.

A future earthquake with an epicenter close to the site could potentially cause a rapid flux of very large volumes of thermogenic methane gas to the surface along the Lincoln Boulevard Fault plane. Because the geologic data from the surrounding wells is only of a general nature and of an early vintage, it is not possible to calculate, or even estimate, the volumes of shallow natural gas beneath the Site. Adequate well logs or other testing data is not available.

Present data indicate that the anomalous methane gas concentrations could extend to the north into Area C. Data from this assessment do not show any evidence that the source of thermogenic gas is from the gas storage facility.

Methane mitigation systems should be required for all buildings in the First Phase of the Playa Vista Development. The design of the methane mitigation systems should follow the same specifications as previously modified and approved for the Fountain Park Apartments in Tract 03.

Because of the very high methane concentrations in soil vapor in the Tract 01 and Tract 02 anomalies, and the future potential for an earthquake-induced flux of additional very large volumes of methane gas in these same anomalous areas, it is recommended that there be mitigation of the 50-foot gravel aquifer in these two areas. A monitor well system should be required to continuously measure methane gas concentrations in the 50-foot gravel aquifer.

A similar subsurface methane assessment should be conducted in the Tract 49104-04 and Tract 52092 areas of the remainder of the First Phase Playa Vista Development. Although the available data is too limited in scope for adequate evaluation, there is no question that a similar methane issue exists in these areas.

Although only leaking minor amounts of thermogenic gas, the Universal City Syndicate Vidor #1 well and the Cooperative Development Co. Community #1 well should be re-abandoned.

1.0 INTRODUCTION

Exploration Technologies, Inc. (ETI) was retained in May 1999 by the City of Los Angeles, Department of Building and Safety (LADBS), and Playa Capital to serve as Peer Reviewer of the previous attempts to characterize subsurface methane gas occurrences in the proposed Playa Vista Development in Los Angeles, California.

1.1 Location

The proposed Playa Vista Development (Site) is comprised of approximately 1,087 acres located approximately 15 miles west of downtown Los Angeles (Figure 1). Regionally, the site is four miles south of the City of Santa Monica, 0.5 miles west of the City of Culver City, and approximately 1.5 miles north of Los Angeles International Airport. The Playa Vista Development is bounded by Marina del Rey on the north, Culver City on the east, Playa del Rey and Weschester Bluffs on the south, and Vista del Mar and Playa del Rey on the west. Playa Vista will be an integrated, mixed-use, master-planned community composed of residential, commercial, recreational, and civic structures. Lincoln and Jefferson Boulevards are the major north-south and east-west traffic arteries, respectively, in the area.

The site has been subdivided into four planning areas based upon the quadrants formed by the intersection of Ballona Channel and Lincoln Boulevard. The planning areas, Area A, B, C, and D, are shown in Figure 2. Proposed development of Playa Vista includes two major phases (Figure 2). The First Phase has been approved and some portions are currently under construction. The Second Phase is currently undergoing environmental review. The subsurface methane assessment conducted by ETI was primarily over the western portion of the First Phase area. The western portion of the First Phase is divided into Tracts 01, 02, 03, 05, and 06 (Figure 3).

1.2 Scope of Work

The scope of work was as follows: (1) Review and comment on previous reports concerning the methane gas issue at the Playa Vista Development. (2) Conduct a four-foot soil gas survey on a 100-foot grid over the west half of the First Phase Playa Vista Development to provide baseline analytical data; these data would show the distribution and magnitude of methane gas that directly underlie the planned construction. (3) To use additional geochemical techniques to determine if the methane gas is biogenic or thermogenic in origin. (4) If the methane gas is thermogenic in origin, investigate the subsurface geology of the area to determine the source and probable vertical pathway(s) of methane gas migration. (5) Review and comment on proposed methane mitigation systems designed for Playa Vista construction. (6) Review the City of Los Angeles Methane Gas Code.

2.0 PREVIOUS WORK

2.1 Geotechnical Boreholes and Monitor Wells

Since approximately 1987, numerous geotechnical and groundwater assessments have been conducted at the Site by various consultants. Borehole lithologic data from reports, both whole and in part, from the following consultants have been reviewed: Leroy Crandall and Associates (LCA), Group Delta Consultants, Inc. (GDC), McLaren Environmental Engineering (MEE), Pacific Soils Engineering, Inc. (PSE), Kovacs-Byer and Associates, Inc. (KBA), Converse Consultants (CC), ENSR Consulting and Engineering (ENSR), and Camp Dresser & McKee (CDM).

Methane monitoring was conducted by Brown and Caldwell during the drilling of some boreholes using a flame ionization detector (FID) and photoionization detector (PID). Numerous bucket auger locations and boreholes had both sustained and non-sustained subsurface methane concentrations while drilling. Some borehole locations were terminated due to hazardous methane concentrations.

Group Delta Consultants previously installed nine monitor wells that were completed in the 50-foot gravel aquifer. The five monitor wells completed in Tract 03 and four monitor wells completed in Tract 01 are shown on Plate 2. Monitor wells MMW 4 and MMW 3 (Plate 2) required one-hour standby after drilling into the 50-foot gravel aquifer due to methane concentrations above 5000 ppmv.

2.2 Soil Gas Surveys

Regional and limited soil gas surveys were conducted over various areas of the Playa Vista Development from 1997 to 1999 by ENSR and CDM to determine distributions of shallow methane gas concentrations. Approximately 132 locations were investigated (tested) for shallow methane concentrations over the entire area by ENSR and CDM. This number of soil gas sample sites is inadequate for the characterization of shallow methane concentrations for a Site comprised of 1087 acres. Methane concentrations were mainly analyzed in the field using FID screening analyses. This method of analysis is also inadequate to properly quantify the methane concentrations in the shallow subsurface. Methane and methane homolog concentrations should be analyzed under laboratory conditions using chromatographs capable of reporting very low concentrations (10 ppbv) of methane, ethane, propane, n-butane, and C5+ speciations in order to provide a proper assessment in regard to biogenic versus thermogenic sources. ETI proposed a different sampling protocol for resampling Tract 03. A detailed description of this methodology is contained in Appendix A.

2.3 Monitor Wells

Methane concentrations in groundwater from three zones were measured in each of the five monitor wells in Tract 03 by Sepich and Associates. The report from this assessment was included in the report by Integrated Environmental Services, Inc. (May 28, 1999). These wells confirmed the presence of large methane concentrations in the 50-foot gravel aquifer, but were not sampled in a consistent enough manner to provide definitive methane content in the aquifer.

2.4 Isotope Analyses

Limited isotopic analyses of methane were performed on selected soil gas and groundwater samples in some portions of Area D. These analyses were discussed in the October 14, 1998 report by CDM. CDM's report suggested the presence of a thermogenic and biogenic gas mix, but did not contain adequate data for resolving this issue.

2.5 Tract 03 Methane Assessment

A preliminary subsurface methane assessment (ETI, 1999) was conducted by ETI during October and November, 1999 over Tract 03 in the proposed Playa Vista Development. The assessment was conducted to determine the nature, magnitude, and distribution of subsurface methane gas that was previously detected by limited sampling and analyses in the area. Although previous studies had suggested the methane gas in this area was mainly biogenic in origin, the previous soil gas studies did not contain adequate sampling density or satisfactory analytical detection limits to properly characterize the subsurface nature, magnitude, and distribution of methane, and the composition of other light gases.

Using the protocol described in Appendix A, light gas analyses for methane through butanes (C1 to C4) were preformed on 136 shallow soil gas samples collected from a depth of four feet on a 100-foot sampling grid. ETI also suggested using a different protocol for sampling monitor wells that is described in Appendix B. This involved the collection of free gas bubbles in an inverted bottle and a dissolved gas sample collected from successive well volumes pumped from each well over an extended period of time. This new procedure for sampling the wells was carried out by CDM Engineers in September of 1999 within Tract 03. These groundwater and free gas samples were obtained from five previously completed monitor wells in the 50-foot aquifer. These samples provided three independent light gas data sets for evaluation of the gas charging in this area.

Concentrations of methane in the vicinity of the most anomalous soil gas sites were several orders of magnitude higher than those detected in previous soil gas surveys. Methane was detected at substantial concentrations (> 50% methane) in 2.3% of the soil gas sites using ETI's methodology. Significant methane concentrations (0.1% to 5.0% methane) were detected in 15% of the soil gas sites. Previous soil gas surveys carried out by CDM and ENSR using the standard California Geoprobe method apparently resulted in the dilution of the soil gases (with the introduction of ambient air) collected and analyzed. In their two previous soil gas surveys, the largest methane reported by CDM was 970 ppmv. ETI's soil gas maps (ETI, 1999) show methane anomalies ranged upwards of 75 percent using ETI's methodology (Plate 2).

Measureable concentrations of ethane, propane, iso-butane, and normal-butane were also consistently detected/reported for the first time from Playa Vista soil gas samples using ETI's protocols. Concentrations for all four of these light gas components were noted to increase in a southwest direction. Ethane, propane and butanes are never found associated with 100% biogenic methane gas. These three independent light gases indicate a definite thermogenic gas contribution in the subsurface of this area. The gases become more thermogenic in composition to the southwest towards the University City Syndicate Inc. LTD #1 well, a possible source of thermogenic gas.

Analytical results from both free gas and dissolved gas collected from the five previously completed monitor wells in Tract 03 also support the same interpretation derived from the soil gas data. The light gas compositions of the free and dissolved gases obtained from the water wells were found to be nearly identical to those measured at four feet in the soil gas samples. Even more important, the presence of ethane, propane and butanes confirmed the presence of thermogenic gases in the water wells.

Methane isotope analyses provide another independent method to identify and separate biogenic from thermal methane. Stable carbon isotopes analyses were performed on free gas samples collected from each of the five monitor wells in Tract 03. Delta C-13 values generally decrease in a southwest direction, indicating an increased thermogenic contribution of methane gas in that direction. Results from the various independent media (soil gas, dissolved gas in ground water, and free gas bubbles) show the concentrations of methane and other light gases have a common source, which generally increases in a southwest direction from MW3.

The University City Syndicate Inc. LTD #1 well blew out while drilling at approximately 1800 feet. Natural gas liberated during the blowout of this well was suggested as a possible source of the thermogenic gas detected in the subsurface of Tract 03. In order to confirm this interpretation, it was necessary to conduct a more regional soil gas survey, followed by the installation of additional monitor wells in the 50-foot gravel aquifer.

3.0 SITE CHARACTERIZATION

The Site is located in the southwestern portion of the Ballona Gap physiographic province. The Ballona Gap is a Recent Age entrenched alluvial valley of the ancestral Los Angeles River within the Los Angeles Coastal Plain and is defined by the upland areas of the Baldwin Hills and Ballona Escarpment to the south and the Beverly Hills to the north. The entrenched valley reached depths of approximately 400 feet in the vicinity of the Baldwin Hills, and 50 feet near the coast. The Los Angeles River was diverted from this westerly flowing course in 1884 by the U.S. Army Corps of Engineers and routed to the present day course into San Pedro Bay

(Poland and others, 1959). The Ballona Channel was straightened and has contained a concrete lined drainage channel since the 1930's.

3.1 Topography and Surface Geology

Native soils at the Site consist of recent alluvial deposits that gradually slope to the west toward the coast; the soils terminate at the coast as a marsh or wetlands area. The original (native) ground surface of the Site has been altered by various emplacements of fill throughout recent time in the four different quadrants. Most of the fill has resulted from either operations on the former Hughes Aircraft Facility, dredging of Ballona Channel, or dredging of Marina del Rey. A detailed discussion of the dates and sources of fill in the four areas is included in CDM report, October 20, 1998 (p. 3-2 to 3-3).

Present day elevations over the Site range from approximately 30 feet to two feet above sea level, depending upon the amount of fill. The south boundary of the Site is the Ballona Escarpment or Playa del Rey Bluffs, which have approximately 120 feet of relief.

Native soils over the Site consist of typical Recent age (Holocene) floodplain deposits comprised of sand, silt, and clays (Figure 4). Sediments on top of the Playa del Rey Bluffs consist of Pleistocene age deposits. Based on similarity of topographic features, the land surface on top of the Playa del Rey Bluffs were divided into four topographic provinces (Metzner, 1935, p. 7-9). The boundaries between the topographic provinces (Figure 5) were interpreted by Metzner to be the surface expression of subsurface faults. The eastern boundary, between Province 3 and Province 4, is parallel and just to the east of Lincoln Boulevard. Projection of this geologic lineament to the north, places the fault through the western portion of Tract 06, Tract 01, and Tract 03 (Figure 5). Although there is no surface expression of this lineament on the Site, the near-surface presence of this fault has been defined by geochemical data collected by this study. This potential subsurface fault has been named herein as the Lincoln Boulevard Fault.

3.2 Subsurface Geology

Both the deep and shallow subsurface geology beneath the Site are well documented by data from numerous oil wells and geotechnical boreholes, respectively. Locations of the former productive oil wells and dry holes in the area are shown on Plate 1.

Oil wells in the area are the result of the discovery, development, and attempts to extend the Playa del Rey Oil Field into the Del Rey Hills area. The Del Rey Hills portion of the oil field (Plate 1, Figure 6) was discovered in May 1931 (Metzner, 1935). Development drilling of the field occurred from 1932 until 1936. In 1942, the depleted oil field reservoir was converted to an underground natural gas storage facility (Riegle, 1953). The Gas Company (Southern California Gas Company) is the current operator of the facility.

The oil producing reservoir in the Del Rey Hills portion of the field was a Miocene age basal conglomerate of the Puente Formation deposited on the surface of a northwest trending Jurassic age Catalina Schist ridge (Plate 1). The Catalina Schist dips to the east from an elevation of approximately 6600 feet below mean sea level (-6600 MSL) at the east edge of the field (Figure 6). The basal conglomerate, which varies in thickness from 0 to over 200 feet, was deposited on the southeast flank of the schist ridge (Figure 6). The surface of the schist is cut by a northwest trending fault that dips to the west and is downthrown to the west (Riegle, 1953, Wright, 1991). The Puente Formation is overlain by the Lower Pliocene Repetto Formation, having an average thickness of 2500 feet. Upper Pliocene deposits comprise the Pico Formation, which is approximately 2000 feet thick.

The Lower Pleistocene San Pedro Formation overlies the Pliocene Pico Formation. The upper 100 to 250 feet of the San Pedro Formation contains fresh water and is referred to as the Silverado Aquifer, which is one of the main groundwater aquifers in the Los Angeles Basin (Figure 7). The Silverado Aquifer is overlain by the Recent alluvial deposits of the Ballona Gap. Water bearing units of the Recent alluvium are referred to as the Ballona aquifer. The primary water-bearing zone of the Ballona Aquifer is a basal lithologic unit composed of sand and gravel, referred to as the 50-foot gravel. The 50-foot gravel aquifer is approximately 15 feet thick beneath the Site and dips to the west from an elevation of approximately –32 feet MSL in Tract 02 to –50 feet MSL in Area B.

3.3 Faults

There is no evidence of surface displacement of Recent age sediments by faults in the area of the Site. There is, however, evidence of subsurface displacement of Pleistocene and older sediments by two faults beneath the Site. These two faults should be classified as potentially active, low-potential faults. Geologic, hydrologic, and geochemical evidence for these two faults is discussed below.

3.3.1 Charnock Fault

The Charnock Fault (Plate 1, Figure 4) was named by Pollard and others (1959, p 77-78) based upon hydrologic and lithologic data. The north trending fault is downthrown to the east and displaces the San Pedro Formation 140 feet. Geologic evidence (Figure 7) for the Charnock Fault has also been presented by McLaren Environmental Engineering (1987, p. III-8). The Charnock Fault is also recognized as a groundwater barrier by the Los Angeles County Flood Control District.

3.3.2 Lincoln Boulevard Fault

The proposed Lincoln Boulevard Fault (Plate 1) is a north trending fault, subparallel to the Charnock Fault, that is downthrown to the west. As previously discussed, the fault displaces the basement rock on the east side of the Del Rey Hills portion of Playa del Rey Field (Figure 6). Evidence for near-surface expression and northward projection of the fault has been discussed above (3.1 Topography and Surface Geology). Additional geochemical evidence for the existence and activity of this fault will be discussed below.

3.4 Shallow Natural Gas

Five wells (dry holes) that were drilled on the Site during the 1920's and early 1930's encountered shallow natural gas during drilling operations. The shallow natural gas was encountered in the wells over the gross interval between 510 feet to 3434 feet. Locations of the five dry holes are shown on Plate 1.

3.4.1 Universal City Syndicate, Inc. Vidor #1

The Universal City Syndicate, Inc. Vidor #1, located in Area B, was drilled to a total depth of 5960 feet and was plugged and abandoned as a dry hole in 1931. Shallow natural gas was encountered while drilling at depths of 1140 to 1150 feet. The well blew out on August 27, 1930, at an estimated rate of 5000 MCF of gas per day, while drilling at 1821 feet. On May 2, 1931 the well blew out a second time while drilling at a depth of 5960 feet. It is not clear from the well records if there were additional gas zones at the depths of 1821 feet and 5960 feet.

3.4.2 Cooperative Development Co. Community #1

The Cooperative Development Co. Community #1, located in the southwest corner of Area D, was drilled to a total depth of 6700 feet and was plugged and abandoned as a dry hole in December 1932. Shallow natural gas was encountered while drilling at depths of 510 to 515 feet, 682 to 709 feet, 1752 to 1770 feet, and 2803 to 2814 feet.

3.4.3 Kitselmann Del Rey #1 and Del Rey #2

The Kitselmann Del Rey #1 and Del Rey #2, located in Area C, were drilled to total depths of 2785 feet and 3434 feet, respectively. Both wells were plugged and abandoned as dry holes in 1922. Shallow natural gas was encountered in the wells while drilling at depths of 1225 feet and 3434 feet.

3.4.4 Mesmer City Realty Co. Well #1

The Mesmer City Realty Co. Well #1, located in the eastern part of Area D, was drilled to a total depth of 6704 feet and was plugged and abandoned as a dry hole in September 1931. Shallow natural gas was encountered while drilling at depths of 1802 to 1885 feet and 2162 to 2354 feet.

The areas of shallow subsurface natural gas encountered in the above mentioned wells are shown on Plate 1. The near-surface projections of both the Lincoln Boulevard Fault and the Charnock Fault intersect within the areas demonstrated to contain shallow natural gas. Geochemical data, to be presented later in the report, indicate these faults are most likely the main migration pathways of the methane gas anomalies observed in the near-surface at the Site.

4.0 METHANE ASSESSMENT METHODOLOGIES AND ANALYSES

The methane assessment of the First Phase of the Playa Vista Development involved sample collection of soil gas from the shallow subsurface and the collection of groundwater and free gas samples from a group of newly installed monitor wells screened in the 50-foot gravel aquifer. The geochemical assessment methodologies and analytical techniques employed in the methane assessment are as follows.

4.1 Soil Gas Survey

A four-foot deep soil gas survey, consisting of 812 samples collected on a surveyed grid with 100 feet between samples, was conducted from October through December 1999 (Plate 3) over the western portion of the First Phase of the Playa Vista Development. The purpose of the soil gas survey was to provide baseline data, which would indicate the distribution and magnitude of methane gas anomalies in the near subsurface directly underlying the planned construction area. The survey was also utilized to determine if there were any associated methane homologs (ethane, propane, or butanes) from a deep thermogenic source. Soil gas samples were collected by Scientific Geochemical Services, Casper, Wyoming. Soil gas collection procedures are contained in Appendix A.

4.2 Soil Gas Sample Analyses

The soil gas samples were analyzed by Microseeps Laboratory in Pittsburgh, Pennsylvania. Concentrations of methane, ethane, propane, and butane were reported with detection limits of approximately 10 ppbv (parts per billion). Analytical laboratory results are included in Table 1. Soil gas samples were also analyzed for benzene, toluene, ethylbenzene, and xylenes concentrations by Microseeps Laboratory. Analytical laboratory results for these analyses are included in Table 2. Hydrogen sulfide (H2S) analyses were also conducted on soil gas samples onsite in real-time using a Jerome 631-X instrument manufactured by Arizona Instruments. The Jerome 631-X was set to the most sensitive mode and programmed to extract 25 cc of soil gas from the sampling probe using an internal sampling pump. H2S concentrations are reported in Table 2.

ETI was initially asked to work on the methane issue, and was not asked to measure BTEX (benzene, toluene, ethylbenzene and xylenes) or hydrogen sulfide concentrations. For this reason these components were not included in the first soil gas survey conducted in Tract 03. When these components became an issue during the planning of the follow-up regional soil gas survey, these analyses were added. A limited number of soil gas sample locations were revisited within Tract 03 during the regional survey to provide some BTEX and H2S data for evaluation of Tract 03. These data are included in Table 2 with the remainder of the regional sample results; not all of the original sites were resampled at this time. Additional construction activities had literally excavated deep holes and even moved the excavated soil (into large piles) such that the original site locations were gone, making it impossible to repeat the original survey.

Hydrogen sulfide analyses for these repeated samples were run using the same protocol used for the regional sites (samples 100 through Z). Table 2 also shows H2S measurements for all sites; those sites that do not have associated BTEX measurements were run using a different protocol. An attempt was made to analyze the original Tract 03 soil gas samples for H2S. BTEX was not attempted on those samples because the samples had expired for BTEX analysis. Evaluation of this H2S data (in the first 83 sites) suggests that the H2S had also expired and been adsorbed by the bottle walls. This experiment was attempted because all of the previous H2S measurements made by engineering companies had used tedlar bags for sample containers. Tedlar bags are well known for their adsorbtive capacity and are not recommended for sample containers. All of the BTEX and H2S samples that were analyzed during the regional program (all samples which have both BTEX and H2S) in Table 2 are valid.

4.3 Monitor Well Installation and Sampling

An array of 32 monitor wells, screened in the 50-foot gravel aquifer, were installed under the supervision of personnel from CDM during March 2000 (Plate 2). The monitor wells were installed in areas of high near-surface methane anomalies delineated by the soil gas survey. Both groundwater and free gas samples (from the 50-foot gravel aquifer) were collected from the monitor wells by CDM personnel during March and April 2000. Samples were also previously collected from nine other monitor wells screened in the 50-foot gravel.

The sampling protocol suggested by ETI involves the collection of free gas bubbles in a inverted bottle and a dissolved gas sample collected from successive well volumes pumped from each well over a period of time. The average well volume is approximately 10 gallons of water. The water flow rate used was approximately ½ gallon per minute. This methodology allowed multiple free gas and dissolved gas samples to be collected over time from different well volumes. When possible, up to five (to seven) well volumes were removed and sampled from each well. Only one well (MMW-476) was too impermeable to allow adequate sampling using this method. Purge logs for this sampling operation are available from CDM Engineers.

The sampling protocol provides representative water samples from the aquifer that are consistent with respect to one another. Independent but separate samples from successive well volumes can be averaged to provide a very well determined estimate of the methane gas levels contained within each monitor well. More detailed methodologies for collection of groundwater and free gas from the monitor wells are contained in Appendix B. Completion logs for the monitor wells are contained in Appendix C.

4.4 Monitor Well Sample Collection and Analyses

Groundwater (dissolved gas) and free gas samples from 41 monitor wells completed in the 50-foot gravel aquifer were analyzed for methane and other light gases.

4.4.1 Groundwater (Dissolved Gas) Analyses

Groundwater samples were analyzed by Microseeps Laboratory; concentrations of dissolved methane, ethane, propane, and butane were reported with detection limits of approximately 10 ng/l (nanograms per liter). Analytical results that range from mg/l to ug/l levels are presented in Table 3.

4.4.2 Free Gas Analyses

Free gas samples collected from the water wells were analyzed by Microseeps Laboratory; concentrations of methane, ethane, propane, and butane were reported with detection limits of approximately 10 ppb (parts per billion). Analytical results that range from % levels to ppmv are presented in Table 4.

4.5 Isotope Analyses

Free gas samples from the monitor wells completed in the 50-foot gravel aquifer were submitted to Isotech Laboratories, Champaign, Illinois for analyses of their stable carbon isotopes. These analyses were performed to determine whether the methane gas was biogenic or thermogenic in origin (Coleman et al. 1977, 1979, 1981, 1988). Analytical results of the isotopic analyses are listed in Table 5.

5.0 RESULTS AND INTERPRETATION

5.1 Soil Gas Survey

The soil gas survey results, consisting of 812 samples, are listed in Table 1. Methane, ethane, propane and normal-butane concentrations are posted and contoured on Plate 4 through Plate 7. Contour maps of hydrogen sulfide, toluene and total xylenes are illustrated in Plates 8, 9 and 10, respectively.

Although methane concentrations (Table 1, Plate 4) are highly variable over the survey area, high concentrations cluster within two main areas. Methane concentrations within these two seepage areas reach values as large as 75% at a large number of the anomalous sites within each area. As compared to other regional surveys that ETI has conducted over many frontier and petroliferous basins, these concentrations are very high considering the shallow depth from which the gases are migrating. The free gas bubbles in Ballona Channel are, by definition, classified as macroseeps. In addition, CDM Engineers documented a macroseep (sample number CDM-SG-4-0) within Tract 03 on 2/12/98 during a rainy period when the surface was too wet to use their Geoprobe. They managed to collect a gas sample at the surface having a methane concentration of 0.4 percent. This sample, analyzed by Global Geochemistry, had a stable carbon isotope value of –39.95 part per mil, suggesting a very mature and probably oxidized gas sample. Given the high methane concentrations (75%) at only four feet in depth, this is not surprising. Two other samples collected by CDM at this time had very appreciable methane and ethane soil gas concentrations. Sample CDM-SG-3 contained 83.8% methane and 0.4% ethane, and sample CDM-SG-2-9 contained 41.2% methane and 0.3% ethane. These samples clearly show there was a methane problem in this area; the survey was otherwise too limited in scope to be used for evaluation.

The presence of methane homologs (ethane, propane, and normal-butane), that have the exact same distribution as the methane, proves that a major portion of the methane is thermogenic, that is generated by heat and pressure at depth within the Pliocene and/or older rocks that underlie this Site. It is well known that biogenic processes do not generate these methane homologs (Jones & Drozd, 1983 and Jones et. al., 2000). Isoconcentration (contour maps) of ethane, propane and normal-butane are shown on Plates 5, 6 and 7, respectively. These component methane homolog maps indicate that a large portion of the methane must be derived from a thermogenic source.

The largest and most extensive methane anomaly occurs along a north–south trend that extends from site 267 on the south edge up to site 164, a distance of 1000 feet. Although slightly lower in magnitude, this anomaly can be extended to at least site 3 in Tract 03 (an additional 700 feet). The width of this impressive anomaly varies from 200 to 400 feet over this distance. Methane concentrations within this anomaly range from 43% to over 75%.

It is well known and accepted that hydrocarbon gases are expulsed from the earth along active fault and fracture traces (Jones and Drozd, 1983 and Jones et. al., 2000). This geochemical signal, especially when accompanied by ethane through butanes, can only be interpreted as deep-earth gases (thermogenic gases) migrating up along an active fault trace. As will be discussed later, additional isotopic measurements of stable carbon isotopes, using the carbon 12/13 ratio, further suggests that these gases can only be related to a deep thermogenic source. Further confirmation of the presence of significant gas potential from this large anomaly was demonstrated by minor blowouts of gas that occurred during the drilling of the monitor wells.

Monitor well MMW-211 was most troublesome to the CDM drilling crew. The initial well at site 211, upon reaching the aquifer, blew water over the derrick of the drilling rig (40 feet into the air). Unfortunately, the crew had to standby for 24 hours while this well discharged. Since the well had bridged (caved in), the drilling crew had to redrill the hole the following day and inject bentonite into the formation to reseal this drill hole. An offset hole was drilled and finally established at an alternate location before the well screen could be set. Another nearby hole that was allowed to vent for 24 hours was site 207. Including these two holes with MMW-3 and 4 (discussed earlier), there were four monitor wells within the large elongated methane anomaly that had adequate gas to require venting before safe handling could be assurred.

Previous experience gathered over artificial, underground gas storage fields and over man-made underground coal bed methane retorts has demonstrated that the time required by gases to migrate through the earth is very short (only a few days to hours from depths of 1000 feet). Actual measurements made over an underground coal-gasification retort located approximately 1000 feet below the surface indicated seepage as large as these would decrease by an order of magnitude within six months if not continuously recharged from depth (Jones and Thune, 1982; Jones et al., 2000). Concentration of 75% methane at a depth of only four feet, without a local source or recharge from depth, is not possible. There is no easy way to determine the actual flux from a seep having such a large surface expression, but there is no doubt that it must be active to sustain these very large concentrations at a depth of only four feet.

The initial regional survey was started under the premise that the methane seepage in this area might be associated with the two abandoned wells, the Universal City Syndicate Vidor #1 and Cooperative Development Co. Community #1. The shallow soil gas survey did detect near-surface seepage in the vicinity of the Universal City Syndicate Vidor #1. Two of the soil gas seeps contained 18% (site 503) and 41% (site 535) methane. When considered on a more regional scale, however, the amount of potential leakage from these two dry holes is very small when compared with the natural seepage associated with the big, elongated methane anomaly described above.

This natural seepage is better demonstrated by the propane and butane contour maps for the free and dissolved gases (Plate 11) found in the 41 monitor wells. The normal-butane contour map clearly shows that the majority of the gases in the 50-foot gravel aquifer issue directly from the Pliocene sediments. The petrogenic nature of the gas composition (ethane through butanes and thermogenic isotopes), and the extended north–south linear orientation of this macroseep, strongly suggests that these gases must be related to a fault. This fault provides communication to the surface from the deeper horizons below.

An independent thermogenic source is further demonstrated by the larger propane and butane concentrations within this fault-related anomaly, as compared to the Universal City Syndicate Vidor #1 abandoned well casing. It is generally accepted that heavier hydrocarbons, such as propane and butane, can be filtered out (lost) during migration, but they can never increase in concentration during migration. There must be a local source within Tract 01 for an increase to occur. The easternmost methane anomaly at sites 928 to 921 contains heavier hydrocarbons (such as butanes) than the anomaly in Tract 01. This again confirms that these two methane anomalies must have independent sources, and these sources are local to each anomaly. Migration of well casing related gases through the aquifer cannot explain this behavior.

Given the very low levels of seepage associated with the Universal City Syndicate Vidor #1 and the Cooperative Development Co. Community #1 wells, it might be advisable to not rework these wells. Many attempts to re-abandon the wells have been unsuccessful. In all likelihood, both wells will need to be re-abandoned in order to insure a safe construction project, however, this will probably have no effect on the gases migrating to the surface from the Lincoln Blvd. fault. It may be significant to note that the Universal City Syndicate Vidor #1 first blewout at 1831 feet, very close to the intersection of this wellbore with the proposed Lincoln Blvd. fault. Communication with this fault could present a complication during the abandonment process.

The second largest methane anomaly occurs on the east side of the survey area at sites 928 to 921. This anomaly is over 600 feet by 800 feet in areal extent. As with the other methane anomalies, this smaller, but significant anomaly was accompanied by other petrogenic gases (such as ethane, propane and butanes), indicating a deep thermogenic source for these gases. Isotopic data confirm this as a thermogenic gas seep. As noted above, this anomaly also has even larger propane and butane concentrations than the western Tract 01 anomaly, again suggesting an independent thermogenic source from depth. The slight changes in composition would be typical of thermogenic gases from depth, but not from biogenic gases which never contain ethane through butanes.

The presence of anomalous concentrations of ethane, propane, and normal-butane, coincident with the anomalous methane concentrations in both of these anomalies, infers that the methane gas is thermogenic in origin. The spatial correlation between the light hydrocarbon soil gases and the 50-foot gravel aquifer, and their similarity in compositions demonstrates their obvious relationship.

In contrast, the BTEX and H2S components in the soil gas show no correlation to any of the other gases, either at the surface or in the 50-foot gravel aquifer. CDM analyzed several of the deep monitor well samples and never found any detectable BTEX in the deeper gases. None of the deep wells has had any H2S reported in the vented gases, nor would they be expected to from the thermogenic sources that underlie this Site.

There are reports of La Brea tar sand fill being used during past filling operations (CDM, October 20, 1998, p.3-2 to 3-3). Although some limited H2S hits were occasionally noted in the drilling logs, there does not appear to be any H2S sources associated with the thermogenic gases. The H2S is also believed to represent near-surface contamination, probably from dumping and/or from organic rich fill that was added to the Site over time. All detectable H2S measurements made by all operators (surveyors) have been random and generally found to be associated with recent sedimentary deposits.

A review of Table 2 as well as the toluene, total xylenes and H2S maps, indicates there are generally very low levels of BTEX contained within the soil gas collected over the survey area. There is essentially no benzene and only modest levels of toluene and total xylenes. Some of the largest toluene and total xylene concentrations do cluster. These fairly minor BTEX anomalies are probably related to near-surface contamination, and do not appear to represent a hazard to construction.

5.2 Dissolved Light Gas Distributions in the 50-Foot Gravel Aquifer

Following the interpretation of the regional soil gas data, it was clear that the groundwater should be sampled to determine whether there was any gas sources in the 50-foot gravel aquifer. It was also necessary to determine the relationship between deeper gas sources and the shallow gases observed at four feet. To accomplish this objective, groundwater was sampled from the 50-foot gravel aquifer in all 41 monitor wells. Nine of the monitor wells had been previously installed, while 32 new monitor wells were added for this assessment. The purpose of the groundwater sampling was to determine the distribution and magnitude of dissolved methane gas within the 50-foot gravel aquifer, and to determine the composition of other associated dissolved gases within the aquifer.

The 50-foot gravel aquifer is approximately 15 feet thick and dips to the west in this area. The measured groundwater flow direction determined from these 41 wells installed within the 50-foot gravel aquifer is to the north-northwest toward Ballona Channel. Previous hydrological studies had suggested that groundwater flow was from west to east (MEE, 1987).

Because methane had previously been detected at fairly large concentrations in the groundwater, it was suggested that these 41 monitor wells be drilled on a grid spacing determined from the soil gas data and used to collect two different and independent types of samples. A free gas sample was collected using a bubble pail and a dissolved gas sample was collected directly from the aquifer in a 125 ml bottle. Both samples were collected under water by water displacement, providing very high quality samples with no ambient air or other possible contaminants. Each well was pumped at a fairly low flow rate (approximately ½ gallon per minute) for an extended period of time, designed to provide numerous samples from successive well volumes. These free gas and dissolved gases samples were then averaged for each well and plotted on contour maps so that any methane gas anomalies in the 50-foot gravel aquifer could be mapped and studied. Average methane concentrations ranged from 0.005 mg/l to 48.3 mg/l (Plate 11). The highest concentration of methane (99.7%) was observed in MMW 226. This sample also contained the 48.3 mg/l dissolved gas concentration.

The methane concentrations in the groundwater are highest in areas of anomalous methane soil gas, and that the largest methane values are accompanied by methane homologs, such as ethane through butanes. This correlation with deep thermal, non-biogenic gases proves that these gases observed near the surface are themselves derived from the 50-foot gravel aquifer, and these gases must be further derived from deeper sediments. The maximum observed average saturation for dissolved methane in groundwater was 48.3 mg/l in MMW 226 (Plate 11) indicating that methane is approximately at maximum saturation in the groundwater for that depth.

Dissolved concentrations of ethane, propane and n-butane are illustrated on Plate 11. As previously noted for methane, the concentrations of these components are also highest in areas of anomalous methane soil gas. The presence of dissolved concentrations of ethane, propane and n-butane in groundwater is indicative of a thermogenic gas contribution.

5.3 Free Gas Distributions in the 50-Foot Gravel Aquifer

Analytical results of methane concentrations in the free gas samples from the 41 monitor wells are illustrated on Plate 11. The highest concentration of methane (99.7%) was observed in MMW 226. In general, the highest free gas methane concentrations are present in areas of anomalous methane soil gas and anomalous methane concentrations in groundwater. However, there is not a direct correlation that would indicate that Henry's law is completely controlling the relationship between the free gases and the headspace (dissolved gases in the groundwater). A very good example is provided by MMW-211, which had enough free gas to blow the water to a height of over 40 feet into the air. When finally sampled, this well had only about 60 % methane and 17 mg/l of dissolved gas, whereas MMW-226 had 99.7% methane and 48.3 mg/l of dissolved gas. Monitor well 211 occurs on the eastern edge of the big, fault-related methane anomaly. There was a very large soil gas anomaly at this site (89.2% methane) despite of the fact that the methane in groundwater was not at a maximum. This suggests that there is gas migration at the top of the aquifer (or at least in the fill above the aquifer) that is independent of the gases in the aquifer. This independent gas pocket was the likely cause of the blowout in monitor well 211.

The strong spatial correlation between the soil gas anomalies and the groundwater anomalies implies that the dominant migration of gas is vertical. There is very little migration of gas laterally within the aquifer. Previous experience by ETI in exploration surveys indicates that groundwater flow almost never has any controlling effect on the distribution of gases within the near-subsurface strata. The time for gas to pass vertically through the aquifer is very short when compared to the time for groundwater to move laterally.

The free gases liberated from the monitor wells provide an independent data set for comparison with the soil gases and with the dissolved gases in the groundwater. When accompanied by significant levels of methane homologs (ethane, propane, and butanes), it is concluded that these gases have a thermal origin. The source of this thermal methane gas has to be derived from Pliocene and possibly deeper gas sands, as previously discussed (3.4 Shallow Natural Gas).

5.4 Isotopic Analyses of Free Gas Samples

The free gas bubbles liberated from the monitor wells were collected into 125 ml gas bottles by volume displacement and sent to Isotech Laboratories in Champaign, Illinois for analysis of the methane through hexane vapors and the permanent gases nitrogen, oxygen, carbon dioxide, helium, argon, hydrogen and carbon monoxide. These analytical results are listed in Table 5 along with the carbon and hydrogen isotopes of the methane, ethane and carbon dioxide. This light gas data provides an independent confirmation on the Microseeps Laboratory analysis. Appendix D provides a report by Dennis Coleman of Isotech Laboratories.

A plot which shows the carbon and hydrogen isotopic compositions of the methane samples from this study relative to typical compositional ranges of gases from different sources is shown in Plate 12a. Most of the samples fall within the mixed zone between the subsurface microbial gas zone and extend into the edge of the thermogenic gas zone. This suggests that these samples represent different mixtures of thermogenic gas and biogenic methane. Another group of samples extends vertically above the thermogenic zone. These latter samples represent gases that have been subjected to bacterial oxidation affects. In addition, there are two samples from MMW-743 that do not appear on this plot because they are off-scale.

Plate 12b provides a map view of the methane concentration with dot size proportional to the methane concentration. The color of the dots has been selected according to the individual carbon isotopic values for each methane sample, with red colors being the most thermogenic and blue the most biogenic. This map clearly shows the strong clustering of the largest magnitude and most thermogenic gas seeps. A comparison with the contour maps shown on Plate 11 clearly defines the presence of two thermal gas macroseeps. A correlation with the soil gas data is also obvious.

Plate 12c provides an expanded view of Plate 12a, showing in more detail the distribution of all the samples. For this plot, these samples have been color-coded according to their clusters as thermogenic (red), biogenic (green), mixed thermo-biogenic (yellow) and thermogenic oxidized (orange). The red group clusters together near the right end of this trend. These samples contain the least, if any, biogenic methane. The samples (orange group) within the very strong vertical trend on this figure have been strongly affected by bacterial oxidation. As shown by the arrow labeled "Oxidation Effects" on Plate 12a, oxidation effects typically move up and to the right. However, in this data set, it appears that there is an oxidation effect that is strongly affecting the hydrogen isotope composition with little, if any, affect on the carbon isotope composition. The result is a shift in a vertical direction, as shown by the orange population on Plate 12c. This appears to be a very strong trend that is different from what is typically observed. The oxygen deficiencies in these samples are also shown by the carbon isotopic composition of the carbon dioxide. One sample, MMW-39, appears to have been strongly affected both by oxidation and mixing with biogenic methane.

The cluster of samples in the lower right hand corner of Plate 12c show the least affects of either methane oxidation or biogenic methane formation. A comparison of the isotopes of this clustered data with the remaining samples, suggests three samples, in particular, which show the least secondary affects, and thus would appear to contain the freshest thermogenic methane. These three are wells MMW-153, MMW-175, and MMW-912. As confirmed by Plate 11 and the soil gas maps, there are at least two very well defined anomalies within the study area where thermogenic gas seeps exist. Thus there is one source of thermogenic methane in the southeast corner of the study area near monitor wells MMW-912 and MMW-921, and the other is just southeast of the intersection of Lincoln Boulevard and Jefferson Boulevard near MMW-153 and MMW-175.

Plate 12d shows the locations of this color-coded data from Plate 12c in a map format. The red dots represent relatively pure unaltered thermogenic gas. The term relative has been applied because some of these gases do appear to show some secondary affects. The yellow dots are those wells, which represent mixtures of thermogenic gas and biogenic methane. The green group of samples are mainly biogenic, and the most interesting group of samples are shown as orange dots. They represent gases that have been significantly altered by bacterial oxidation. Most of these samples, which have been severely oxidized, are thermogenic gases, although some of the biogenic mixtures may also have been subjected to some oxidation affects. The geographical order of this data clearly suggests two main thermogenic seeps, which have been oxidized and partially mixed with some biogenic gas.

According to Dennis Coleman (see letter report in Appendix D) this data suggests an interesting relationship that appears to exist between the thermogenic gas seeps and the biogenic methane. There are many other sites where biogenic methane appears to be associated with thermogenic natural gas seeps (Jones and Burtell, 1996, Jones and Agostino, 1998, Thompson 1966). In this environment, there can be a very substantial culture of bacteria developed that lives on this thermogenic gas. In such situations, the interface between the oxic and anoxic zones can change depending upon hydrostatic conditions, barometric pressure, and the rate of gas seepage. Therefore a specific location that is anoxic at one time could be oxic at another time, or vice versa. If an oxic zone becomes anoxic, it may be possible for anoxic bacteria to consume the residual cell material present in that zone and convert it to methane. Thus, the methanogens could be living on the dead methanotrophs. Therefore, the zones where biogenic gases reside today may have been the site of methane oxidation at some time in the past. In this case these seeps have probably existed for hundreds to thousands of years, allowing amply time for such behavior.

In addition, there is the possibility that some methanogens are actually switch hitters. That is, under some conditions they can be methane producers whereas under other conditions they can be methane consumers. In particular this appears to apply to sulphate reducing bacteria. It is well known that sulphate reducing bacteria can consume methane. If this type of phenomena is occurring at Playa Vista, that would explain the lack of carbon isotope fractionation that is observed with the methane oxidation. This may be a site of anaerobic oxidation and not aerobic oxidation. This could also suggest that the oxidation may actually be occurring at greater depth and not in the near-surface where these samples were collected.

As discussed above, the areas of thermogenic gas coincide with areas of anomalous methane soil gas and the presence of heavier methane homologs (ethane, propane and butanes). The majority of the isotopic analyses performed on samples obtained within the largest magnitude gas anomalies indicate the presence of immature thermogenic gas, in the range of –55 to –60 parts per mil.

This interpretation is easily confirmed by comparing these gases with some actual reservoir gases measured directly from other commercial gas fields in California. Table 6 contains nine reservoir gases collected directly from commercial gas fields in California. These reservoir gas samples were collected and analyzed by Global Geochemistry Corporation as part of a Crustal Gas Data File sponsored by the Gas Research Institute. The stable carbon isotopes of these samples (Table 6) range from –50.0 to –61.3, and are very similar to those measured from the 41 monitor wells in Playa Vista. In addition, the presence of low, but significant ethane accompanied by measurable and much smaller propane is typical of shallow immature thermogenic gases. Another distinction and marker commonly noted in shallow immature thermal gases is the presence of iso-butane, that is dominant over normal-butane. Any one of these eleven commercial gases are directly comparable to the Playa Vista gas seepage. This composition is exactly what would be expected for a shallow, immature, but definitely thermal gas as observed on the Playa Vista Site.

The levels of the more biogenic-type gases occur mainly between the main two thermal gas seeps. Monitor wells located to the west of the Universal City Syndicate Vidor #1, site 509 and to the south, near the Cooperative Development Co. Community #1 contain very little gas in the aquifer. This is consistent with the shallow soil gas data. Both methods yield valid indications regarding gas anomalies from depth. The two wells that have isotopic values that indicate extensive biological oxidation, MMW 272 (-23.48 parts per mil) and MMW 509 (-34.55 parts per mil), also occur in these areas; they also exhibit very low methane concentrations. These very heavy carbon isotopes indicate significant levels of oxidation of the hydrocarbons in the aquifer, as would be expected if there were no methane present in the aquifer at these locations.

The soil gas and monitor well data from site 509 indicates there is no gas migration at this location from the adjacent Playa del Rey gas storage field. The groundwater data clearly indicate there are areas within the gravel aquifer where there is no gas present, either biogenic or thermal. Regional surveys using these methods will allow the gas-charged and non-gas-charged portions of the proposed construction site to be delineated and used for planning and permitting. It is strongly recommended that soil gas and groundwater surveys be conducted over all areas planned for future construction. There will be many areas where no methane mitigation of any kind will be required.

The two main methane anomalies contain thermal gases that have, and still are migrating upward from the potential gas sources defined by the non-commercial wells drilled in this area. The only scientific explanation that makes sense is that deep thermogenic gases from the zones located between 500 to 3000' are migrating to the surface along fault planes.

Without additional deep gas drilling and testing, it will be impossible to determine the true potential for future gas flux into these anomalous areas. Many scientific studies have been conducted throughout the world by geochemists using similar methods to attempt to predict earthquakes through the use of deep gas fluxes issuing from active and open fault zones (Jones and Burtell, 1996). The best approach would be to leave these seepage areas open. If they have to be used for construction, then one should build non-residential buildings within such areas. Active and aggressive monitoring systems should be designed to predict the onset of significant gas seepage from depth that could cause a loss of life or limb.

We believe that to ensure a safe environment, it will be necessary to mitigate the underlying groundwater aquifer if residential housing is to be constructed. In the event of a major earthquake in this area, there will be little to no warning of the onset of significant gas seepage from depth. In addition, the volume of a natural seep cannot be calculated, nor turned off in the event of an earthquake, as with natural gas lines.

An oil field related rupture of this type occurred in the early morning hours in February 9, 1971 associated with a 6.6 magnitude earthquake. The epicenter of this earthquake was near the town of Saugus, California, yet the area of surface rupture and greatest damage occurred some five to six miles away in the San Fernando-Sylmar area, Slossen, 1971. One rupture zone occurred just to the south of a mapped fault that was referred to as the Hospital Fault. However, according to Slossen this fault more closely coincided with a fault zone that has little surface expression, but had been interpreted from subsurface data. Another rupture zone coincided with the location of a ground water barrier, which had suggested geological activity. Both of these examples have a clear analogy to the fault relationships mapped in the Playa Vista area.

Of even more interest, is the fact that five oil and gas seepages were reported to have occurred within the old Salt Lake oil field. These seepages were the result of rupture in the near surface zone of some abandoned oil wells. One example cited by Slossen was of a well located within a residential area that started to produce approximately 20 barrels of oil per day and 100,000 cubic feet of gas per day after the earthquake. According to Slossen, this situation did create a fire and explosion hazard, which had to be corrected.

The senior author has had previous experience with sampling of water wells located within the San Andreas and other fault zones where the seepage production rates changed in response to changes in the geological stress fields associated with earth movement (Jones and Burtell, 1996 and Jones et. al. 2000). Additional references are provided by these latter two citations.

6.0 METHANE MITIGATION SYSTEM FOR 50-FOOT GRAVEL AQUIFER

In addition to methane mitigation for the building foundations in Tracts 01 and 02, methane mitigation systems are also recommended in the 50-foot gravel aquifer. The mitigation of the 50-foot gravel aquifer will require a "pump and treat" system consisting of recovery/extraction and injection wells. The wells should be installed in areas containing methane concentrations in excess of 70%, as shown by the brown to orange contours on the free gas map in Plate 11. The number of wells required will depend upon the radius of influence of a series of test wells, as determined by performing pump tests over the methane charged aquifer. The final spacing and the number of wells will be determined from the results of these pump tests. Ten to fifteen feet of PVC slotted well screen should be set in each recovery well, beginning at the top of the 50-foot aquifer.

These methane recovery/extraction wells will be utilized to pump water from the 50-foot gravel aquifer to the surface, where the water will be "degassed" or stripped of methane and other gases. This can be accomplished using an air-stripper or equivalent system. The treated water should then be re-injected into the 50-foot aquifer utilizing wells located on the updip, outside edge of the recovery well system (these will probably be located in the yellow, green and blue contoured areas shown on the free gas map in Plate 11. The spacing and number of injection wells will also be determined based upon the results of the pump testing. The re-injection of the water will prevent de-watering of the aquifer and possible land subsidence.

Existing monitoring wells will be utilized during pump testing of the recovery wells to determine the area of influence of each pumping well. Monitoring wells will also be sampled during the mitigation of the 50-foot aquifer to determine the effectiveness of the pump and treat system, and the progress of the methane mitigation.

Once the mitigation system is in equilibrium a real-time monitoring system can be established, using the technology previously outlined for monitoring in Tract 03 for the Visitor Center and Fountain Park Apartments.

7.0 CONCLUSIONS

1. Results from this comprehensive assessment indicate the source of the anomalous thermogenic methane is primarily from shallow natural gas within the Upper Pliocene Pico Formation. These shallow natural gas sands are beneath the area of First Phase Playa Vista Development, and are migrating up the Lincoln Boulevard Fault.

2. A previous subsurface methane assessment, limited to the area of Tract 03, indicated that the probable source of anomalous methane was leakage of thermogenic gas from the Universal City Syndicate Vidor #1 well. Although there is some leakage from this well, the dominant seepage appears to issue from a natural, fault related seep.

3. Methane concentrations in soil gas samples from the near-subsurface and from groundwater samples within the 50-foot gravel aquifer range from background to nearly 100%. The correlation between these samples is excellent, indicating migration from natural subsurface pathways.

4. There are two main areas of high methane concentrations (above 70% methane, see Plate 11) in the west half of Tract 01 and the south half of Tract 02. Anomalous levels of ethane, propane, and butanes are also coincident with these two methane seepage areas, indicating the methane is related to deeper thermogenic sources.

5. There is a north-south linear trend (1700 feet long and 200 feet wide) of very large to intermediate methane concentrations of soil gas, which lies to the east and parallel to Lincoln Boulevard. This anomaly has been interpreted as migration of thermogenic gases from depth from an associated subsurface fault.

6. Areas of anomalous methane concentrations dissolved in groundwater and methane from free gas in the groundwater from the 50-foot gravel aquifer are coincident with the anomalous areas of ethane, propane and butanes, which are only sourced by thermogenic sources. The data indicate that all three data sets have a

common origin. This correlation of independent data sets confirms that the methane is from a deeper thermogenic source.

7. Methane isotope analyses on free gases collected from the 50-foot gravel aquifer further confirm a thermogenic source for the anomalous methane gas. Areas of background to low methane concentrations are primarily biogenic in origin, but bear a spatial relationship that suggests that the biogenic gases have been generated in response to the thermogenic gases.

8. Three independent analytical data sets (soil gas, groundwater, and isotopes) are in concert and confirm that the source of areas of anomalous methane soil gas is due solely to a thermogenic source.

9. The source of the thermogenic gas observed at the Site is most likely derived from shallow natural gas sands within the Upper Pliocene Pico Formation, probably sourced from the gross interval from 510 feet to 3434 feet, encountered in the non-commercial wells surrounding the Site.

10. It is not possible to calculate, or even estimate, the volumes of shallow natural gas beneath the Site due to nature of the surrounding well data. Adequate well logs or other testing data is not available.

11. The position and attitude of the proposed Lincoln Boulevard Fault is based upon a combination of subsurface geologic data, surface topographic lineations, and a north-south trend of anomalous geochemical data. With respect to seismic activity, this fault should be considered as a potentially active low-potential fault. Geochemically, this fault is an active pathway for vertical natural gas migration.

12. The proposed Lincoln Boulevard Fault provides a permeable vertical pathway for the natural gases at depth to migrate to the near-surface, and exhibit the distribution and magnitudes observed.

13. A future earthquake with an epicenter close to the Site could potentially cause a rapid flux of very large volumes of thermogenic methane gas to the surface along the Lincoln Boulevard Fault plane.

14. Present data indicate that the anomalous methane gas concentrations could extend to the north into Area C.

15. Data from this assessment do not show any evidence that the source of thermogenic gas is from the gas storage facility.

8.0 RECOMMENDATIONS

1. Methane mitigation systems and methane monitoring systems should be required for all buildings in the First Phase of the Playa Vista Development. The design of the methane mitigation systems should follow the same specifications as previously approved for the Fountain Park Apartments in Tract 03.

2. Because of the very high methane concentrations of free gas (greater than 70 %, see free gas contour map, Plate 11) in the gravel aquifer, and the future potential for an earthquake-induced flux of large volumes of methane gas in these same anomalous areas, it is recommended that there be mitigation of the 50-foot gravel aquifer in these areas having methane concentration in excess of 70%.

3. For the methane mitigation system of the 50-Foot gravel aquifer a pump and treat methane stripper system is recommended. Pump tests in the aquifer are required in order to determine the number and spacing of the recovery wells required. This must also include water reinjection to prevent subsidence.

4. A monitoring well system following the design approved for the Visitor Center in Tract 03 will also be required to continuously measure methane gas concentrations in the 50-foot gravel aquifer. The monitoring well system will be designed to follow the effectiveness and status of the pump and treat mitigation systems installed within the anomalous (greater than 70 %) methane-charged areas of the 50-foot gravel aquifer.

5. A similar subsurface methane assessment should be conducted in the Tract 49104-04 and Tract 52092 areas of the First Phase Playa Vista Development.

6. Although only leaking minor amounts of thermogenic gas, the Universal City Syndicate Vidor #1 well and the Cooperative Development Co. Community #1 well should be re-abandoned.

7. In the future, methane assessments should be conducted and methane mitigation and monitoring systems completely designed at sites slated for development before zoning is approved.

8. A similar subsurface methane assessment should be conducted in the area of Second Phase Playa Vista Development before zoning use is established and, more important, to aid in the planning.

9. The City of Los Angeles Methane Gas Code should be revised to provide conditions for mitigation based upon whether the methane gas is of a biogenic or thermogenic origin.

Submitted this 17th day of April, 2000

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