PROJECT DESCRIPTION
and
ENVIRONMENTAL ASSESSMENT

by

U.S. GEOLOGICAL SURVEY
Earthquakes Hazards Team

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Title:

Salton Seismic-Imaging Project (SSIP): A Survey to Evaluate Earthquake Hazards and Structure of the Earth's Crust in Imperial and Coachella Valleys

Located in:

Salton Trough: Coachella and Imperial Valleys (Riverside, Imperial, San Bernardino and San Diego Counties, California, and Yuma County, Arizona)

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SECTION I: PROPOSED ACTION

A. Purposes and Need

The U.S. Geologic Survey (USGS), California Institute of Technology (Caltech), and Virginia Polytechnic Institute and State University (Virginia Tech) will conduct a seismic-imaging survey of the Salton Trough as part of the National Earthquake Hazards Reduction Program and the National Science Foundation's EarthScope and MARGINS programs. The "Salton Trough" includes the Coachella and Imperial Valleys. Our survey will address the following goals of these programs:

1) To acquire data needed for the prediction of ***strong ground shaking*** during future large earthquakes. Factors that contribute significantly to strong ground shaking are a) the thickness and seismic velocity of sedimentary deposits, b) the shape of the basins containing the sedimentary deposits, and c) the location and shape of the rupturing fault. Shaking is stronger for greater thickness and for lower seismic velocities in sedimentary deposits. ("Seismic velocity" is the speed at which seismic waves travel through a given material.) Basin shape determines how efficiently earthquake energy is trapped in the sediments. The location and shape of a fault determines from what origin point(s) and in what directions energy is radiated during earthquake rupture. Information on ground shaking can be used in designing buildings to make them safer.

2) To better locate ***earthquakes.*** Our survey will better calibrate the permanent Southern California seismographic network, permitting us to more accurately locate earthquakes. More accurate earthquake locations lead to clearer images of faults.

3) To understand the causes of and the nature of rifting and ***subsidence*** in the Salton Trough. In the Gulf of California region to the south, Baja California has rifted completely away from mainland Mexico. In the Salton Trough, this process is in its early stages. Our survey will investigate the way in which a continent is rifted.

In particular, the region of the northern Imperial Valley and Salton Sea is subsiding. Extensional faults have been discovered beneath the southern part of the Salton Sea in preliminary surveys (by colleagues at the University of California at San Diego). Our land survey will be combined with a survey of the Salton Sea itself to understand where these extensional faults root, what triggers movement on them, and what subsidence rate are they producing.

4) To elucidate the geologic structure beneath the Salton Trough so that we can better understand the processes by which earthquakes are generated. This goal includes determining the type and distribution of various rock layers in the subsurface and identifying and determining the shape of active faults (see #1 above).

5) To ***communicate*** earthquake hazards information and information on how the Earth works to the public. The ***ShakeOut Earthquake Scenario,*** of November 13, 2008 (http://pubs.usgs.gov/circ/1324/), was an example of how earthquake hazards can be communicated to the public for the purposes of reducing potential losses. ***In this scenario, a M 7.8 earthquake was assumed to result from a rupture of the southern segment San Andreas fault, from its origin on the east side of the Salton Sea, through the Coachella Valley, and northward. An actual prehistoric rupture on this segment of the fault is documented in trenches across the fault: it occurred 320 years ago, around 1685 A.D. Ruptures prior to that event have an average inter-event interval of 225 years, suggesting that this segment of the San Andreas fault is near failure. Hence, the motivation for the ShakeOut and for our seismic-imaging survey.***

A repeat of the earthquake of 1685 A.D. will be the greatest natural disaster this nation will face in the foreseeable future, and we must continue to focus on mitigating the damage that it will produce.

B. Plate-Tectonic and Earthquake Setting of the Salton Trough

Southern California straddles two of the Earth's plates that move past each other, the Pacific and North American plates (Fig. 1). The Pacific plate is moving relatively to the northwest and consists of the region southwest of the San Andreas fault and southwest of the Gulf of California. (This large plate extends all the way to Japan). The North American plate is moving relatively to the southeast and consists of the region that is northeast of the San Andreas fault and northeast of the Gulf of California. (This large plate extends eastward to the center of the Atlantic Ocean). The boundary between the two plates is quite crooked and includes places where there are steps to the right, such as in the Gulf of California and Salton Trough, and at least one place where there is a big bend to the left, in the Transverse Ranges of southern California. Where the plate boundary is oriented in the direction of motion between the plates, the plates slide past one another without colliding or pulling away from one another. Where the plate boundary steps to the right, holes (rifts) in the Earth's crust occur, and when the boundary bends to the left, pile-ups (mountains) are generated (See Fig. 1). The Gulf of California and its onshore extension, the Salton Trough (which includes Mexicali, Imperial, and Coachella Valleys), are located over a series of rifts in the Earth's crust, which are filling with sediment from above, chiefly from the Colorado River, and magmatic material from below. The Cerro Prieto geothermal field in Mexico and the Brawley Seismic zone in the U.S. are located above two of these rifts, and young volcanoes in these locations are evidence of intrusion of magma from below. These two regions are linked by a plate-boundary segment known as the Imperial fault. The Cerro Prieto rift is linked by the Cerro Prieto fault to the next rift south in the Gulf of California, and the Brawley Seismic Zone is linked by the San Andreas fault to a junction of three plates at Cape Mendocino, California (well beyond the north end of Fig. 1). In addition to the plate-boundary faults, there are faults on either side that take up some of the motion between the North American and Pacific plates, including the Elsinore and San Jacinto faults and faults in the Mojave Desert (see below).

Generally, large earthquakes (M as large as 8) occur along the plate-boundary faults, and swarms of smaller earthquakes (M as large as 6) occur in the rifts. Since earthquake recording began in ~1933, four large earthquakes have occurred on the San Andreas and Imperial faults (Fig. 1), and many swarms of earthquakes have occurred in the Cerro Prieto geothermal area and Brawley Seismic zone. In prehistoric times, major earthquakes (M~8) have occurred on the San Andreas fault. Evidence for fault ruptures that accompanied these ancient earthquakes are revealed in trenches across the San Andreas fault. As discussed above in Goal #5, the last major earthquake on the southern segment of the San Andreas fault occurred around 1685 A.D. Unfortunately, earthquake ruptures that occurred at even earlier times have inter-event time intervals that average 225 years. Thus, the San Andreas fault is capable of generating a very large earthquake at any time.

C. Previous work

In 1979, the USGS conducted a seismic-imaging survey in the Imperial Valley to investigate the various rock layers that make up the Earth's crust in this region and also the faults that offset these various layers. This survey was quite modest by today's standards, with only seven shotpoints and 100 seismographs (see below for a description of shotpoints and seismographs for this project), but nevertheless, some surprising discoveries were made. These discoveries include the fact that the central part of the Imperial Valley contains no old rocks, only new crust consisting of young sedimentary deposits and a large body of solidified intrusive rocks that lie below the sediments (Fig. 2). We obtained some information on the shape of the Imperial and San Jacinto faults, but little information on the San Andreas fault, which is located on the edge of the survey. The 1979 data set was augmented by a couple of low-resolution profiles recorded in 1992. ***In constrast to the 1979 and 1992 surveys, the proposed Salton Seismic-Imaging Project (SSIP) will employ 170 shotpoints and 3000 seismographs.***

In 1994 and 1999, the USGS and the Southern California Earthquake Center (SCEC) conducted surveys, known as the Los Angeles Region Seismic Experiment (LARSE), which are similar to ***SSIP*** (see USGS Fact Sheets 110-99 and 111-99; http://pubs.usgs.gov/fs/1999/fs110-99/; http://pubs.usgs.gov/fs/1999/fs111-99/fs111-99.pdf). The LARSE surveys consisted chiefly of two medium-resolution profiles through the Los Angeles metropolitan area and the mountains to the north (Transverse Ranges). Major discoveries about the San Andreas fault and the "blind thrust faults" beneath the Los Angeles metropolitan area were made with data from these surveys. These "blind thrust faults" have primarily vertical movement, do not reach the Earth's surface, and have given rise to 4 of the largest earthquakes in the last 40 years, including the M 6.7 San Fernando and Northridge earthquakes and the M 5.8-5.9 Whittier Narrows and Sierra Madre earthquakes. The LARSE surveys documented the existence of these faults, as well as, the depths, shapes, and seismic-velocity distributions of the Los Angeles, San Gabriel, San Fernando, and Santa Clarita sedimentary basins. Thus, providing model constraints so that the earthquake shaking potentials of these basins can be better estimated.

The Salton Seismic-Imaging Project (SSIP) is designed in a fashion similar to the LARSE surveys, although the cumulative line length is longer. ***The LARSE surveys***

demonstrated that the USGS and collaborators can safely and effectively conduct seismic-imaging surveys in urban, suburban, and remote areas, on lands with many different owners or managers. They produced information that could not have been obtained any other way and that has changed key ideas on how earthquake-producing "machinery" works in southern California. These surveys had no significant environmental impact.

D. Location of Proposed Action

Generally, our Salton Seismic-Imaging Survey is laid out as a series of intersecting lines that will allow us to get an approximate 3-D image of the subsurface in chiefly the Coachella and Imperial Valleys (Fig. 3). The survey includes an axial line that begins at the southwest tip of Arizona and extends northwestward through the Mexicali, Imperial, and Coachella Valleys to a point north of Palm Springs, California. Cross lines are laid out in northeasterly directions straddling the San Andreas and Imperial faults, which are both located within the valleys. These lines extend beyond the edges of the valleys so that we may image the full shapes of the sedimentary basins underlying the valleys. The following is a brief description of the need for each line.

Line 1 is composed of segments 1S, 1M (marine), 1N (Fig. 3). 1S is the part of the line from San Luis, AZ, that extends northwestward across a corner of Mexico, back into the U.S. east of El Centro, CA, and northwestward to the Salton Sea. 1N begins on the north shore of the Salton Sea and extends to the northwest end of the Coachella Valley. 1M is a marine component, in the Salton Sea, and connects 1S and 1N. This axial line is intended to image the deepest parts of the sedimentary basins in the Salton Trough (estimated to reach depths as great as 6 km). Shaking severity from earthquakes increases with basin depth; therefore knowing the basin depth and its variations are important for evaluating the earthquake hazard. This long line will also allow us to investigate the composition of the crust and underlying mantle and provide an answer to the question: at what point northwestward in the Salton Trough, do magmatic contributions to the crust cease? Currently, the northernmost surface manifestation of magmatic intrusions are the (active) Salton Butte volcanoes at the southeast end of the Salton Sea.

Line 2 extends from a point on the international border east of San Diego, CA, northeastward to the Colorado River south of Blythe, CA (Fig. 3). This line crosses the Peninsular Ranges, Imperial Valley, and Chocolate Mountains. The line is intended to extend the image of the sedimentary basin obtained on line 1S to the east and west for a better image of the shape of the Imperial Valley and, hence, to better evaluate earthquake shaking hazard within the Valley. This line will also image the shape (dip) of the plate-boundary fault, the Imperial fault, so that earthquake energy radiation from this fault can be better estimated. This fault has generated 2 large earthquakes in the last 70 years, the 1940 M 6.9 and 1979 M 6.4 earthquakes. Active faults in the Peninsular Ranges, the Elsinore and San Jacinto faults, which generate moderate earthquakes will also be imaged. In addition, this line is intended to image the older rocks on either side of the Imperial Valley and the boundaries between these rocks and the new crust that is forming within the Imperial Valley. We hope to image differences in lower crust/mantle beneath the Imperial Valley and the flanking ranges, in order to discover where new magmatic additions to the crust are being generated. ***Subsidence is occurring in the Mesquite basin, between Brawley and El Centro. Line 2 will investigate the origin of this subsidence.***

Line 3 extends from Line 2 on the west side of the Imperial Valley northeastward through the Salton Buttes volcanoes, along the south shore of the Salton Sea, and into the Chocolate Mountains (Fig. 3). This line crosses one of the rifts in the Salton Trough, the Brawley Seismic zone, where magmatic intrusions into the crust are active. In addition to addressing sedimentary basin depth, this line is intended to investigate the quantity and shapes of magmatic material that have been added to the upper part of the crust and also the sizes and locations of active magma chambers below the volcanoes. Our investigations will be of general use to the geothermal industry in this area. In addition, this line will investigate branches of the San Jacinto fault known as the Superstition Hills and Superstition Mountain faults. The Superstition Hills fault ruptured in a M 6.6 earthquake in 1987.
Observed subsidence in the northern Imperial Valley and Salton Sea areas will be investigated with our survey and a companion seismic survey in the Salton Sea itself (conducted by colleagues at University of California at San Diego—Line 1M). Faults involved in this subsidence have been imaged beneath the southern Salton Sea in preliminary surveys, and our combined imaging surveys will be aimed at understanding these faults, including where they are rooted, what triggers offset on them, and what is the rate of offset (and subsidence) on them.

Lines 4, 5, and 6 are intended, like lines 2 and 3, to extend our knowledge of sedimentary basin thickness (and hence earthquake shaking severity) in as many locations as feasible in the Coachella Valley (Fig. 3). Rapid urban and suburban growth in the Coachella Valley requires rapid evaluation of earthquake shaking hazard. The location of Line 4 was chosen so we could straddle the San Andreas fault, obtaining an image of not only the sedimentary basins on either side of the fault but also of the fault itself (and its dip). Microseismicity suggests the fault dips moderately northeastward here, and it is important to confirm (or reject) this possibility because of its implications for energy radiation during a major earthquake. Line 5 will address the sedimentary basin depth beneath Palm Desert, CA, one of the large suburban cities of the Coachella Valley, and Line 6 will address the basin depth in the vicinity of Palm Springs, the largest urban area in the Coachella Valley. Line 5 is located to take advantage of access southeastward into the Peninsular Ranges along Hwy 74, and Line 6 is located to take advantage of access through the Little San Bernardino Mts along "Kickapoo trail" (a dirt road from Desert Hot Springs to Yucca Valley; see below). Line 6 will image the San Andreas fault where it has split into three branches, the Garnet Hill, Banning, and Mission Creek faults. The M 6+ earthquakes of 1948 (Desert Hot Springs) and 1986 (North Palm Springs) appear to have occurred on the Banning branch which dips moderately northward, and again, it is important to investigate the structure of the fault zone here (northward dips) for earthquake hazard evaluation. Lines 5 and 6 terminate near the ruptures of the 1991 M 6.1 Joshua Tree and 1992 M 7.3 Landers earthquakes, respectively.

Line 7 is a 9-km- long profile that crosses the San Andreas fault at Salt Creek, on the northeast shore of the Salton Sea, where microseismic evidence indicates that the San Andreas fault dips moderately (57-59 deg) northeastward. This is the best location to obtain a crisp image of the fault and to confirm (or reject) the northeastward dip. It is important to obtain independent seismic-imaging data for this stretch of the San Andreas fault for earthquake hazard evaluation.

E. General Description of Proposed Action

Imaging Method

The seismic images we seek to obtain in the Salton Trough are of two types, "refraction" and "reflection" images and are analogous to ***CAT scan and sonogram*** images, respectively, in the medical industry. Both of the seismic image types utilize seismic energy generated at or near the surface. In seismic-refraction imaging, the energy travels laterally through rocks, and one maps out distributions of fast and slow rocks, much as medical CAT scan images map out regions of the human body that are transparent or opaque to X-rays. In seismic-reflection imaging, the energy travels approximately vertically downward and reflects (or echo) off rock interfaces, returning to the surface to be recorded on seismographs, much as medical sonogram (ultrasound) images are generated by reflections off of fluid and tissue interfaces within the human body.

Our seismic images extend to varying depths, depending on the depths of our targets. Targets include a) bottoms of sedimentary basins (10's of meters to 6 km), b) initiation depths of large earthquakes (10-15 km), c) magma chambers (a few km to 10's of km), and d) the base of the crust (20-40 km). Sources for seismic images include man-made sources, such as vibrator trucks and detonations of deeply buried seismic charges, and natural sources such as earthquakes. For the type of images we propose, detonation of buried seismic charges iis required for the following reasons:

1) Vibrator-truck sources, such as used by the oil industry for exploration, produce only very shallow refraction images (1 to 2 km deep), and, generally reflection images extend no deeper than 10- to 15-km depth. In addition, because of the relatively weak signals they produce, the trucks must vibrate at many points (essentially continuously) along the profile, and long vibration times are required. The extensive footprint of shaking disturbance required for this type of imaging makes it impracticable in most suburban and urban settings.

2) Natural earthquake sources are inadequate by themselves. Earthquakes are irregular in distribution and uncertain in location. The "image" one gets using earthquake sources alone is too fuzzy and inaccurate to be of use for earthquake hazards evaluation.

3) Detonation of seismic charges, on the other hand, can produce both refraction and reflection images to the required depths. Seismic charges can be detonated in boreholes in open spaces within subsurban and urban settings, such as parks, golf courses, construction sites, farmlands, dumps, and other places where they can be set back sufficiently from residential and other structures. Our LARSE surveys in the 1990's (see above) utilized all such types of open spaces along a total of more than 300 km of profile, including many kilometers in suburban and urban settings.

In summary, there is no way other than detonation of buried seismic charges to obtain reliable detailed images of the subsurface that we need for earthquake hazards mitigation. Using this kind of methodology through suburban Los Angeles and the adjacent mountain ranges in the 1990's produced a new, unexpected picture of how the "earthquake-producing machinery" works beneath that region. That survey had no significant environmental impact.

Seismic detonations

Our project plans to detonate nearly 170 buried seismic charges, or "shots,» with the charge size ranging from approximately 5 to 3000 lbs. In the agricultural areas and in cities, the shot size is at the small end of this range. The shots are arranged along the lines at spacings ranging from 0.5 to 25 km or more. Most of these shots are detonated in 6-inch, fully cased drill holes **below** a depth of 60-70 feet (see Fig. 4a for diagram). The total depth of each drill hole varies with charge size. The charge is a commercial ammonium-nitrate-based product that is pumped into the drill holes. The charge is buried or covered with 60-70 feet of "tamp" that includes bentonite sealant and drill cuttings or gravel. The charge is inert until it is "primed" just minutes prior to detonation on the night of the shot. The charge is primed by attaching an electrical blasting cap to detonating cord that extends through the tamp to the surface. Seismic charges are detonated at night, when wind and cultural noise are at their lowest levels at our seismograph sites. For more detail on drilling and loading shotholes, please visit to http://geopubs.wr.usgs.gov/open-file/of01-408/ and view the section on "Shotpoints and Shot Size Determination". Also see Appendix I.

An important element in assuring that our seismic detonations do not cause damage to structures or undue alarm to residents is determining proper set-back distances for structures and residences. We have developed tables for such set-back distances (Appendix I). Two tables have been prepared, both of which fit equally well seismic-amplitude data from prior surveys but differ in details. We use both of these tables and average the recommended set-backs. We determine the final amount of charge to load in shotholes after the hole is drilled and after we have information on the type of material encountered. For a detailed explanation of set-back determination, please visit the website and section cited above.

Seismographs

The seismic detonations will be recorded by approximately 3000 seismographs spaced 100 meters (~330 feet) to 200 meters apart. The great majority of seismographs are slightly larger than a soda can with a sensor (2x2 inch cylinder with a spike for firm attachment to the ground) attached by a short cable (few feet)(see Fig. 4b). Generally, the entire seismograph system can be installed in a shallow hole that is the width and depth of a normal shovel blade. Thus the seismograph system is completely buried to avoid wind noise, vandalism, and visual impact.

Schedule

Drilling for shotholes would take place during a period of a few months prior to the survey. The holes are drilled and cased by a contract water-well drilling rig. After completion of drilling at each site, the casing, which protrudes approximately 6 inches above the surface is capped and locked and covered with a small pile of dirt to reduce its visibility. During a period of a week or so prior to detonation, a contract truck carrying "blasting agent" (which has the texture of toothpaste) visits each site and pumps the required amount of blasting agent into the hole. Just prior to pumping the blasting agent, a detonating cord with attached booster charges is lowered into the hole and secured in the interval to be filled with blasting agent. Hole loading is completed by pouring bentonite sealer on top of the blasting agent, followed by gravel and (or) hole cuttings. The detonating cord is tied to the locking cap at the surface and the hole is reburied with a small pile of dirt (Fig. 4a). After the seismographs have been deployed, the charges are detonated one after another, at night (to avoid wind and cultural noise). Shooting 170 shotpoints will require approximately 2 weeks of actual shooting. A period of a few days is scheduled in the middle of the shooting sequence to redeploy the seismographs.

Shothole cleanup involves excavating the casing to a depth of at least 2 feet below the surface, cutting the casing at that point, attaching a water-tight cap on top, filling the hole, and recontouring the ground surface to its original shape. Cleanup will occur during the month following detonation

Our calendar schedule has shifted from our original schedule (wherein we would have acquired the data in the Winter or Spring of 2010); the shift resulted from the lengthy process of permitting federal lands. Currently, our schedule is the following:

Shothole drilling—Aug. 2010-Mar 2011
Shothole loading—Jan-Mar 2011
Seismograph deployment—Feb-Mar 2011
Shooting—Feb-Mar 2011
Cleanup—late Mar 2011

Note that drilling will likely continue during shooting and recording. Our experience indicates that some permits are not obtained until quite late.

F. Frequently Asked Questions

The chief environmental concerns that are usually expressed about our surveys are as follows:

1) Will the shots trigger earthquakes?
2) Will the shots damage water supplies?
3) Will the shots damage man-made structures?
4) How far can the shots be felt?
5) What do the shots sound like?
6) Will the shots damage the landscape, archaeological resources, or endangered species of plants or animals?
7) Will activities generate dust?
8) Will roads be closed during your operations?

Answers to these questions are as follows. See also APPENDICES I and II.

1) ***Will the shots trigger earthquakes?*** ***Our shots will not trigger earthquakes.*** We have been performing this type of survey for more than 40 years, all over the world, in many different types of actively faulted areas, and with shots larger than those proposed for this project, and we have never triggered an earthquake. Our shots are similar in size to freeway-construction or mine blasts and pose no greater hazard to triggering of earthquakes than do those blasts. Furthermore, we detonate our charges near the Earth's surface, whereas the region where large earthquakes originate is generally 6 or more miles deep. Our signals are very weak by the time they reach that region. Finally, our largest shots will have a size equivalent to an M 2-2.5 earthquake. The Southern California region is shaken by an average of four M 2.5 earthquakes daily, and similar magnitudes are generated by mine and quarry blasts that occur nearly every workday of the year. We have examined 17,000 mine and quarry in southern California and have determined that none have triggered earthquakes. Thus, the hazard of our operation is not significant.

To our knowledge, ***the only events that DO trigger earthquakes are major earthquakes, like the M 7.3 Landers earthquake of June 1992.*** This event triggered a M 5.2 earthquake in southern Nevada and numerous smaller earthquakes at several volcanic areas in the western U.S., including Mammoth Lakes, CA, the Geysers, CA, and Yellowstone National Park. The Landers earthquake represents 10's of millions times the energy in our shots.

2) ***Will the shots damage water supplies?*** ***Our shots will not harm water supplies.*** We have performed water-quality tests before and after shots that were detonated directly in water to determine if there were any residual nitrate, nitrite, ammonia, or pH changes. The results were negative (Appendix II). ***The seismic charge is completely consumed during detonation.***

In our 30 years of experience, we have never damaged a spring or well, although we have shot within a few hundred feet of springs and wells. Except for cases where a seismic charge is detonated directly in a spring or well, the only events that affect springs and wells are major earthquakes. (Major earthquakes apparently increase upper-crustal porosity, by shaking and opening cracks, and cause water tables to be lowered as the water drains downward.)

3) ***<u>Will the shots damage man-made structures?</u> Our shots will not damage man-made structures. In siting our shotpoints, we use tables of ground velocity that we have established from years of shooting experience in order to ensure that we are below the lowest damage threshold for built structures*** (2 in/sec; Appendix I). That is not to say that our shots may not be felt (see 4 below).

Our shotpoints will not damage irrigation infrastructure in the agricultural areas. We have detonated test charges at varying distances (20-50 ft) from buried clay drain tiles (which we exposed for the tests), and there was no damage from these charges. (In fact, there was no ground disturbance at all; see Mitigation Measures below). These tests were observed by an engineer from the Imperial Irrigation District.

4) ***<u>How far can the shots be felt?</u> Most shots can be felt only within a few hundred feet of the shotpoint.*** The larger shots can be felt for a 1000 feet or possibly more. We have made an effort to keep the shotpoints well away from houses in order not to disturb people at night. Unfortunately, a few people may feel the shots. Prior to our LARSE surveys we communicated the purposes and effects of our activities to the public by way of city council meetings, radio, newspaper, and TV.

5) ***<u>What do the shots sound like?</u> The shots usually sound like a dull "thud."*** Occasionally, when steam is vented, a hiss will occur for a period of seconds following the shot.

6) ***<u>Will the shots damage the landscape, archaeological resources, or endangered species of plants or animals?</u> Areas chosen for shotpoints are, to the extent possible, areas that have been affected by grading, dumping, or storage, such as road pull-outs, abandoned roads, dumps, and equipment or hay storage lots.*** There are almost never archaeological resources near the shotpoints nor endangered species of plants and animals. If archaeological resources or endangered species of plants or animals are found within the footprints of the drilling operations, then the shotpoints are moved. The drilling operations affect an area approximately 50 by 50 feet. We leave each site in a condition as close to its original condition as possible. At perhaps 10% of our shots, there may be ground disturbance, including upward movement of casing or a small collapse crater around the shot hole, generally less than a few feet in size. If disturbance does occur, it develops immediately after the shots in almost all cases. We excavate the casing to at least 2 feet below the surface, cap it, and bury it. We fill in any craters with imported fill and recontour the ground surface to as nearly its original condition as possible. In a small percentage of our shots at bedrock sites (outside of the Imperial and Coachella Valleys), flyrock may be generated within about 100-200 ft or so of the shotpoint. This debri is cleaned up as necessary. The drilling and shooting operations at sites that are hand augered have a minimal footprint of only a few square feet. shots in these hand-augered holes rarely affect the surface.

7) ***<u>Will your activities generate dust?</u> Our activities do not generate significant dust.*** Drilling is done with water, and dust is not generated. The shots are contained underground, and detonation does not generate dust. In the cases where venting occurs during a shot, steam (not dust) is vented.

8) ***<u>Will roads be closed during your operations?</u>*** ***Several shotpoints will be within 500 feet of paved roads***, including Highway 74 (Peninsular Ranges), Thousand Palms Canyon Road (Indio Hills), and Highway 195 (Mecca Hills). For safety, we will need to request and carryout temporary closures during shot detonations.

SECTION II: ALTERNATIVES

Alternatives to the survey, as proposed, include the following:
1) Move the lines
2) Move shotpoints within the lines
3) Eliminate the study (No Action Alternative),
4) Eliminate certain shotpoints
5) Use vibrator trucks instead of seismic detonations,
6) Use earthquakes instead of seismic detonations.

The consequences of each of these alternatives are as follows:

1) The reasons for locating the lines as shown (Fig. 3) are as follows:

a) Line 1. This line (consisting of segments, 1S, 1M, and 1N) is designed to image the sedimentary basins along the axis of the Salton Trough at points where they are inferred to be deepest from prior seismic work (1979 and 1992) and prior gravity studies. This line will also address the boundary between new and old crust, and it will address possible crustal thickness changes from south to north. The southern end of line 1S is fixed at the SW corner of Arizona for political and logistic reasons. (It is very difficult to detonate seismic charges in Mexico.) The position of line 1S at the international border with California is motivated by a need to tie the new survey to the 1979 and 1992 surveys, which shared a shotpoint at the location shown (at the border). Moving Line 1 would eliminate imaging the deepest parts of the sedimentary basins in the Salton Trough and would prevent us from tying the new data set as confidently as possible to the older ones.

b) Line 2. This line is designed to image the deep structure of the Salton Trough and the mountains on either side. Primary imaging targets are 1) the (buried) boundaries between the old crust in the mountains on either side of the trough and the new crust within the trough, 2) the Imperial fault (the plate boundary fault), 3) the large body of solidified intrusive rocks in the middle and lower crust of the trough, and 4) the base of the crust (how thick is the crust?) in the trough and on either side (see Fig. 2). The eastern third of line 2, through the eastern part of the Salton Trough and Chocolate Mts, is determined by road access. Hwy 78 is the only driveable access through East Mesa and the Algodones dunes for 10's of km on either side. This route threads its way between the Chocolate Mts. Bombing and Gunnery Range on the north and a Naval Bombing Reservation on the south. The western third of Line 2, through the Peninsular Ranges, is also to some extent determined by road access. The line needs to be near road access through the rugged Jacumba Mts and to remain north of the international border for political and logistical reasons. For scientific reasons, the line needs to be as straight as possible, in order to be able to interpret the data, and this requirements fixes the central third of the line, through the Imperial Valley, given the constraints on the eastern and western thirds. This line could possibly be moved to the international border, along the border road that is being built. However, a line along the international border would not cross the Imperial fault, one of the chief imaging targets, in a perpendicular fashion, as is required for data interpretation.

c) Line 3. This line is designed to image the Salton Buttes volcanoes and possible magma chambers beneath them and therefore cannot be moved away from them and still address these targets. Line 3 also addresses subsidence that is apparent in the northern Imperial Valley.

d) Line 4. This line is designed to image the base of the sedimentary basin underlying the southernmost part of the Coachella Valley and to image the San Andreas fault. This line is constrained by road access to lie along Hwy 195 through Box Canyon, in the Mecca Hills, as there is no other crossing of the fault for more than 10 km on either side. For us to image the San Andreas fault, which appears from microseismicity to be dipping to the northeast, our profile must straddle the fault with sources on both sides, but especially on the northeast side, along Hwy 195.

e) Line 5. This line is designed to image the base of the sedimentary basin beneath the city of Palm Desert, one of the larger cities in the Coachella Valley, and to connect with high-resolution data sets, current and planned, along Thousand Palms Canyon Road, the only road access through the Indio Hills at this latitude in the Coachella Valley. The southwest end of the line is constrained to lie along Hwy 74 into the rugged Peninsular Ranges. The central part of the line crosses the Coachella Valley National Wildlife Refuge (for the Fringed-toed Lizard). We propose no shots within this refuge but do propose (Refuge-supervised) installation of seismographs every ~300 ft. We could move the line to avoid this Refuge but would run into access and profile alignment problems in the Indio Hills to the northeast.

f) Line 6. This line is designed to image the base of the sedimentary basin in the vicinity of Palm Springs, the largest city in the Coachella Valley, and to image the San Andreas fault zone where we know one or more branches are dipping moderately northeast, based on aftershock sequences (1948, 1986). This line is constrained in its central part to lie along "Kickapoo Trail", a dirt road, which is the only access road through the Little San Bernardino Mts. An alternate route for this line might lie along Hwy 62 into Morongo Valley. Disadvantages of the latter route include 1) safety and seismic-noise issues in deploying and detonating seismic charges along this very busy highway, especially through the narrow canyon leading into Morongo Valley, and 2) the difficulty in extending this line in a straight fashion northward of Morongo Valley into the rugged San Bernardino Mts.

g) Line 7. This line is designed to get a high-resolution image of the San Andreas fault in a location where the evidence in microseismicity is clearest for a moderate northeastward dip on the fault. It is important to confirm (or reject) this dipping geometry with independent seismic-imaging data in order to correctly calculate rupture and shaking from a large earthquake along this stretch of the San Andreas fault. This location was also chosen because a railroad track provides access along much of the line. Only the western 2 km, or so will require that we walk cross country to plant seismometers and hand-auger shot holes.

2) Moving shotpoints within lines is certainly possible, and we have done this in a number of cases in order to provide environmentally feasible shots, to allow drill-rig access, and to give proper set-backs from structures. However, our imaging method produces the best results when the shots are approximately evenly spaced along the line.

3) No methods of investigation of the subsurface other than seismic methods produce reliable estimates of sedimentary basin depth on a regional basis. Modeling of gravity data produces estimates, but these can be in serious error unless calibrated by seismic methods. Deep drilling can also determine basin depth, but not on a regional basis, unless the region is extensively drilled. The Salton Trough is not extensively drilled. (We will, of course, use all deep drilling results available to complement our study.)

4) In order for us to obtain a coherent image of the subsurface beneath the Salton Trough, we need a fairly continuous and even distribution of shotpoints. Elimination of any group of shotpoints degrades the image seriously, especially the part of the image immediately beneath these shotpoints. It is never possible to predict where an image can safely be degraded while still allowing us to make sense of what we see.

5 and 6) See discussion of the "Imaging Method" above. Use of vibrator trucks or earthquakes as sources will not substitute in the survey we propose, which relies on detonation of deeply-buried seismic charges. We will not get clear images that will improve our knowledge of earthquake hazards of this region.

SECTION III: AFFECTED ENVIRONMENT

A. Topography

Not affected by proposed action.

B. Climate

Not affected by proposed action.

C. Air Quality

Not affected by proposed action.

D. Geology

Not affected by the proposed action. Also, no earthquakes will be triggered by the shots (see Section I, FAQ).

E. Soil Quality

In all cases, drilling would occur in areas already impacted by grading or dumping. Therefore, no significant impact of the proposed action is anticipated. Our drilling will produce approximately ½ cubic yard of drill cuttings. With permission, we will spread this small amount along canal banks or local depressions. Otherwise, we will haul it off.

F. Water Quality

Water quality has been tested before and after seismic charges have been detonated directly in water and no change except a temporary (two week) increase of suspended particles has been detected (Appendix II). Also, in our 30-year experience, we have never damaged a spring or a well (Section I, FAQ)

G. Vegetation/Wildlife

Drillhole sites are placed so as to have minimal impact on vegetation. Access to the sites is by existing dirt roads and tracks. Seismographs will be carried off road by foot, and digging of the sensor holes will be done by hand shovels. We will have biological monitors present during drilling at sensitive sites in order to avoid harming endangered species of plants or animals.

H. Archaeological Resources.

We have had archaeological surveys performed at all shotpoint sites on federal and state lands (approximately 65 sites). At the few sites where archaeological resources have been found, the shotpoint locations have been moved so as not to disturb the resources.

I. Traffic Control

Temporary traffic control will be needed in a few locations along road easements, including Hwy 74 (one or two locations), Thousand Palms Canyon Road (two or three locations), and Hwy 195 (several locations).

SECTION IV: MITIGATION MEASURES

1) Drilling, loading, shooting. During drilling, a minimal amount of water is used to help flush cuttings from the hole and to mitigate clay adherence to the drill steel. The footprint of the drill rig is approximately 30 x 50 feet, and in all feasible cases, we place

this footprint on gound that has previously been disturbed. Most of our drill holes are planned to be 6 inches in diameter by 60-75 feet deep, producing approximately ½ cubic yard of drill cuttings. We will dispose of the cuttings locally, if permission is granted, or we will haul off the cuttings. The drill hole is generally cased to the bottom, especially in clay-rich areas, and plugged at the bottom. Approximately a week prior to detonation,the seismic charge (an ammonium-nitrate-based blasting agent) is delivered to the site in a pump truck. This product is pumped down hole to a depth of approximately 60-70 feet from the surface. A bentonite seal is placed on top of the charge and the remainder of the drill hole is filled with gravel or hole cuttings. Detonating cord extends upward through the gravel or hole cuttings to the surface and is wrapped around a locking bar which holds the locked cap in place on the casing (see Fig. 4a). The charge is inert until an electrical blasting cap is attached to the detonating cord approximately 5 minutes prior to shot time.
<u>2) Reclamation</u>. Should there be any casing movement or slumping at the shothole after detonation, it will be filled with imported fill. For approximately 10% of our shots in the Los Angeles Region Seismic Experiment (in the 1990's), casing moved up in the drill hole and/or there was a small ground disturbance (collapse crater up to a few feet in diameter). Any casing protruding from the hole will be cut off at least two feet below the surface and removed from the site. Any collapse crater will be filled with imported fill. The drilling area will be raked and recontoured to as near to its original condition as possible.
<u>3) Test Shots</u>. In June 2009, a series of calibration shots were detonated in the southern Imperial Valley in an unused field adjacent to Hwy 7 just north of the U.S. /Mexican border. These shots were used to measure peak particle velocity and acceleration and to test the effects of seismic energy on buried clay drainage pipes that are used by the irrigation districts in both the Coachella Valley and Imperial Valley. We exposed sections of pipe several meters long with a backhoe at distances of 20-50 feet from the shot holes, and, after each shot, visually inspected the pipes. Our shots produced no pipe damage. An engineer from the Imperial Irrigation District (IID) observed these tests and concluded our survey posed no danger to the irrigation system.

SECTION V: CALENDAR

Our calendar schedule has shifted from our original schedule (wherein we would have acquired the data in the Winter or Spring of 2010); the shift resulted from the lengthy process of permitting on federal lands. Currently, our schedule is the following:

Shothole drilling—Aug. 2010-Mar 2011
Shothole loading—Jan-Mar 2011
Seismograph deployment—Feb-Mar 2011
Shooting—Feb-Mar 2011
Cleanup—late Mar 2011

Note that drilling will likely continue during shooting and recording. Our experience indicates that some permits are not obtained until quite late.

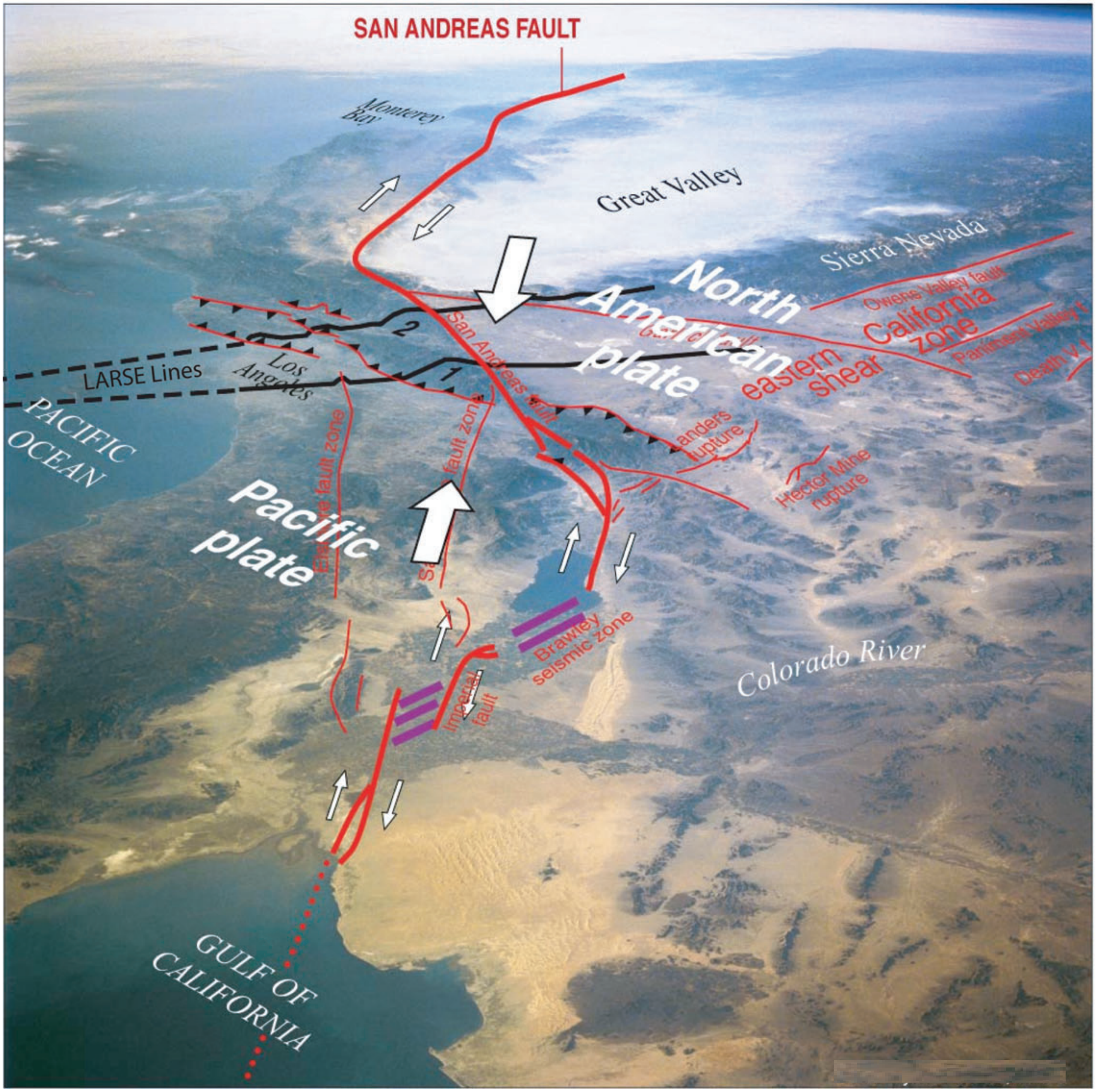


Figure 1. Shuttle Photo of Southern California. Oblique view from the Gulf of California looking toward northern California. Faults are shown in red; extentional areas are shown in purple.

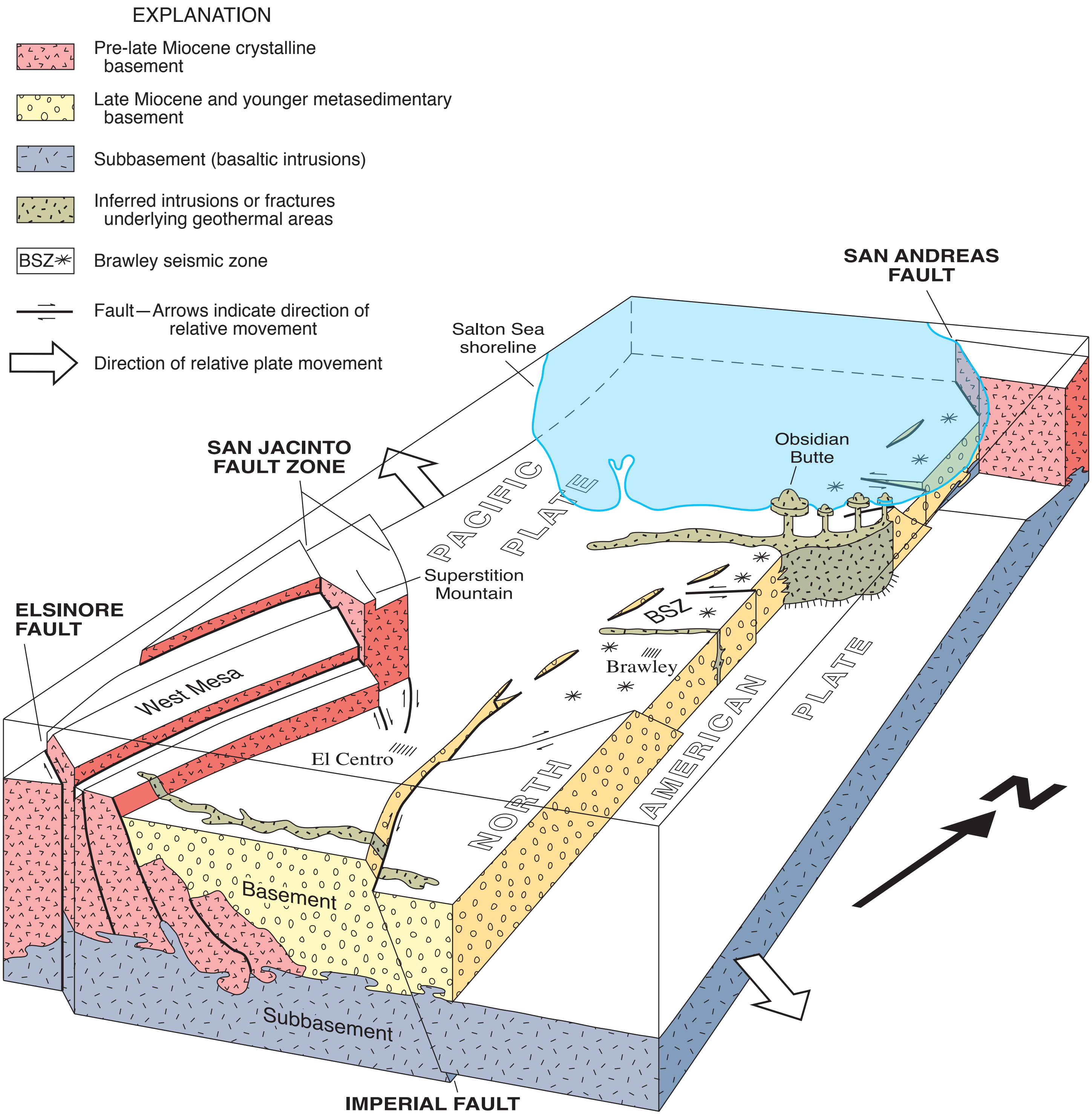


Figure 2. Block diagram of Imperial Valley with soft sediments stripped off; from 1979 seismic-imaging survey. Red, granitic basement; yellow, metamorphosed young sediment from Colorado River; blue-grey, solidified magmatic rocks (basaltic); light green, young basaltic and other intrusive and extrusive rocks. Diagram shows Brawley seismic zone (BSZ)—a spreading center—between San Andreas and Imperial Faults.

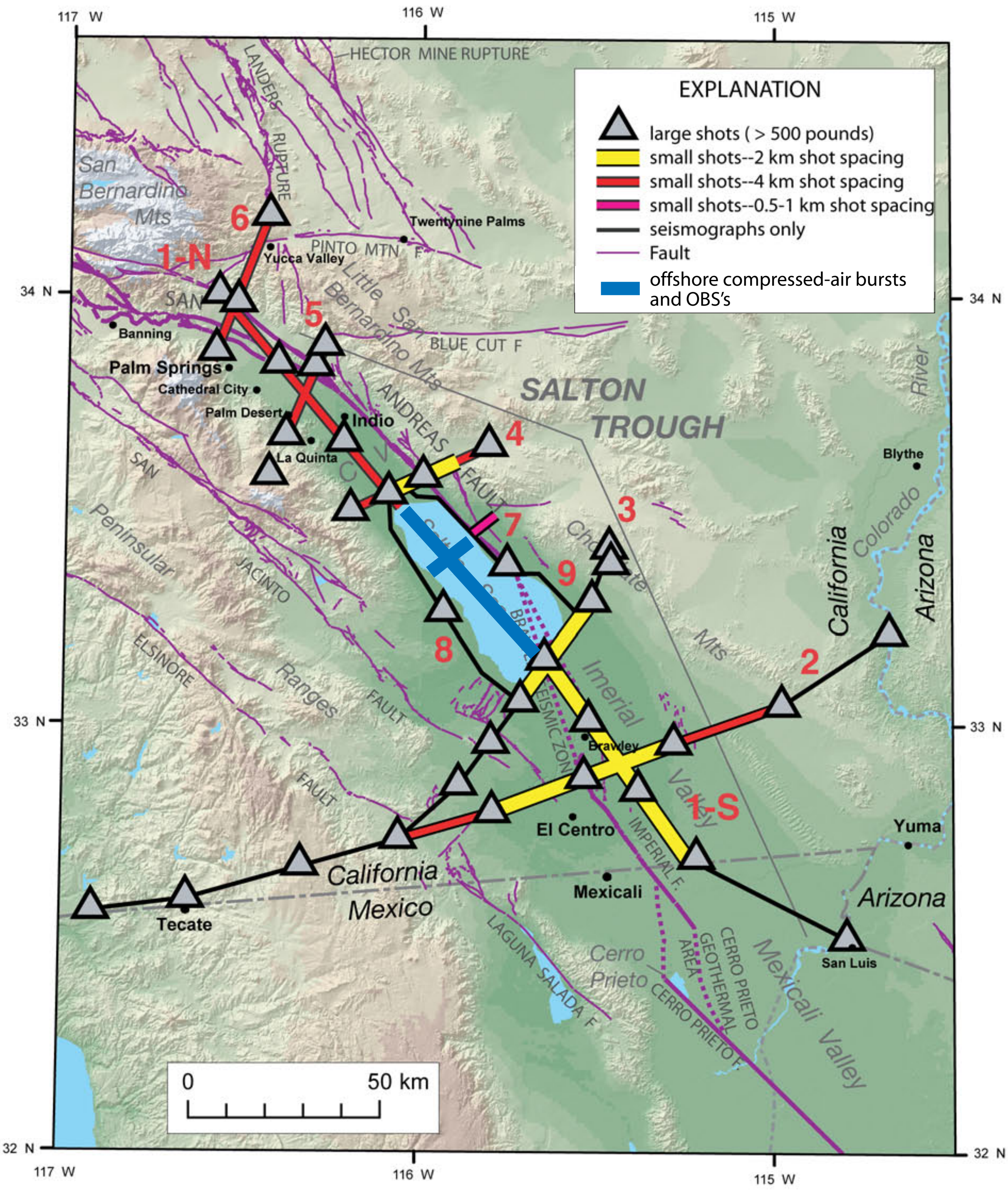
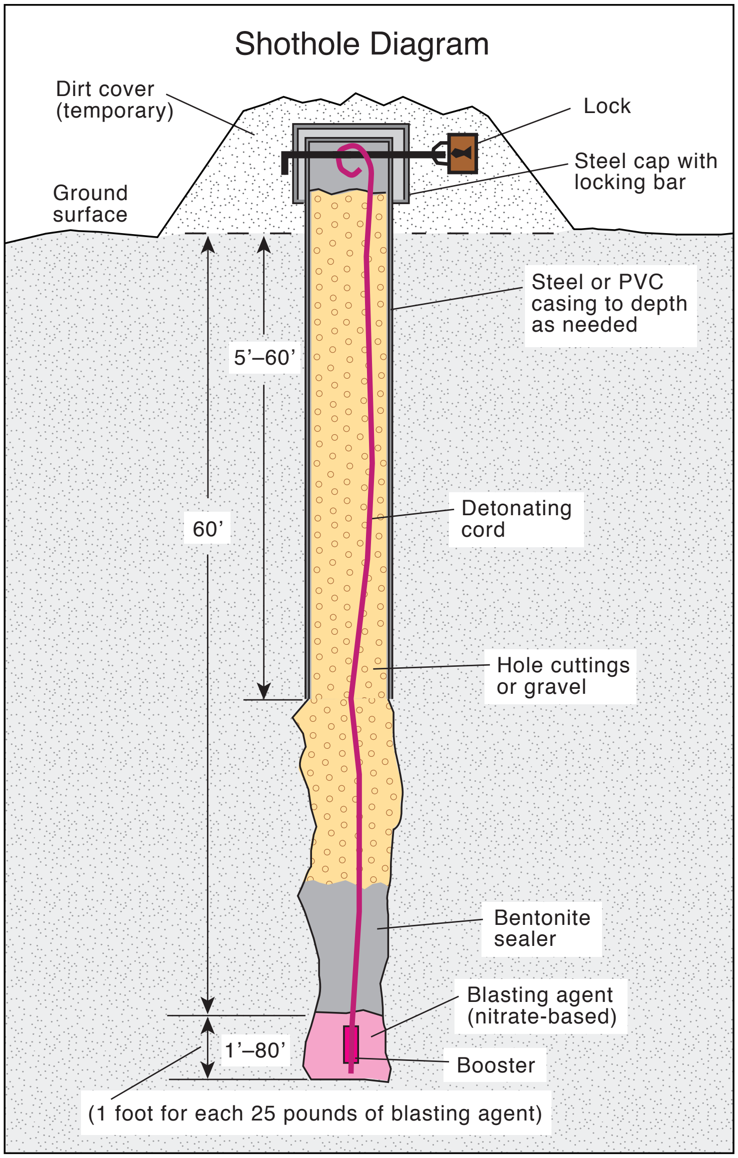


Figure 3. Map of Salton Seismic-Imaging Project (SSIP). Line 1-S: San Luis, AZ to southern end of Salton Sea, Line 1-M: southern to northern end of Salton Sea (marine); Line 1-N: northern end of Salton Sea to San Bernardino mountains; Line 2: San Diego County to Colorado River, AZ, Line 3: Peninsular Ranges to Chocholate mountains; Line 4: southwest to northeast flank of southern Coachella Valley; Line 5: southwest to northeast flank of central Coachella Valley (through Palm Desert); Line 6: Palm Springs to Yucca Valley; Line 7: Salt Creek to a point 7-km east of Salton Sea; Line 7-M: marine extention of Line 7 into Salton Sea; Line 8: western shore of Salton Sea; Line 9: eastern shore of Salton Sea.

A



B

Figure 4. (a) Diagram of a shot hole with blasting agent loaded and shot hole secured. (b) “Texan” seismic recorder with geophone (orange) attached.

APPENDIX I - Minimum Setback-Distance Tables

The following tables provide minimum setback distances (in feet) for shots of various sizes (in pounds), various geologic site conditions ("Hard rock," "Wet Alluvium," "Dry Alluvium," and "Sedimentary Rock"), various thresholds of ground velocity (1-, 2-, and 5 in/s), and various certainty levels (90, 95, and 99%) (See Fuis et al., 2001).

Human sensations and building damage are related to ground velocities produced by shots approximately as follows:

> 1 in/s of ground velocity can trigger complaints from humans
> 2 in/s of ground velocity can cause hairline fractures in old stucco
> 5 in/s of ground velocity can cause incipient/cosmetic damage to older engineered buildings and structures.

[These thresholds were developed by us from the data of Edwards and Northwood, 1960; Nicholls and others, 1971; Northwood and others, 1963; Dupont de Nemours & co., 1977; Stagg and others, 1980; and W. Bender, written manual "Explosives Training Course," 1992).]

There is some random variability in the ground velocities produced by shots. For example, one hundred shots of identical charge size recorded at the same distance will produce a range of ground velocities. Our tables specify that approximately 90, 95, or 99 of these shots will produce ground velocities less than the three thresholds listed above.

We use these tables as follows

1) Determine the distance to the nearest building or structure (or nearest sensitive building or structure)
2) Determine if the building is occupied
3) Determine certain construction factors for the building or structure, including
    a) approximate age
    b) presence or absence of stucco
    c) engineered or not
    d) other sensitivities
4) Choose an appropriate certainty level. We typically use the 95-99% certainty level for the 1-in/s threshold (potential human complaints), 95-99% certainty level for the 2-in/s threshold (potential cosmetic damage to old stucco), and 90-95% certainty level for the 5-in/s threshold (potential incipient/cosmetic damage to engineered structures).

Use of these tables during the Los Angeles Regional Seismic Experiment (LARSE) was successful in avoiding damage to buildings and other structure, and no valid human complaints about shaking were reported to us during the survey (Fuis et al., 2001). This survey traversed parts of the City of Los Angeles, including Santa Monica and several municipalities in the San Fernando Valley, as well as the City of Santa Clarita. However, in later (2005) discussions of this survey with the chief of the Los Angeles Office of Emergency Management, complaints about our survey were reported. Unfortunately, no record was kept as to whether the complaints were a) valid complaints about shaking produced by our shots, b) complaints attributed to our shots that were shaking from the 1999 M 7.3 Hector Mine earthquake and its aftershocks (which occurred before and during our survey), or c) complaints that our activities might trigger earthquakes or otherwise cause damage. The latter type of complaint is, by far, the most common.

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MINIMUM SETBACK DISTANCES FOR SHOTS OF VARIOUS SIZES,
GEOLOGIC SITE CONDITIONS,
GROUND-VELOCITY THRESHOLDS,
AND CERTAINTY LEVELS

90.00 percent of shots
will produce ground velocities less than 1.00 in/s at this distance.

	Distance (feet)			
Shot Size (lb)	Hard Rock	Wet Alluvium	Dry Alluvium	Sed Rock
5	77	67	36	24
10	108	94	51	33
15	131	114	61	40
20	151	131	71	46
25	168	146	78	51
30	183	160	86	55
35	198	172	92	60
40	211	183	98	63
45	223	194	104	67
50	235	204	110	71
60	257	223	120	77
70	277	241	129	83
80	295	257	138	89
90	313	272	146	94
100	329	286	153	99
150	402	349	186	120
200	462	402	214	138
250	516	448	239	153
300	564	490	261	168
350	608	528	281	181
400	649	564	300	193
450	688	597	318	204
500	724	629	335	215
600	792	688	366	235
700	855	742	395	253
800	913	792	421	270
900	968	840	446	286
1000	1019	884	470	301
1500	1245	1080	573	367
2000	1436	1245	660	422
2500	1603	1390	737	471
3000	1755	1522	806	515

95.00 percent of shots
will produce ground velocities less than 1.00 in/s at this distance.

	Distance (feet)			
Shot Size (lb)	Hard Rock	Wet Alluvium	Dry Alluvium	Sed Rock
5	103	90	48	31
10	144	125	67	44
15	175	152	82	53
20	201	175	94	61
25	225	195	105	68
30	245	213	114	74
35	264	230	123	79
40	282	245	131	85
45	299	260	139	90
50	315	273	146	94
60	344	299	160	103
70	371	322	172	111
80	396	344	184	118
90	419	364	195	125
100	441	383	205	132
150	538	467	249	160
200	620	538	287	184
250	692	600	320	205
300	756	657	350	224
350	816	708	377	242
400	871	756	402	258
450	924	802	426	273
500	973	844	449	287
600	1064	924	491	314
700	1149	997	529	339
800	1227	1064	565	361
900	1300	1128	598	383
1000	1370	1188	630	403
1500	1675	1452	769	491
2000	1932	1675	886	566
2500	2158	1871	989	631
3000	2363	2048	1082	691

MINIMUM SETBACK DISTANCES FOR SHOTS OF VARIOUS SIZES,
GEOLOGIC SITE CONDITIONS,
GROUND-VELOCITY THRESHOLDS,
AND CERTAINTY LEVELS

99.00 percent of shots
will produce ground velocities less than 1.00 in/s at this distance.

	Distance (feet)			
Shot Size (lb)	Hard Rock	Wet Alluvium	Dry Alluvium	Sed Rock
5	177	154	82	53
10	247	215	115	74
15	301	262	140	90
20	346	301	161	104
25	386	336	179	115
30	422	367	196	126
35	455	396	211	136
40	486	422	225	145
45	515	447	239	153
50	542	471	251	161
60	593	515	275	176
70	640	555	296	190
80	683	593	316	203
90	724	628	335	215
100	762	662	352	226
150	931	808	429	275
200	1072	931	494	316
250	1197	1039	551	353
300	1310	1137	603	386
350	1414	1227	650	416
400	1511	1310	694	444
450	1602	1389	736	470
500	1687	1463	775	495
600	1847	1602	848	541
700	1994	1729	915	584
800	2131	1847	977	623
900	2259	1958	1035	661
1000	2381	2064	1090	696
1500	2914	2525	1332	849
2000	3364	2914	1536	979
2500	3760	3257	1716	1093
3000	4119	3568	1878	1195

90.00 percent of shots
will produce ground velocities less than 2.00 in/s at this distance.

	Distance (feet)			
Shot Size (lb)	Hard Rock	Wet Alluvium	Dry Alluvium	Sed Rock
5	51	44	24	16
10	71	62	33	22
15	86	75	41	26
20	99	86	47	30
25	111	96	52	34
30	121	105	57	37
35	130	113	61	39
40	139	121	65	42
45	147	128	69	44
50	155	134	72	47
60	169	147	79	51
70	182	158	85	55
80	194	169	91	58
90	206	179	96	62
100	216	188	101	65
150	263	229	123	79
200	303	263	141	91
250	338	294	157	101
300	369	321	172	110
350	398	346	185	119
400	425	369	197	127
450	450	391	209	134
500	474	412	220	141
600	518	450	240	154
700	559	486	259	166
800	597	518	276	177
900	632	549	293	188
1000	666	578	308	198
1500	813	706	376	241
2000	937	813	432	277
2500	1046	907	482	309
3000	1144	993	527	337

MINIMUM SETBACK DISTANCES FOR SHOTS OF VARIOUS SIZES,
GEOLOGIC SITE CONDITIONS,
GROUND-VELOCITY THRESHOLDS,
AND CERTAINTY LEVELS

95.00 percent of shots
will produce ground velocities less than 2.00 in/s at this distance.

	Distance (feet)			
Shot Size (lb)	Hard Rock	Wet Alluvium	Dry Alluvium	Sed Rock
5	68	59	32	21
10	95	83	45	29
15	115	100	54	35
20	133	115	62	40
25	148	128	69	45
30	161	140	75	49
35	174	151	81	52
40	185	161	87	56
45	196	171	92	59
50	207	180	96	62
60	226	196	105	68
70	243	212	113	73
80	260	226	121	78
90	275	239	128	82
100	289	252	135	87
150	353	307	164	105
200	406	353	188	121
250	453	393	210	135
300	495	430	229	147
350	534	464	247	159
400	570	495	264	169
450	604	524	280	179
500	636	552	294	189
600	695	604	322	206
700	750	651	347	222
800	801	695	370	237
900	849	737	392	251
1000	894	776	413	264
1500	1092	948	503	322
2000	1259	1092	579	371
2500	1406	1219	647	413
3000	1539	1334	707	452

99.00 percent of shots
will produce ground velocities less than 2.00 in/s at this distance.

	Distance (feet)			
Shot Size (lb)	Hard Rock	Wet Alluvium	Dry Alluvium	Sed Rock
5	116	101	54	35
10	162	141	76	49
15	198	172	92	60
20	227	198	106	68
25	253	220	118	76
30	277	241	129	83
35	299	260	139	89
40	319	277	148	95
45	338	293	157	101
50	355	309	165	106
60	388	338	180	116
70	419	364	194	125
80	447	388	207	133
90	474	411	220	141
100	499	433	231	149
150	608	528	282	181
200	701	608	324	208
250	782	679	361	232
300	855	742	395	253
350	923	801	426	273
400	986	855	455	291
450	1045	907	482	308
500	1100	955	507	325
600	1204	1045	554	355
700	1299	1127	598	383
800	1388	1204	638	408
900	1472	1276	677	433
1000	1550	1345	712	455
1500	1896	1644	870	555
2000	2187	1896	1002	640
2500	2444	2118	1119	714
3000	2676	2319	1224	781

MINIMUM SETBACK DISTANCES FOR SHOTS OF VARIOUS SIZES,
GEOLOGIC SITE CONDITIONS,
GROUND-VELOCITY THRESHOLDS,
AND CERTAINTY LEVELS

90.00 percent of shots
will produce ground velocities less than 5.00 in/s at this distance.

	Distance (feet)			
Shot Size (lb)	Hard Rock	Wet Alluvium	Dry Alluvium	Sed Rock
5	30	26	14	9
10	41	36	19	13
15	50	44	24	15
20	57	50	27	18
25	64	56	30	19
30	70	61	33	21
35	75	65	35	23
40	80	70	38	24
45	85	74	40	26
50	89	78	42	27
60	97	85	46	30
70	105	91	49	32
80	112	97	52	34
90	118	103	55	36
100	124	108	58	38
150	151	132	71	46
200	174	151	81	52
250	194	169	91	58
300	212	184	99	64
350	228	198	106	69
400	244	212	114	73
450	258	224	120	77
500	271	236	126	81
600	297	258	138	89
700	320	278	149	96
800	341	297	159	102
900	362	314	168	108
1000	381	331	177	114
1500	464	403	215	138
2000	534	464	248	159
2500	596	518	276	177
3000	652	566	302	194

95.00 percent of shots
will produce ground velocities less than 5.00 in/s at this distance.

	Distance (feet)			
Shot Size (lb)	Hard Rock	Wet Alluvium	Dry Alluvium	Sed Rock
5	39	34	19	12
10	55	48	26	17
15	67	58	31	20
20	76	67	36	23
25	85	74	40	26
30	93	81	44	28
35	100	87	47	30
40	107	93	50	32
45	113	98	53	34
50	119	103	56	36
60	130	113	61	39
70	140	122	65	42
80	149	130	70	45
90	158	137	74	48
100	166	145	78	50
150	202	176	94	61
200	233	202	108	70
250	259	225	121	78
300	283	246	132	85
350	305	266	142	92
400	326	283	152	98
450	345	300	161	103
500	364	316	169	109
600	397	345	185	119
700	428	372	199	128
800	457	397	212	136
900	485	421	225	144
1000	510	443	236	152
1500	622	541	288	185
2000	717	622	331	213
2500	800	695	370	237
3000	875	760	404	259

MINIMUM SETBACK DISTANCES FOR SHOTS OF VARIOUS SIZES,
GEOLOGIC SITE CONDITIONS,
GROUND-VELOCITY THRESHOLDS,
AND CERTAINTY LEVELS

99.00 percent of shots
will produce ground velocities less than 5.00 in/s at this distance.

	Distance (feet)			
Shot Size (lb)	Hard Rock	Wet Alluvium	Dry Alluvium	Sed Rock
5	67	58	32	20
10	94	81	44	28
15	114	99	53	34
20	131	114	61	40
25	146	127	68	44
30	159	138	74	48
35	171	149	80	52
40	183	159	85	55
45	194	168	90	58
50	204	177	95	61
60	223	194	104	67
70	240	209	112	72
80	256	223	119	77
90	271	236	126	81
100	285	248	133	86
150	348	302	162	104
200	400	348	186	120
250	446	388	207	133
300	488	424	226	145
350	526	457	244	157
400	562	488	260	167
450	595	517	276	177
500	627	545	290	186
600	686	596	317	203
700	740	642	342	219
800	790	686	365	234
900	837	727	387	248
1000	882	765	407	261
1500	1077	935	496	318
2000	1241	1077	571	366
2500	1386	1202	638	408
3000	1517	1316	697	446

APPENDIX II - Chemical Effects of Seismic Detonations on the Environment

This appendix contains several items:

1. Letter from explosive manufacturer (DuPont de Nemours & Company, Wilmington, Delaware) stating the post-detonation products of the seismic charge we use. The chief products are water vapor (62.8%), nitrogen (20.46%), and carbon dioxide (9.7%).

2. Letter from explosive manufacturer (IRECO Incorporated, Salt Lake City, Utah) stating the fact that the seismic charge we use will not dissolve significantly in ground water.

3. Table from testing laboratory (Northern Testing Laboratories, Fairbanks, Alaska) showing results from testing water samples we collected in 3 Alaskan lakes before and after detonation of submerged seismic charges in them. The only significant change is an increase in total suspended solids following the detonations, which returns to normal in an estimated 2 weeks or so (see graph in #5 below). Following the detonation in one lake (Manley Lake), there is a slight increase in nitrate and decrease in dissolved oxygen, that may be due to the stirring up of mud from the bottom of the lake (increase in total suspended solids).

4. Results from testing by limnologist, Prof. Michael Miller, University of Cincinnati, for changes in various chemical species before and after a detonation submerged seismic charges in a 4th Alaskan Lake (Oly Lake). No significant changes were detected.

5. Graph of total suspended solids as a function of time following detonation of a submerged seismic charge in Oly Lake, Alaska.

6. First page of journal describing chemical effects of detonation of submerged seismic charges in East African Lakes. No changes in chemistry that exceed natural variations were found.

CC: M. Irvin

DU PONT
ESTABLISHED 1802
E. I. DU PONT DE NEMOURS & COMPANY
INCORPORATED
WILMINGTON, DELAWARE 19898

FABRICATED PRODUCTS DEPARTMENT

May 4, 1987

Ed Criley
U.S. Geological Survey
345 Middlefield Road
MS 977
Menlo Park, CA 94025

Dear Ed:

This is in response to your request for information on the post detonation products of Tovex® Extra Special marine watergel.

Ninety-seven percent of the post detonation products are gaseous, consisting of: water vapor (62.8%), nitrogen (20.46%), carbon dioxide (9.7%), hydrogen (2.4%), carbon monoxide (1.26%) and ammonia (0.38%). The remaining solids consist of sodium carbonate (2.8%), and sodium silicate (0.1%). Tovex® Extra Special marine watergels are formulated and oxygen balanced to detonate under confined borehole conditions without any additional source of oxygen necessary for complete detonation.

Tovex® Extra Special marine formulation watergel has been widely used for deep hole and submarine blasting approximately fifteen years.

Very truly yours,

TI Jerman / tjw

Theodore I. Jerman
Technical Specialist

TIJ/tjw
I:11

IRECO Incorporated

Eleventh Floor Crossroads Tower
Salt Lake City, Utah USA 84144
Telephone: (801) 364-4800
Telex: 388353

6 May 1987

Mr. Ed Criley
U.S. Geologic Survey
M.S. 977
345 Middlefield Road
Menlo Park, CA 90425

Dear Mr. Criley:

Emulsion blasting agents are inherently very water resistant. The continuous phase of the emulsion is oil, which surrounds each droplet of the aqueous phase (inorganic nitrate solution). Borehole water which comes in contact with the emulsion contacts only the continuous oil phase. The leaching of inorganic nitrates from the emulsion would therefore be minimal and would not present a significant pollution hazard.

We would expect that the detonation would consume 100% of the emulsion in the borehole and that the products of detonation (carbon dioxide, nitrogen and water) would not present a significant pollution hazard.

Bulk emulsion blasting agents are widely used throughout the world and I know of no instances where the groundwater has been contaminated by their use.

Very truly yours,

IRECO Incorporated

Herbert K Knight
Herbert G. Knight, Jr.
Manager, Environmental Affairs

HGK/hbg

cc: S.R. Poulter
M.D. Lott
L.D. Lawrence

R5826

Northern Testing Laboratory (NTL), Inc., 600 University Plaza West, Suite A, Fairbanks, Alaska and 2506 Fairbanks Street, Anchorage, Alaska

Client: U.S. Geological Survey, 345 Middlefield Road, Menlo Park, CA 94025 — Attention: Gary Fuis

Water quality measurements in Alaskan lakes before and after nearby seismic explosions — Date: 8/28/1987

Sample Numbering Scheme: Example: 70 A, B, C-1, 2

Shotpoint # = 70 | A = West | B = East | C = Center | 1 = Before shot | 2 = After shot

Lake name	NTL Ids	Location (Shotpoint)	Sample Date	Total Suspended Solids (TSS) mg/l	Alkalinity mg/l	Hardness mg/l	Conductivity	Nitrate mg/l	pH	Dissolved Oxygen taken at 3 sites 0-100' apart mg/l		
Salcha	082887-18M	55 B-1	8/14/1987	4.8	28.7	27.0	720	0.72	n/a	n/a	n/a	n/a
Salcha	082887-19M	55 B-2	8/21/1987	61.0	30.9	28.8	750	0.48	n/a	n/a	n/a	n/a
Salcha	082887-20M	55 C-1	8/14/1987	6.8	29.8	27.8	730	0.62	n/a	n/a	n/a	n/a
Salcha	082887-21M	55 CC-1	8/14/1987	8.0	30.9	27.8	790	1.2	n/a	n/a	n/a	n/a
Salcha	082887-22M	55 C-2	8/21/1987	87.0	30.9	27.0	760	0.55	n/a	n/a	n/a	n/a
Bonanza	082887-23M	70 A-1	8/22/1987	<1	36.5	40.3	880	<0.1	6.86	8.60	8.90	8.80
Bonanza	082887-24M	70 A-2	8/25/1987	115.0	36.5	39.4	880	0.2	6.76	8.00	8.30	n/a
Bonanza	082887-25M	70 B-1	8/22/1987	2.8	37.6	39.4	890	<0.1	6.86	8.85	9.20	9.10
Bonanza	082887-26M	70 B-2	8/25/1987	14.0	38.7	41.3	900	0.1	6.88	n/a	n/a	n/a
Bonanza	082887-27M	70 C-1	8/22/1987	1.6	37.6	40.3	880	<0.1	7.00	n/a	n/a	n/a
Bonanza	082887-28M	70 C-2	8/25/1987	4.8	37.6	40.3	880	<0.1	7.00	7.85	n/a	n/a
Manley	082887-29M	74 A-1	8/23/1987	4.7	9.9	15.4	470	<0.1	6.04	8.40	8.20	8.65
Manley	082887-30M	74 A-2	8/26/1987	221.0	13.3	16.3	550	0.55	5.84	n/a	n/a	4.15
Manley	082887-31M	74 B-1	8/23/1987	<1	9.9	15.4	470	<0.1	6.23	n/a	n/a	n/a
Manley	082887-32M	74 B-2	8/26/1987	236.0	14.4	17.3	560	0.79	5.84	n/a	4.60	6.80
Manley	082887-33M	74 C-1	8/23/1987	1.0	11.1	15.4	460	<0.1	6.24	n/a	n/a	n/a
Manley	082887-34M	74 C-2	8/26/1987	265.0	14.4	18.2	550	0.84	5.93	n/a	n/a	n/a

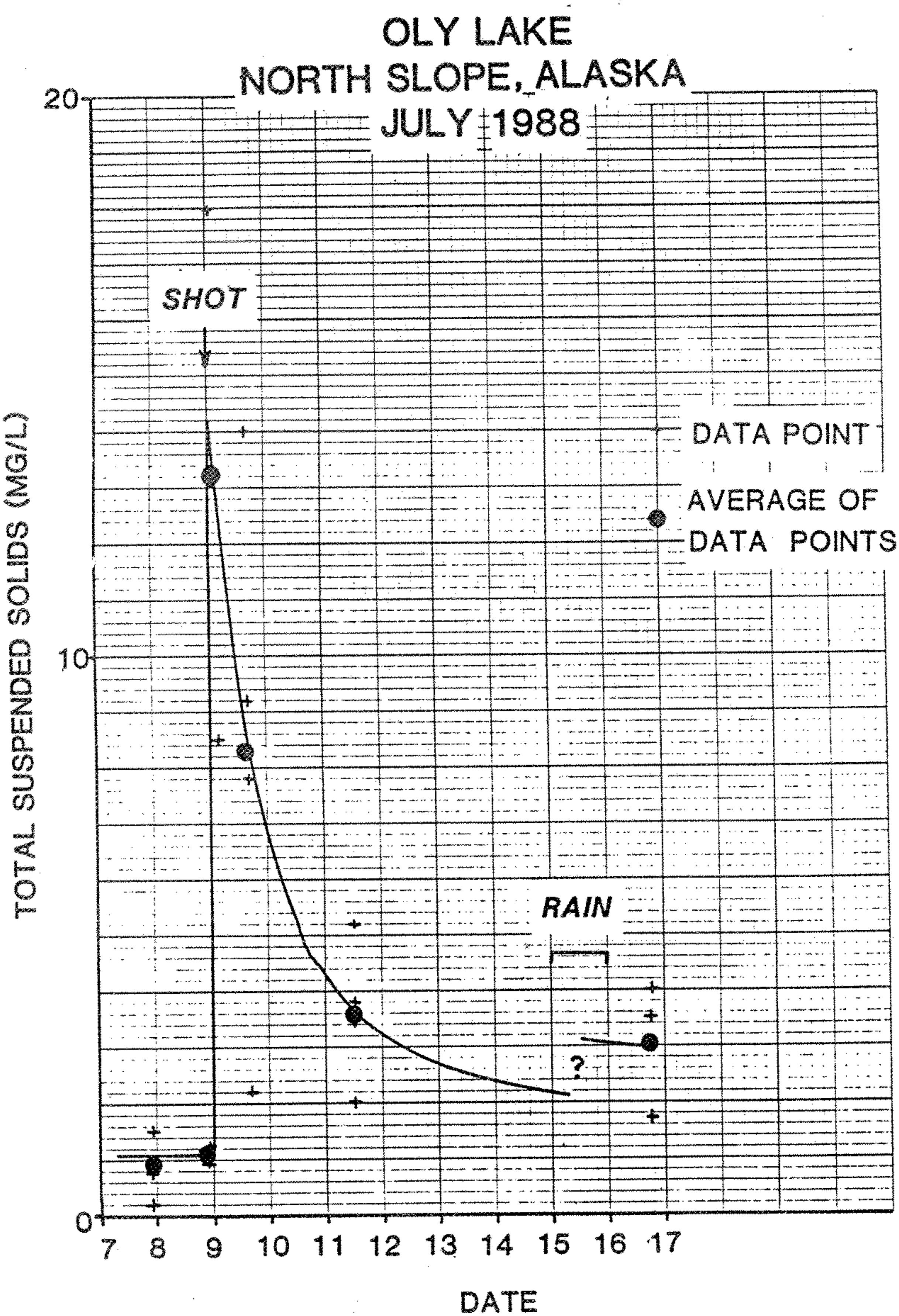
Location	Latitude	min	Longitude	min	Elev. (m)
Salcha	64	26.839	146	35.514	228
Bonanza	66	36.115	150	59.185	224
Manley	65	3.421	150	11.263	134

Water quality changes in Oly lake (lat. 68° 44'N., long. 148° 55'W.), North Slope, Alaska. A shot of charge size 960 lbs. was detonated at midnight 7/8/88.

Species	Change in concentration (measured within 12 hrs. of the shot) in milligrams/liter
1. Dissolved oxygen	range: 0.3-1.7 mg/l average change: 0.9 mg/l
2. Nitrogen as nitrate and nitrite	0.015 mg/l
3. Nitrogen as ammonia	0.040 mg/l
4. Phosphorus as phosphate	0.0033 mg/l

(changes were measured by Prof. Michael C. Miller, University of Cincinnati).

Changes in total suspended solids were measured in a time sequence over a 1 week period - see Figure on the following page.



Oly lake - suspended solids as a function
of time after shot

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Temporal geochemical variation in Ethiopian Lakes Shala, Arenguade, Awasa, and Beseka: Possible environmental impacts from underwater and borehole detonations

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Abstract

We present chemical analyses of 25 major, minor, and trace elements in 59 water samples from four lakes and five streams in central Ethiopia. Our major-element data extend to 2003 the intermittent series of measurements that reach back 40–65 years for Lakes Shala, Arenguade, Awasa, and Beseka within or adjacent to the Main Ethiopian Rift. Our minor-element and trace-element data help establish baselines for future monitoring of these four lakes.

Water chemistry was analyzed using samples taken in Lake Arenguade and Lake Shala both before and after detonation of submerged explosive charges as part of an active-source seismic survey of the Main Ethiopian Rift. Our data demonstrate no clear impact on the chemistry of Lake Shala from a 900-kg detonation suspended in the water column, whether from dispersal of the explosive charge in the body of water, or from mixing of the lake, or from stirring up of bottom mud into the lake water. In contrast, some changes in the chemistry of Lake Arenguade, most notably a decrease in Na and K concentration of 15–20% occurring between 1 and 11 days after detonation of a 1200-kg charge placed on the lake bottom, may possibly be ascribed to reaction between lake water and sediment stirred up by the detonation. However, these chemical changes that are potentially caused by our seismic detonation are significantly smaller than the natural variations in lake chemistry documented by long-term records. Additionally, we found no change in water chemistry of samples taken from Lakes Awasa and Beseka and from several streams both before and after nearby borehole detonations of 50–1775 kg.

Detonating explosive charges underwater greatly enhances seismic data quality. Bottom charges stir lake-bottom sediments into the water column, perhaps resulting in temporary changes in lake chemistry. Our borehole and suspended lake charges had no measurable chemical or lasting environmental effects. These 'negative' results – the lack of alteration of lake habitats consequent on seismic detonations – are a positive outcome.

1. Introduction

1.1. Need for, and consequences of, underwater seismic detonations

Seismic survey design favors underwater detonations as being both cost-effective and energy-efficient (Kohler and Fuis, 1992; Jacob et al., 1994) because source coupling is an order of magnitude greater in water than in rock. The incompressibility of water allows for very efficient energy transfer from underwater shots compared to detonations in boreholes, which use much of their energy in fracturing rock. It is also cost-effective to shoot in lakes whenever possible because much of the cost of a field experiment is attributable to shot-hole drilling (Kohler and Fuis, 1992). This cost-efficiency is particularly significant for the very largest seismic controlled sources, which may therefore only be logistically feasible in lakes, e.g. a 5-tonne shot detonated in the Dead Sea, Israel (Gitterman and Shapira,

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