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FINAL TECHNICAL / SCIENTIFIC REPORT

**GEOHERMAL RESOURCE EXPLORATION PROGRAM
TRUCKHAVEN AREA**

IMPERIAL COUNTY, CALIFORNIA

submitted to the:

**U.S. Department of Energy
Golden Field Office
Golden, Colorado**

under Cooperative Agreement No. DE-FC04-2002AL68296

GRES II Program

by:

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1.0 EXECUTIVE SUMMARY

With financial support from the U.S. Department of Energy (DOE), Layman Energy Associates, Inc. (LEA) has completed a program of geothermal exploration at the Truckhaven area in Imperial County, California. Truckhaven is an undeveloped geothermal resource which was first explored by industry in the early 1980's, but leases were subsequently dropped due to a sustained period of declining energy prices. In 2001, LEA recognized the development potential of this resource and the need for further exploratory work to better delineate drilling targets and potential resource areas for future development.

The exploratory work conducted by LEA included the following activities: compilation of public domain resource data (wells, seismic data, geologic maps); detailed field geologic mapping at the project site; acquisition and interpretation of remote sensing imagery such as aerial and satellite photographs; acquisition, quality control and interpretation of gravity data; and acquisition, quality control and interpretation of resistivity data using state of the art magnetotelluric (MT) methods. The results of this exploratory program have allowed LEA to develop a structural and hydrologic interpretation of the Truckhaven geothermal resource which can be used to guide subsequent exploratory drilling and resource development.

Of primary significance, is the identification of an 8 kilometer-long, WNW-trending zone of low resistivity associated with geothermal activity in nearby wells. The long axis of this low resistivity zone is inferred to mark a zone of faulting which likely provides the primary control on the distribution of geothermal resources in the Truckhaven area. Abundant cross-faults cutting the main WNW-trending zone in its western half may indicate elevated fracture permeability in this region, possibly associated with thermal upwelling and higher resource temperatures. Regional groundwater flow is inferred to push thermal fluids from west to east along the trend of the main low resistivity zone, with resource temperatures likely declining from west to east away from the inferred upwelling zone.

Resistivity mapping and well data have also shown that within the WNW-trending low resistivity zone, the thickness of the Plio-Pleistocene sedimentary section above granite basement ranges from 1,900–2,600 meters. Well data indicates the lower part of this sedimentary section is sand-rich, suggesting good potential for a sediment-hosted geothermal reservoir in porous sands, similar to other fields in the region such as Heber and East Mesa. Sand porosity may remain higher in the eastern portion of the low resistivity zone. This is based on its location hydrologically downstream of the probable area of thermal upwelling, intense fracture development, and associated pore-filling hydrothermal mineral deposition to the west.

2.0 OVERVIEW OF PROJECT ACTIVITIES

The Truckhaven geothermal area is located in Imperial County, California west of the Salton Sea near the small community of Salton City (**Figures 1, 2 & 9**). Layman Energy Associates, Inc. (LEA) acquired geothermal leasing rights in the area in 2001.

DOE funding history: In September 2002, LEA was awarded \$324,080 under the U.S. Department of Energy's (DOE) program for Geothermal Resource Exploration and Delineation (GRED II). The grant was provided under cooperative agreement number DE-FC04-2002AL68296 between DOE and LEA. Erik B. Layman of LEA was designated as the Principal Investigator for the project. This initial grant supported Phase I of the Truckhaven geothermal exploration program, which consisted of geologic and geophysical studies. The Phase I work program is described in more detail below.

In May 2005, under a continuation of the original cooperative agreement, DOE approved a budget of \$687,625 in additional DOE funding for Phase II of the Truckhaven geothermal exploration program. Phase II of the program was to consist of permitting for, drilling and testing of an exploratory well. However, in September 2005, DOE notified LEA that funding for the Phase II program was cancelled due to DOE budget cutbacks. The Phase II drilling program was thus never initiated. However, DOE authorized the use of the unspent obligated funds for the Phase I program (\$19,682) as carry over DOE funding for initial permitting activities for the Phase II drilling program.

Phase I work program completed: The Phase I work program, completed by LEA in September 2003, included the following elements:

- purchase of commercial SPOT satellite, infrared photo and orthophoto aerial images, with geologic interpretation conducted by LEA;
- on-site field geologic mapping and integration with published geologic data conducted by LEA;
- a gravity survey consisting of 126 stations, with data acquisition and interpretation conducted by GSY-USA, Inc. under sub-contract to LEA;
- a resistivity survey consisting of 95 combined time-domain electromagnetic (TDEM) and magnetotelluric (MT) soundings, with data acquisition and interpretation conducted by GSY-USA, Inc. under sub-contract to LEA
- quality control of gravity and resistivity data acquisition and interpretation, conducted by William Cumming of Cumming Geoscience under sub-contract to LEA
- permitting for the geophysical survey with various regulatory agencies, including archaeological and biological monitoring conducted by EDAW, Inc. under sub-contract to LEA

Results of the Phase I geological and geophysical studies are summarized in **Section 3**, while Phase I permitting results are described in **Section 4**.

Phase II work program completed: LEA completed a significant portion of the initial permitting work required for the Phase II drilling and testing program. Results of the permitting program are summarized in **Section 4.0**.

3.0 RESULTS OF GEOLOGIC AND GEOPHYSICAL STUDIES

3.1 Regional geology

The Truckhaven geothermal area lies within the Salton Trough, a tectonically active sedimentary basin in southern California and northern Mexico. The area comprises a transition zone from the spreading center and transform fault tectonics of the East Pacific Rise in the Gulf of California to the pure strike slip tectonics of the NW-trending San Andreas fault system. North of the Mexican border, the axis of the Trough is marked by the Imperial Valley, Salton Sea and Coachella Valley (**Figure 1**). Geothermal activity is abundant in the Trough, including high-temperature (>250 deg C) resources associated with active spreading centers at the Salton Sea and Brawley geothermal fields. The spreading centers at these sites are buried under thick sections of sediment of Miocene to recent age which fill the Salton Trough. Lower temperature geothermal resources (<200 deg C) such as the Heber and East Mesa fields are encountered away from buried spreading centers and/or towards the margin of the Trough.

San Jacinto Fault Zone: The Truckhaven area lies on the eastern margin of the San Jacinto Fault Zone (SJFZ), a series of NW-trending right-lateral strike slip structures running parallel to and 45 km west of the San Andreas fault (**Figures 1 & 2**). The SJFZ is seismically active, as indicated by the abundant epicenters from events of recent years located along the various fault traces within the zone. The seismicity along the SJFZ broadens in the Truckhaven area, extending to the NE away from the main fault trace. This may reflect activity along NE-trending structures orthogonal to the main SJFZ trend, and possibly indicate good potential for development of fracture permeability in the Truckhaven geothermal resource.

Individual faults along the SJFZ near the Truckhaven area include the Buck Ridge, Clark, Coyote Creek, San Felipe Hills, and Superstition Hills faults. None of these major structures as mapped at the surface occur within the area of this study. However the Clark fault terminates 5 miles to the NW and projects into the study area, and the San Felipe Hills fault passes within 2 miles to the SW.

San Felipe Hills uplift: The Truckhaven geothermal area lies within the San Felipe Hills (or badlands), an area of low hills bounded by San Felipe Creek on the west and the Salton Sea on the east (**Figure 2**). The hills form a SE extension of the more imposing Santa Rosa Range to the north, which rises to elevations of over 6700 feet a.s.l. and in which pre-Tertiary basement rocks are extensively exposed. The NW-SE trend of the San Felipe Hills parallels the SJFZ, and the uplift of the hills is very likely controlled by structures related to the SJFZ, such as the San Felipe Hills fault on the SW side of the hills. Buried splays of the SJFZ which offset the basement but do not penetrate to the surface may also play a role in the uplift

of the range. The existence of such buried structures is supported by gravity and resistivity studies of this area conducted by GSY-USA, Inc. (2003).

Rocks exposed in the San Felipe Hills are late Tertiary age sediments shown as units "QPc" and "P" in **Figure 2**. A more detailed breakdown of the stratigraphic units is presented below. These sediments have been uplifted, folded, and extensively eroded due to their poorly indurated nature. In many areas these sediments are beveled by erosion to a nearly flat surface, and may be mantled with a thin veneer of alluvial gravels.

Subsidiary structural trends: While the NW structural grain of the SJFZ dominates the Truckhaven region, other subsidiary structural trends are apparent. Orthogonal NE-trending faults are present in several areas (**Figures 1 & 2**). These include:

- the fault along the base of the NE-trending spur of the Santa Rosa range ("Travertine Ridge") which reaches to within 2 miles of the shoreline of the Salton Sea;
- several NE-trending faults located between the San Felipe Hills and the Superstition Hills fault;
- the NE-trending belt of seismicity extending from the SJFZ into the Truckhaven area; and
- a more linear zone of seismicity extending from the southernmost point of the Salton Sea to the SW, and overlapping with the NE-trending faults in the Superstition Hills

Seeber and Armbruster (1999) interpret these NE-trending structures as left-lateral, strike slip faults which bound and accommodate rotation of a series of crustal blocks located between the Brawley Seismic Zone (**Figure 1**) and the SJFZ.

Axen and Fletcher (1998) describe low-angle detachment faults in the Santa Rosa range. These structures cut the pre-Tertiary basement rocks and coarse-grained Tertiary sediments of the Canebrake Conglomerate (see stratigraphic discussion below). One of these structures is shown in **Figure 3** as the sinuous fault trace with sawteeth on the upper plate which juxtaposes QPc sediments against basement rocks. These low-angle features apparently formed early in the history of the development of the Salton Trough, and facilitated the initial opening of the basin.

Stratigraphy of western Salton Trough region: The Tertiary stratigraphic units shown in **Figure 2** include Miocene continental sediments (Mc); Pliocene marine sediments (P); Plio-Pleistocene continental sediments (QPc); and Quaternary continental sediments (Q). These units have been broken down in more detail and individual formation names provided by Dibblee (1954) and Winker (1987), and their work is summarized in **Figure 3**. Dibblee's column provide basic lithologic descriptions of the formation units, while Winker's provides updated information on ages and facies relationships. Two units shown on Winker's column, the Alverson Formation and Fish Creek Gypsum, and are not encountered in the near vicinity of the Truckhaven area, and thus are not discussed further here.

Basement rocks in the region include Mesozoic granitic rocks and older metasedimentary rocks including schists, gneisses, and limestone. The Tertiary sequence begins with the Split Mountain Fm. of Miocene age, which consists of coarse-grained sediments and conglomerate

lying on the pre-Tertiary basement. The Imperial Fm. of Plio-Miocene age overlies the Split Mountain Fm. and consists mainly of claystone with lesser amounts of sandstone and oyster shell reefs. This unit was deposited in a shallow marine environment.

Units above the Imperial Fm. represent the transition to a continental depositional environment, with more coarse-grained facies deposited closer to the mountain ranges on the margins of the Salton Trough. These coarse grained facies include the Canebrake Conglomerate of Plio-Pleistocene age, and the Ocotillo Conglomerate of Pleistocene age. Closer to the axis of the Trough, finer-grained sandstones and claystones are encountered, representing fluvial-deltaic and lacustrine depositional environments. The Palm Springs Fm. of Plio-Pleistocene age consists of interbedded sandstones and red clays, and appears to have been deposited in a fluvial-deltaic environment. The overlying Borrego and Brawley Formations, both of Pleistocene age, are dominated by claystone with minor sandstone. These units represent a predominantly lower energy, lacustrine environment of deposition.

Quaternary deposits of Holocene to recent age include alluvium (Qa), older alluvium (Qoa), terrace gravels (Qtg), dune sand (Qd), and lacustrine deposits of pre-historic Lake Cahuilla (Ql). These deposits are not broken out into separate units in the stratigraphic columns of **Figure 3**, or in the geologic maps of **Figures 2 & 4** where they are lumped as "Q" or "Qu". However, the distribution of these units is shown in the imagery of **Figures 5**.

The high stand of Lake Cahuilla is marked around the margins of the Trough by beach deposits and/or erosional benches at an elevation of about +40 feet a.s.l. Several high stands of the lake have been documented since 700 A.D., including the most recent in the 1600's (Waters, 1983). In the San Felipe Hills, the Lake Cahuilla deposits tend to be preserved near existing drainages where they drape the topography. These deposits can be readily identified by abundant remains of thin-shelled clams and ostracodes, typically contained in clay or fine silt.

Recharge area for artesian aquifers in San Felipe Hills: At the south end of the Santa Rosa range, QPc sediments (Palm Spring Fm. and Canebrake Conglomerate) are folded and uplifted to elevations of over 3,000 feet a.s.l. (**Figure 2**). This region is presumed to comprise the elevated recharge area for artesian aquifers encountered by drilling in stratigraphically equivalent QPc sediments at lower elevations in the San Felipe Hills. Both the Truckhaven No. 1 and Holly Corp. wells (**Figures 2, 4 & 5; section 3.3**) are known to have produced artesian flows of groundwater from QPc sediments at depths shallower than about 2,000 feet. The flow from Truckhaven No.1 was reported during drilling, while that from the Holly Corp. well continued for many years after the well was completed until it was finally abandoned. Such a "U-tube" arrangement of sandy aquifer units, sealed by impermeable clay-rich confining layers, is presumed to produce the overpressure of the aquifers in the San Felipe Hills.

3.2 Geology of Truckhaven geothermal area

A geologic map covering an approximately 70 square mile area centered on the Truckhaven geothermal prospect is shown in **Figure 4**. This map was prepared by modifying Dibblee's (1984) map using the results of LEA's detailed field mapping in the vicinity of the Truckhaven No. 1 well. Further detail is provided in **Figure 5**, which shows the results of a portion of LEA's mapping efforts, on an orthophoto base, within an ~7 square mile area which includes the Truckhaven No. 1 and Holly Corp. wells.

Rocks exposed in the study area consist of the Brawley, Borrego and Palm Spring Formations, mantled by alluvium, terrace gravels and lake beds. Palm Spring Fm. crops out extensively in the central and western part of the map area, with Borrego and Brawley Formations mostly confined to the eastern half. Small exposures of Borrego Fm. occur near the west margin of the map area.

Small-scale folding: Folding is widespread in the sediments of the Palm Spring and Borrego formations. The folding is quite evident on aerial photographs (e.g. **Figure 5**), due to the beveled erosional surface in the Palm Springs Fm. and the color contrast between sandstone and claystone layers. Most of the folding is at a relatively small-scale, with fold axes ranging from 0.5-2.5 miles in length. Dips on fold limbs are typically less than 30 degrees, and many of the folds axes plunge as described below. Orientations of fold axes are predominantly E-W to NW. Most of these folds are concentrated in a NW- to WNW-trending belt about 3 miles in width, the northern margin of which passes just south of the Holly Corp. and Truckhaven No. 1 wells. The fold axes are in general slightly oblique to the fold belt trend, suggesting a crude right-stepping, en-echelon pattern. Such an en-echelon fold trend may reflect movement along an underlying strike slip fault zone which has not penetrated to the surface. This fold belt aligns reasonably well with a SE projection of the Clark fault, and may be the surface expression of a buried projection of this structure.

Larger-scale anticlinal structure: The axis of a larger-scale anticlinal structure, over 6 miles in length and trending N-S to NNE, is interpreted to pass just west of the Holly Corp. well. The following features suggest the existence of this structure:

- 1) the older Palm Spring Fm. is flanked both on the west and east by outcrops of the younger Borrego Fm;
- 2) the plunges on the small-scale folds are consistently to the west in the western part of the map area, and consistently to the east in the eastern part;
- 3) the Palm Spring - Borrego Fm. contact east of the Truckhaven No. 1 well trends consistently NNW over a distance of over 6 miles, suggesting this area comprises the east limb of the anticline, dipping to the east
- 4) consistent east dips are mapped at the surface in the eastern part of the map area and are also indicated by the interpretation of a seismic line which crosses the area, as described below.

This large-scale anticlinal structure is likely continuous with the easternmost of two large scale anticlines shown in a geologic section by Dibblee (1984) across the southern San Felipe

Hills, several miles south of the area included in **Figure 4**. This compressional feature may be related to the general uplift of the San Felipe Hills described above.

NE-trending fault zone with calcite mineralization: A zone of NE- to NNE-trending faults approaches to within 1 mile west of the Truckhaven No. 1 well. The faults in this zone, which were not recognized by Dibblee, cut the Palm Spring Fm. and are typically marked in the field by bedding truncations and tight drag folding with steep dips close to the fault trace. The maximum observed strike length for individual faults within the zone is about 1 mile, although some of these project under alluvium and recent lake deposits, and could potentially be longer. About 2 miles west of the Holly Corp. well, several fold axes appear to bend into the fault zone, suggesting possible drag along the fault. If correct, the sense of motion indicated by the drag is right-lateral. However, this would not be consistent with the regional tectonics of the Trough. A NE-trending fault would be expected to exhibit left-lateral motion as a conjugate structure orthogonal to the dominant regional trend of NW-oriented right-lateral faults.

Many of the fault traces are mineralized with secondary calcite (**Figure 18**). The mineralized fault zones may project above the surface as resistant "ledges", with thickness ranging from 1-5 cm. This vein calcite ranges in form from very fine grained, chalky masses to flattened botryoidal clusters of radiating crystals, with individual crystals up to 1 cm in length. No fluid inclusion analyses were conducted on the vein calcite to determine their temperature of formation. However, it is possible that the calcite in these veins was deposited by an early phase of geothermal activity in the Truckhaven area. The veins are geologically young since they cut the Plio-Pleistocene age Palm Spring Fm., and may vertically overlie a still active portion of the Truckhaven geothermal system. It is conceivable that the recent uplift of the San Felipe Hills has elevated these veins above the water table and effectively isolated them from an underlying active system.

3.3 Subsurface structure from well and seismic data

Existing public domain wellbore and seismic data were reviewed to help delineate the subsurface structure in the Truckhaven area. Well data also provided a preliminary indication of the subsurface temperature regime.

Well data: The location of selected wells in the Truckhaven area is shown in **Figures 4, 11-12, 16-18**. Truckhaven-1 is a geothermal exploratory well drilled by Phillips Petroleum in the early 1980's to a total depth of 8,089 feet. This well was non-commercial but yielded a stabilized bottom hole temperature of approximately 200°C. The Holly Corp. "hot well" was drilled to an unknown depth as a water supply well for a housing development. This well produced 59°C water under artesian conditions and supplied a local thermal bath for many years before it was plugged and abandoned in 1993. Pure Oil No. 1 was a non-productive oil and gas exploratory well drilled in the early 1960's to a total depth of 6,061 feet.

Data on subsurface lithology in the Truckhaven area was obtained from the Pure Oil No. 1 and Truckhaven-1 wells (**Figure 6**). Formation tops for Pure Oil No. 1 were reported in

Dibblee (1984), while lithologic data for Truckhaven No. 1 was taken from an R.F. Smith Corp. mud log on file with the California Dept. of Conservation.

Pure Oil No.1 encountered Palm Spring Fm. from surface to 2330'; Imperial Fm. from 2330-5688'; and Split Mountain Fm. from 5688' to the basement contact at 5854'. No descriptions of the lithologies encountered were provided by Dibblee to allow further evaluation of the interpreted stratigraphy in the well.

Truckhaven No. 1 was spudded in Palm Spring Fm., and encountered a clay-dominated section from surface to 2,100', below which a sand-dominated section extends to 5550'. Coarse-grained sediment and conglomerate, indicated by rock fragments in well cuttings, extend from 5550' to the basement contact at 6300'. This interval is presumed to correlate with the Split Mountain Fm. It is unclear whether this well penetrated the Imperial Fm. between the Palm Spring and Split Mountain Fms. Dibblee's (1984) description of this unit indicates it is dominated by claystone and locally fossiliferous. No fossils were reported in the mud log for Truckhaven No. 1, and the sand-dominated section below 2100' is not consistent with the description of "classic" Imperial Fm. However, it is possible that fossil fragments in cuttings may have been misidentified on the mud log as calcite vein fragments, and that this area comprises a more sandy facies of the Imperial Fm. Additional analysis of the cuttings from this well would be required to resolve this ambiguity.

Seismic reflection profile: A seismic reflection profile ("C-3") acquired by Chevron USA in the early 1970's crosses the Truckhaven area. Data acquisition utilized a vibroseis seismic energy source. The profile is oriented NE-SW and extends for 11 km from the shoreline of the Salton Sea to the SW (line location shown in **Figures 7 & 13**). The Truckhaven No. 1 well is located about 1.7 km to the SE of the line, while the Pure Oil No. 1 well is located about 5.0 km from the line to the NW. Field data tapes for this line were reprocessed and interpreted by Severson (1987) under a government sponsored crustal studies program. Severson provides detailed specifications for the seismic data acquisition and processing.

Severson's geologic interpretation of the reflection time section is presented in modified form in **Figure 7**, amended to show the Truckhaven No. 1 well in place of Pure Oil No. 1. The depth-scaled seismic section, converted from time using an average seismic wave velocity of 2460 meters/second and with granitic basement highlighted, is provided in **Figure 8**. The interpreted time section includes a shallowly east dipping section of Tertiary sediments above pre-Tertiary basement. The sediments appear to onlap an undulating erosional surface developed on a basement platform. The basement drops off steeply towards the Salton Sea east of km 2.5 on the profile, apparently the result of offset along an inferred fault zone. A small graben is interpreted to offset the basement contact in the vicinity of the Truckhaven-1 well (**Figure 8**).

The shallowly east-dipping bedding in the Tertiary sediments shown in the seismic section is consistent with its position on the east flank of the inferred large-scale, north-trending anticlinal structure shown in on **Figure 4**. The stratigraphy interpreted on the profile is based on Severson's projection of the units encountered in the Pure Oil No. 1 well. As described above, it is not clear whether the Imperial Fm. reported in Pure Oil No. 1 is also present in the

Truckhaven No. 1 well, and the latter well is located significantly closer to the seismic profile than the former. The upper and lower contacts for the Imperial Fm. are therefore shown with question marks on the interpreted profile.

A possible alternative interpretation of the basement-sediment interface imaged on the seismic profile is that it represents a detachment surface, or low-angle fault. As described above, detachment faults separating the basement from the Tertiary Canebrake Conglomerate have been mapped in the Santa Rosa range to the north, as have similar structures in the western Salton Trough (Axen and Fletcher, 1998). In this scenario, the discordance between the bedding attitudes in the Tertiary section and the basement contact would be seen as a result of fault juxtaposition, as opposed to a sedimentary onlap relationship. This alternative view is considered less likely because detachment structures recognized in the Trough region are generally restricted to the edges of the basin, and associated with "fault scarp" facies such as the Ocotillo and Canebrake Conglomerates. No such structures have been recognized in the immediate areas of deposition of the Palm Spring and/or Imperial Fms.

A graben structure was interpreted on the seismic reflection section crossing the area as shown in **Figures 8**. The graben is about 1.5 kilometers wide, and was identified based on offsets of up to about 250 meters of the contact between the pre-Tertiary granitic basement and the overlying sediments. The graben is also shown in map view in **Figure 16**, located along the seismic line about 2 kilometers north of the Truckhaven No. 1 well. The graben is not evident on the inferred configuration of the basement surface as inferred from MT data (*see discussion below*).

The relative absence of interpreted reflective layers in the seismic profile between km 6.0-8.5 may be related to the Truckhaven geothermal system. Severson (1987) noted that such gaps in reflectivity or "washout" zones on seismic profiles coincide with the locations of geothermal systems in other areas of the Salton Trough, i.e. the Salton Sea and Brawley geothermal fields. This washout effect may relate to hydrothermal mineralization of the sedimentary section, which increases the density of the sediments and reduces the reflectivity contrast between sand and shale layers.

3.4 Geophysical survey results

The area of coverage for the DOE-funded geophysical surveys is shown in **Figure 9**. The 95 magnetotelluric (MT) soundings cover a central area of about 80 square kilometers. The 126 gravity stations extend over a broader area of about 150 square kilometers, centered on the same area covered by the MT soundings. A detailed description of the instrumentation and data acquisition procedures used for both surveys is provided in GSY-USA, Inc. (2003a).

Gravity surveys are commonly used in geothermal exploration to map variations in the strength of the earth's gravitational field which reflect variations in the density of rocks in the subsurface. Gravity surveys may delineate subsurface features such as fault zones, buried intrusive rocks, and/or areas of hydrothermal alteration.

Resistivity surveys are widely used in geothermal exploration to identify zones of low resistivity (or elevated conductance) which are commonly associated with productive geothermal reservoirs. The low resistivity may result from several factors, including changes in hydrothermal mineralogy, elevated temperature and elevated fluid salinity. In most geothermal fields, the low resistivity zones are caused by a halo of electrically conductive hydrothermal clay minerals (smectite and mixed-layer illite/smectite) which forms within the cooler margins of geothermal systems at temperatures between 50-180 deg C (*Ussher et al, 2000; Gundersson et al, 2000*). The deeper, productive reservoir is often characterized by higher resistivity because illite, the stable hydrothermal clay at higher temperatures (>180-200 deg C), is less conductive and occurs in relatively lower abundance in the reservoir compared to clay content in the caprock. For geothermal reservoirs with higher fluid salinity, electrically conductive fluids may also play an important role in formation of low resistivity anomalies.

3.4.1 Gravity

Gravity anomalies at Salton Trough geothermal areas: Many of the geothermal fields of the Salton Trough are associated with gravity anomalies. The Salton Sea, North Brawley, East Brawley, East Mesa and Heber fields are all characterized by positive gravity anomalies, indicating a region of denser rock associated with the geothermal activity. These gravity positives appear to be primarily the result of densification of the porous sand and shale sequence of the basin filling sediments by hydrothermal alteration. In response to sustained periods of elevated temperatures, a well-documented series of mineralogic changes occur in these sediment-hosted reservoirs which eventually increase the rock density sufficiently to create a measurable gravity signature. These include filling of pores in sandstones by secondary minerals and changes in clay mineralogy in shales from less to more dense phases. This relationship between hydrothermal alteration and gravity positives in the Salton Trough has been widely recognized and investigated in detail for the East Mesa geothermal field by Goldstein and Carle (1986) and for the Salton Sea field by Elders et al (1972). Aeromagnetic data suggests that the gravity positive at the Salton Sea field may also in part reflect the presence of young, dense intrusive rocks at depth.

Hydrothermal alteration within the sedimentary section plays a dominant role in generating local gravity signatures at Heber and East Mesa because the basement rocks are quite deep in these areas. Regional gravity modeling suggests basement rocks may lie at depths of over 20,000 feet in the lower elevation, central areas of the Trough. In geothermal areas located closer to the margin of the Trough such as Truckhaven, basement rocks are likely to be relatively shallow. These dense rocks will have a significant effect on the gravity signature of such areas.

Truckhaven gravity signature: Basement rock distribution almost certainly dominates the gravity signature of the Truckhaven geothermal area. This is based on the proximity of the geothermal area to the basement uplift of the Santa Rosa Range to the northwest (**Figure 2**) and on the intersection of granite basement at 6,300 feet in the Truckhaven-1 well (**Figure 6**).

The results of the Truckhaven gravity survey are summarized in a map of complete Bouguer gravity for the area (**Figure 10**), calculated at a reduction density of 2.2 gm/cc. The major feature is a NNW-trending gravity positive in the western part of the survey area which passes through the Holly Corp. well. This feature represents a continuation of the fault-bounded basement uplift of the Santa Rosa Range below a relatively thin cover of Plio-Pleistocene sediments. The western margin of this feature corresponds to the likely projection of the Clark Fault to the SE from its mapped termination in the Santa Rosa Range. A NNE-trending gravity positive lies to the north of the Truckhaven-1 well, and is separated from the main NNW-trending anomaly to the west by a region of relatively lower gravity. Seismic reflection data (**Figure 7 & 8**) show that this gravity positive correlates well with a localized shallowing of the basement.

In general, the close correspondence of the gravity highs with areas of shallow resistive basement as inferred from magnetotelluric data (**Figures 16 & 17**) further reinforces the conclusion that granitic basement dominates the gravity signature in the Truckhaven area. However, the correspondence breaks down in the area between the Truckhaven-1 and Holly Corp. wells. There the top of the basement as indicated by the MT data is relatively deep, whereas the gravity signature remains relatively high, in the form of southeastward bulge in the main NNW-trending gravity positive that passes through the Holly Corp. well. Interestingly, this area coincides with a region of calcite veining from surface mapping. The strong gravity signature in an area of relatively deep basement may indicate that hydrothermal alteration has “densified” the sediments in this area.

3.4.2 Magnetotelluric resistivity

Resistivity anomalies at Salton Trough geothermal areas: Resistivity surveys have proven to be a valuable tool for delineating geothermal resources in the Salton Trough. This has been achieved despite the relatively low inherent background resistivity of the basin-filling sediments due to abundant contained clays and evaporitic deposits. Localized areas of anomalously low resistivity have been identified at all the geothermal fields in the Trough which have been extensively explored by deep drilling (Meidav and Ferguson, 1972; Charre-Meza et al, 2000; Jensen et al, 1990). These include the Salton Sea, Brawley, Heber, East Mesa, and Cerro Prieto fields. As a group, these fields exhibit a wide range of reservoir temperatures (180->300 deg C) and fluid salinities (14,000-300,000 ppm total dissolved solids). Observed resistivity values in the caprock above the productive reservoir in these fields range between 0.1-2.0 ohm-meters (ohm-m). At all these sites, lateral increases in resistivity are noted away from the center towards the periphery of the geothermal areas, allowing delineation of specific exploration target areas using resistivity mapping.

At Salton Sea and Cerro Prieto, modeling of the deeper resistivity structure has shown that the reservoir itself is more resistive than the caprock, with resistivity values between 5-8 ohm-m in the reservoir zone. These are both high-temperature fields (>300 deg C). As such, the "conductor over resistor" pattern is likely to reflect the same mineralogic changes observed in other high-temperature fields, i.e. the transition from mixed layer smectite-illite clays to illite at temperatures of 180-200 deg C. However, to our knowledge no systematic study has been

conducted to determine if hydrothermal mineral zonation in these fields correlates with the observed resistivity structure. Charre-Meza et al (ibid) note a possible correlation between mineralogy and resistivity structure at Cerro Prieto, but provide no details.

The Heber and East Mesa fields may provide the closest Salton Trough analogues to Truckhaven in terms of reservoir temperature. Reservoir temperatures at all three sites range from 180-200 deg C. Meidav et al (ibid) describe low resistivity anomalies associated with the shallow levels of both the Heber and East Mesa fields. However, no data is available regarding the deeper resistivity structure of these fields. It is not clear whether Heber and East Mesa would show the "conductor over resistor pattern" characteristic of the high-temperature fields, because the reservoir temperatures are close to the temperature of the smectite-illite to illite transition. Nonetheless, Meidav et al's work clearly shows that these moderate temperature resources in the Salton Trough, which are geologically similar to Truckhaven, can be delineated by mapping resistivity above the reservoir zone.

Truckhaven resistivity signature: MT data acquired during the survey were of uniformly good quality in the frequency range 1,000 to 0.001 Hertz (Hz) (GSY-USA, 2003a). Evaluation of apparent resistivity curves indicates responses are close to 1-D down to frequencies of about 10 Hz. At greater depths (lower frequency) the response was initially 2-D then 3-D at lower frequencies.

Because of these data characteristics, smoothed 3-D modeling of the Truckhaven MT data (100-0.003 Hz range) was undertaken to allow mapping of lateral and vertical variations in resistivity across the field (GSY-USA, 2003b). For the resistivity depth slice mapping, a depth of 1,000 meters is emphasized here because this is the approximate depth of the transition from conductive to convective thermal gradients in the Truckhaven-1 well. For mapping of total conductance, the 0-1,500 meters depth interval was emphasized because the lowest resistivity layer generally bottoms above this depth, and deeper levels provide minimal input to the integrated total conductance value.

A prominent low resistivity (high conductance) anomaly was identified in the vicinity of the Truckhaven-1 and Holly Corp. wells. The anomaly is indicated in the maps of resistivity at 1,000 meters b.s.l. (**Figure 11**) and of total conductance from 0-1,500 meters depth (**Figure 12**). The low resistivity zone at Truckhaven is strongly elongated in a WNW to E-W direction and runs for a distance of about 11 kilometers. The elongate axis of the resistivity anomaly passes roughly a kilometer north of the Truckhaven-1 well (~200°C near total depth of 8,089 feet) and a similar distance south of the Holly Corp. well (artesian flow of 59°C water).

Conductance increases and resistivity decreases consistently from west to east along the axis of the anomaly. This trend is inferred to reflect regional facies changes in the Plio-Pleistocene sedimentary section. Increased amounts of clay-rich, electrically conductive lacustrine sediments and evaporites, and decreasing amounts of more resistive sand and gravel deposits, are expected with distance from the basin margin toward the Salton Sea and the axis of the Salton Trough. Thus the position of the low resistivity axis, as opposed to the numeric

values of resistivity or conductance, is inferred to be the critical feature for delineating areas with good geothermal development potential.

Resistivity cross-sections (**Figures 15 & 16**; location in **Figure 14**) illustrate the sub-horizontal low resistivity zone associated with a section of clay-rich sediments in Truckhaven-1 at depths shallower than about 900 meters. There is some uncertainty regarding the origin of the shallow clay-rich section in Truckhaven-1 because the lithologic log for the well does not differentiate between clays of sedimentary vs. hydrothermal origin. However, a hydrothermal component to the clays seems likely given the higher temperatures at depth in the well, and the characteristic halo of clay-rich hydrothermal alteration which forms above or on the margin of geothermal reservoirs (Ussher et al, *ibid*; Gunderson et al, *ibid*).

Further evidence in support for a hydrothermal origin of the clay-rich zone in Truckhaven-1 is provided the discordance between the dip of the sedimentary section and the low resistivity zone. This is illustrated by comparison of the resistivity-temperature section NE-3 in **Figure 14** with the seismic reflection section adapted from Severson (1987), shown in **Figures 7 & 8**. The seismic and resistivity sections are sub-parallel, pass within 1.5 kilometers of each other near Truckhaven No. 1, and cross at their northeast ends. Note that the low resistivity zone is sub-horizontal, while the seismic section shows that the sedimentary sequence containing the low resistivity zone dips to the northeast at 20-25 degrees. If the clay-rich section was purely sedimentary in origin, the low resistivity zone would be expected to dip to the northeast at a similar angle as the bedding in the sediments, which apparently is not the case. The sub-horizontal base of the low-resistivity zone may thus represent a temperature-dependent transition in hydrothermal mineralogy. Based on patterns observed in other fields, the transition is likely to be from mixed layer smectite-illite clay alteration to underlying more resistive, clay-poor alteration, in which illite is the main clay mineral.

Resistive basement configuration: The top of the granitic basement intersected by Truckhaven-1 coincides with the 20 ohm-meter resistivity contour in the resistivity cross-sections of **Figures 14 & 15**. The 20 ohm-meter “surface” within the modeled 3-D resistivity volume can thus be used to infer the configuration of the top of the basement across the survey area, resulting in the map shown in **Figure 16**. The actual basement resistivity values exceed 100 ohm-meters based on resistivity logs from the Truckhaven-1 well. However, the strong discontinuity in resistivity at the sediment-basement contact is not reflected in the modeling results due to the smoothing procedures used in the modeling. Nonetheless, the generally good correspondence between the resistive basement configuration and gravity variations (**Figure 17**) and with seismic reflection data (comparison of **Figure 8** with **Figure 16**) support that the modeled 20 ohm-meter surface reasonably approximates the top of basement.

A series of structures are inferred from the top of resistive basement map where the basement surface drops off steeply along linear zones. Fault zones are inferred on the margins of the NW-trending basement high passing through the Holly Corp. well, including an extension of the Clark Fault zone on the western flank of the basement high. This trend is consistent with the strongly developed regional NW structural trend (**Figures 1 & 2**). NE-trending structures

are inferred along the margins of the NE-trending basement high north of Truckhaven-1, and just south of the Holly Corp. well, within the generally NNW-trending basement high. Similar NE-trending structures are evident at the surface about 10 miles NW of the Truckhaven-1 well (**Figure 2**), at the base of the NE-trending basement uplift.

As described in **section 3.4.1**, there is a lack of correspondence between the gravity response and the resistive basement configuration in the area between the Holly Corp. and Truckhaven-1 wells (**Figure 17**). This area, characterized by relatively high gravity values and relatively deep resistive basement, correlates with an area of faults with calcite-vein filling at the surface. This may represent an area of densification of the Plio-Pleistocene sedimentary section by hydrothermal mineralization.

3.5 Integrated structural and hydrologic interpretation

A structural and hydrologic interpretation of the Truckhaven geothermal area, based on integration of the geological and geophysical data described here, is summarized in **Figure 18**. Major elements of the interpretation include the following:

Primary structural control along WNW-trending axis of resistivity anomaly: A through going, WNW-trending structural zone of about 8 kilometers strike length is inferred from the elongate axes of the resistivity and total conductance anomalies. Two wells showing indications of geothermal activity (Truckhaven-1 and Holly Corp) are located on the margin of this inferred structural zone. This feature may provide a key structural control on geothermal resources in the Truckhaven system. As described below, this structure is not evident from geologic mapping at the surface or from mapping of the top of the granitic basement based on 3-D modeling of MT resistivity data. This structural zone therefore does not appear to penetrate to the surface or produce a significant offset of the buried top of the granitic basement.

Regional east- and northeast-directed groundwater flow: Groundwater flow is likely to influence the subsurface flow of geothermal water at Truckhaven, as has been documented at the Heber field located about 65 kilometers to the southeast (James et al, 1987). At Heber, northward-directed groundwater flow tilts the plume of rising thermal fluid northward and creates a tongue of hot fluid centered at about 800 meters depth which flows laterally to the north away from the zone of upwelling

At Truckhaven, surface streams generally run towards the east and northeast along the topographic gradient towards the Salton Sea, and groundwater flow is likely to follow a similar path. Groundwater flow in the Truckhaven area was investigated as part of a regional study of water wells in the Imperial Valley by Loeltz et al (1975). This work showed a consistent NE- to ENE-directed hydrologic gradient in the Truckhaven area, with horizontal gradients on the potentiometric surface ranging from 20-120 vertical feet /mile. This is significantly higher than the 5 vertical feet/mile hydrologic gradient present in the Heber area, indicating significant potential for groundwater flow to affect the subsurface movement of geothermal fluids at Truckhaven.

Regional groundwater flow is likely to drive thermal fluids along strike of the WNW-trending low resistivity zone at its western end. At the east end of the low resistivity zone, groundwater flow is anticipated to push thermal fluids to the northeast, as an outflow zone away from the WNW-trending structural zone.

Enhanced fracture permeability in western half of the WNW-trending structural zone: The western half of the WNW-trending structural zone defined by resistivity data may exhibit higher fracture permeability than the eastern half. Numerous cross-structures intersect the WNW-trending zone in this area. These include:

- 1) abundant surface faults, dominantly with NE trend, cutting the Plio-Pleistocene sedimentary section;
- 2) common calcite vein fillings along many surface fault sections, many of which are composed of coarse-grained crystals up to 1 cm in length, indicating that these faults were conduits for thermal fluids;
- 3) the ENE-trending structure south of the Holly Corp. well inferred from MT data; and
- 4) the NW-trending zone north of the Truckhaven-1 well which is indicated by both seismic reflection and MT data, and also is associated with a zone of seismic activity (Hauksson, 2000).

This western region also has the unusual pairing of relatively high gravity values in an area of relatively thick sedimentary section and deep basement, as indicated by seismic and MT data (**Figure 17**). This may reflect densification of the Plio-Pleistocene sediments by pore-filling hydrothermal minerals, possibly resulting from vigorous upwelling of thermal fluids along fractures in this region.

Potential for sand matrix reservoir to supplement fracture production: The Truckhaven No. 1 well showed that the Plio-Pleistocene sedimentary section is over 1900 meters (6,300 feet) thick in the Truckhaven area. The lower part of this section is sand-rich, indicating good potential for a sediment-hosted geothermal reservoir in porous sands, similar to the Heber and East Mesa fields. Mapping of the contact at the base of the sedimentary section with underlying granite basement using MT and seismic reflection data shows that the thick sedimentary section at Truckhaven extends across a wide area. Within the WNW-trending structural zone defined by the MT data, sediment thickness ranges from 1900-2600 meters. Sand matrix porosity may be more common in the eastern half of the WNW-trending structural zone. This eastern half of the WNW-trending zone is less structurally complex and possibly less fractured than the western half. Sand porosity may remain higher to the east, given its location hydrologically downstream of the probable area of thermal upwelling and associated hydrothermal mineral deposition to the west.

4.0 RESULTS OF PERMITTING ACTIVITIES

4.1 Permits for Phase I geophysical surveys

The resistivity and gravity surveys for the Truckhaven project were conducted in early 2003 across areas of federal, state and private lands. LEA obtained permits and/or approvals to conduct the geophysical survey from the Bureau of Land Management (BLM) for federal lands (“Notice of Intent to Conduct Geothermal Resource Exploration”); from the California Department of Parks and Recreation (Ocotillo Wells State Vehicular Recreation Area- OWSVRA) for state lands; from the Imperial County Dept. of Planning and Building for private lands; and from the Imperial County Dept. Public Works for the County landfill area. LEA also obtained permission to conduct the survey from several private landowners in the area, including Holly Corporation.

In response to permit requirements imposed by the OWSVRA, LEA contracted with EDAW, Inc. to provide archaeological and biological monitors for the project. The monitors accompanied the geophysical crews to pre-clear each proposed MT/TDEM measurement site for cultural resources and flat-tailed horned lizards, a threatened species. Small trenches for holding MT instruments were dug by the advance geophysical crew immediately after clearance of the site by the monitors. Data acquisition crews occupied the sites one or more days after the pre-clearing and digging. No significant shifts of location for the measurement sites from their original locations were required by the monitors. LEA staff facilitated communications between the geophysical contractor, archaeological and biological monitors, and BLM and OWSVRA to insure that the survey operations proceeded smoothly and were conducted in accordance with permit requirements.

EDAW prepared two summary reports related to its operations and provided copies of these to LEA and the permitting agencies. LEA conducted a site visit to Imperial County in May 2003 for follow-up meetings with BLM staff Ocotillo Wells SVRA staff. The purpose of the meetings was to insure that no outstanding issues remained related to the conduct of the geophysical surveys and that all permit requirements were satisfied. No outstanding issues were identified, and the permitting activities were completed.

4.2 Permits for Phase II drilling and testing of exploratory well

The major permitting tasks for drilling and testing of the Truckhaven exploratory well were accomplished during 2005. Two key project permits were obtained by LEA:

- Conditional Use Permit No. 04-0016, issued on 27 July 2005 by the Imperial County Department of Planning and Development Services
- Right of Entry Permit, issued on 25 August 2005 by the California Department of Parks and Recreation

These are the two primary permits necessary for the project to proceed, and indicate the project has met all CEQA (California Environmental Quality Act) requirements. More details on these two major permits are provided below, along with a description of progress made toward obtaining additional minor / sundry permits. LEA’s efforts to finalize several of the

minor / sundry permits for the well were put on hold in late 2005 after DOE notified LEA that funding for the Phase II drilling program was cancelled.

Conditional Use Permit, Imperial County Dept. of Planning and Building: The County is the *Lead Agency* for permitting for the proposed project. At a hearing of the County Environmental Evaluation Committee on 9 June 2005 which was attended by an LEA representative, the Committee determined that a *mitigated negative declaration* shall apply. This indicated that the environmental impacts of the project would be considered insignificant provided LEA conducts mitigation measures. These measures include archaeological and biological monitoring per State Dept. of Parks and Recreation; compliance with requirements of State Air Pollution Control District; County Dept. of Public Works; and State Dept. of Transportation. At a hearing of the County Planning Commission on 27 July 2005, the Commission approved Conditional Use Permit No. 04-0016 for the project, and the permit Agreement was executed by LEA on 28 July 2005.

Permit to Enter, California Dept. of Parks and Recreation (DPR): LEA met with DPR Director and staff at DPR headquarters in Sacramento on 14 April 2005. At the meeting, the Director indicated that DPR supported the proposed drilling program in principle but requested that LEA provide more information on the ultimate impacts of geothermal development on the Ocotillo Wells off-road vehicle area. LEA provided such information to DPR on 18 April 2005. On 20 May 2005, DPR's Deputy Director notified LEA that DPR intends to approve the permit for the well. On 3 June 2004 the Ocotillo Wells SVRA Park Superintendent issued a preliminary Permit to Enter letter to LEA which spelled out basic conditions to allow the project to proceed. This letter was supplied to Imperial County and incorporated into the Conditional Use Permit process. During June - August 2005, LEA worked with DPR's Land Agent to finalize the form and content of the final Permit to Enter document, and the Right of Entry Permit was issued to LEA on 25 August 2005.

Permit for temporary use of landfill access road to drillsite, County Dept. Public Works: LEA received this permit from DPR on 13 May 2005.

Drilling Permit, Calif. Division of Oil, Gas and Geothermal Resources: LEA worked with DOGGR staff to determine requirements for this permit, which include filling application forms and posting a \$25,000 bond with DOGGR for well plugging and abandonment.

Approval of drainage and grading plan / encroachment permit, County Dept. Public Works: LEA worked with DPW to determine the requirements for this permit. LEA will need to contract with a licensed civil engineer to prepare a grading plan for the access road and wellpad, which will subsequently be submitted to DPW for approval.

Authority to Construct / Permit to Operate, Imperial County Air Pollution Control District: LEA worked with APCB to determine the requirements for this permit. LEA will need to obtain details regarding the emissions profiles for the specific diesel engines used by the drilling rig for the project. Therefore, this permit will not be issued until after LEA has procured a drilling contractor and drilling rig for the project.

Discharge Permit, State Water Quality Control Board: LEA submitted a project description and application form to WQCB on 19 July 2005. Further action by WQCB is pending submission of additional application forms and fees by LEA and its development partner at Truckhaven.

5.0 COMPARISON OF PROJECT RESULTS VS. OBJECTIVES

The original project objectives for the Truckhaven geothermal exploration program were outlined in the Statement of Objectives in the initial Cooperative Agreement executed by LEA and DOE in September 2002. These included:

- a Phase I program of surface exploration;
- a Phase II program of permitting and drilling of an exploratory well; and
- a Phase III program of well testing, plugging and abandonment.

As described in **section 2.0**, DOE provided funding for Phase I and for permitting activities in Phase II. However, in September 2005 DOE cancelled funding for the remainder of the Phase II and Phase III programs and these were never completed. Layman Energy Associates, Inc. (LEA) achieved all of the original objectives for those portions of the program for which funding was provided by DOE. Specifically, the original objectives for the Phase I surface exploration program were as follows:

- Acquire and interpret existing exploration data (well data, geologic maps, seismic data)
- Acquire and interpret remote sensing images
- Acquire, provide quality control for, and interpret gravity data
- Acquire, provide quality control for, and interpret magnetotelluric resistivity data

LEA achieved all of these Phase I objectives as summarized in detail in **sections 2 & 3** of this report. Significantly, this program was also completed on schedule and under budget. In addition, LEA also conducted an intensive program of field geologic mapping in the Truckhaven area to obtain more detailed information than was available in the public domain.

With the limited funds DOE provided for the Phase II permitting activities, LEA was able to secure the two major permits required for the drilling program: the Permit to Enter from the California Department of Parks and Recreation and the Conditional Use Permit from Imperial County. Significant progress was also made toward investigating requirements for other minor / sundry permits for the program.

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MAJOR FAULTS AND SEISMICITY IN AND AROUND THE SALTON TROUGH

from Agnew et al (2000)

FIGURE 1

REGIONAL GEOLOGY OF THE TRUCKHAVEN AREA, IMPERIAL COUNTY, CA

adapted from Jennings (1977)

Rock unit symbols:

Q = Quaternary sediments QPc = Plio-Pleistocene continental sediments

P = Pliocene marine sediments M / Mc = Miocene sediments

pre-Tertiary basement rock = gr-m, gr Mz, m, ls, sch

FIGURE 2

STRATIGRAPHIC UNITS OF NORTHWESTERN IMPERIAL VALLEY

Dibblee (1954)

Modified from Winker (1987)

GEOLOGY OF THE TRUCKHAVEN AREA

based on mapping by Dibblee (1984) and Layman Energy Associates (2003)

FIGURE 4

ORTHOPHOTO IMAGE OF VICINITY OF TRUCKHAVEN NO. 1 WELL WITH SELECTED GEOLOGIC FEATURES HIGHLIGHTED

0 .5 1.0 miles

- = fault, locally with calcite veining
- = fault, location uncertain
- 15 = bedding attitude
- = contact between geologic formation units
- + = fold axis
- ↓ = syncline axis
- ↑ = anticline axis
- ↘ = plunging fold axis

- Qa = alluvium
- Ql = lacustrine sediments
- Qoa = older alluvium
- Qs = dune sands
- QPc = fluvial lacustrine sediments

TrkOrtho-w-Geol 10Aug08

FIGURE 5

* from Dibblee (1984) ** from R.F.Smith mud log

LITHOLOGY OF DEEP WELLS DRILLED IN TRUCKHAVEN AREA

FIGURE 6

FIGURE 7

FIGURE 8

TrkSurvArea 10Aug06

FIGURE 9

FIGURE 10

FIGURE 11

FIGURE 12

FIGURE 13

FIGURE 15

FIGURE 18