Basewide Hydrogeologic Characterization Case Study: Naval Air Weapons Stations China Lake

U.S. Environmental Protection Agency
Office of Solid Waste and Emergency Response
Technology Innovation Office
Washington, D.C. 20460

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FOREWORD

Cost-effective cleanup (remediation) of hazardous waste sites cannot occur unless the type, quantities, and locations of chemical contaminants present at the site are adequately determined by a process called characterization. Sampling and chemical analysis of environmental media (water, soil, sediment, etc.) is vital to designing a remediation regimen that will accomplish the desired goal of reducing risk to human health and the environment. Unfortunately, site characterization has historically been very costly and time consuming because the technological options have been few and sometimes inefficient.

Recent technological advances promise better site characterization at less cost and in a shorter time frame, yet adoption of new technologies into mainstream engineering practice is very slow. Three widely acknowledged barriers to the adoption and use of innovative site characterization technologies at hazardous waste sites are:

- Potential users lack personal awareness and/or experience with the technology.
- Potential users lack the established performance criteria needed to assess the applicability of the technology for a prospective project, and
- Potential users lack the cost and performance information needed to efficiently plan the project and allocate resources.

The collection and dissemination of cost and performance information is essential to overcoming these barriers. While technology developers and vendors can be valuable sources of this information, their claims often carry less weight than evaluations from colleagues who have used the technology themselves. Case studies are a means by which technology users and impartial observers may disseminate information about successful applications of innovative technologies and add to the pool of knowledge that helps move a technology past the "innovative" stage, thus significantly shortening the time required for widespread benefits to be realized. Case studies can also be a rich source of feedback to researchers and developers seeking to improve or refine technology performance under various site conditions.

Individual case studies may focus on a particular technology or on a characterization approach or process. Case studies focused on process can provide education about how efficient characterization strategies can be implemented on a site-specific basis, and thus can be valuable adjuncts in training courses. For many reasons, case studies are valuable tools for the environmental remediation community.

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FIGURES

CASE STUDY ABSTRACT

NAWS China Lake
Inyo and Kern County, California

Site Name and Location:
Naval Air Weapons Station China Lake, Inyo County, California

Sampling & Analytical Technologies:
1. Isotope geochemistry;
2. Radon gamma spectroscopy (Teledyne Brown Engineering Environmental Services)
3. Carbon, oxygen and deuterium mass spectrometry VG602 (Laboratory of Isotope Geochemistry at The University of Arizona)
4. Tritium, quantulus 1220 LSC #2 (Laboratory of Isotope Geochemistry at The University of Arizona)
5. Chlorine, modified VG 602C mass spectrometer # 2 (Laboratory of Isotope Geochemistry at The University of Arizona)
6. Chlorine, low level beta counting (Teledyne Brown Engineering Environmental Services)
7. Boron, VG336 thermal ionization mass spectrometer, (Laboratory of Isotope Geochemistry at The University of Arizona)
8. Strontium, thermal ionization mass spectrometer (Geochron Laboratories, Inc)
9. CFC, purge and trap capillary column gas chromatography (University of Miami)
10. X-ray florescence and X-ray diffraction analysis (XRAL Laboratories)
11. Thin section petrographic analysis (DCM Science laboratory, Inc)
12. Physical property testing (A and P Engineering)

Period of Operation:
1943 to present. Supports research and development of navel air craft and ordnance.

Current Site Activities:
RI/FS and IRP work on 53 sites

Point of Contact:
Robert Howe
Tetra Tech EMI.
4940 Pearl East Circle
Suite 100
Boulder, CO 80301
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Media and Contaminants:
Groundwater and soils at NAWS China Lake are contaminated with chlorinated and aromatic solvents, metals, and petroleum compounds.

Technology Demonstrator:

Number of Samples Analyzed during Investigation:
A soil sampling program from 12 bore holes produced the following: 40 samples collected for XRF analysis, 8 for XRD analysis. A groundwater and surface water sampling program produced: 59 oxygen-18, deuterium, and carbon-14 analysis, 36 tritium and sulfur 34 analysis, 38 strontium 87/86 analysis, 46 radon 222 analysis, 35 CFC analysis, and 47 boron 11 analysis.

Cost Savings:
The cost savings using this approach are estimated at 50% of traditional methods

Results:
The China Lake CSM was used as a dynamic decision making tool during the basewide hydrogeologic characterization of IWV. The construction of the CSM resulted in a better understanding of the system, which sites pose the greatest risk, and which sites should be considered for no further action status.

EXECUTIVE SUMMARY

A geologic and hydrogeologic conceptual site model (CSM) was constructed for the Navel Air Weapons Station (NAWS) China Lake in order to fulfill objectives set forth by the NAWS China Lake record of decision (ROD). The objectives of developing a CSM for NAWS China Lake were to: 1) gain a fundamental understanding of the geology and hydrogeology in and around the facility; 2) locate groundwater recharge sources, groundwater flow directions, and travel times in water bearing zones; 3) understand and map changes in groundwater quality (geochemistry), and 4) to identify areas were activities from the NAWS China Lake facility could be impacted water quality in the Indian Wells Valley (IWV).

The overall objective of the program was to design a monitoring well network of wells to support closure of the over 56 sites identified at the facility and protect groundwater quality and resources in the area. The data collection design included the collection of data to support contaminant fate and transport evaluations. Groundwater quality and changes in pieziometric surfaces over time were evaluated to evaluate long-term trends in water quality with groundwater use. Any loss of potable groundwater in IWV due to degrading water quality is given considerable attention because IWV water supply is limited and demand for water is growing.

SITE INFORMATION

Naval Air Weapons Station (NAWS) China Lake

Kern and Inyo Counties, California

BACKGROUND

Most of the NAWS China Lake facility is located in IWV in the northern Mojave Desert of California. IWV is located in the southwest corner of the Great Basin section of the basin and range physiographic province (**Figure 1**). IWV is bordered on the west by the Sierra Nevada, on the east by the Argus Range, on the north the Coso Range and on the south by the El Paso Mountains, Rademacher Hills, and Spangler Hills (TtEMI 2001a).

Elevations in IWV vary from approximately 3,000 feet above mean sea level (msl) at the margins of the valley to approximately 2,150 feet msl at the China Lake playa in the southeastern corner of the China Lake Complex. Elevations of the Sierra Nevada to the west exceed 9,000 feet msl, the Coso range to the north average 6,500 feet msl, and the highest point in the Argus Range is Maturango Peak at 8,839 feet msl (TtEMI 2001a).

IWV has an average annual precipitation of 3 to 6 inches. Most precipitation occurs between October and March, with December generally being the wettest month (TtEMI 2001a).

Prior to the development of this CSM, a conceptual model of the groundwater flow in IWV (**Figure 2**) was proposed by Dutcher and Moyle 1973, Warner 1975, and Berenbrock and Martin 1991. This earlier conceptual model was used as the starting point for the development of the current CSM. However, this model suggested the presence of a single unconfined system where water entered the system from the west and flowed towards the center of the playa where it would discharge to the China Lake Playa. With reversal of the gradient away from the playa, located near the center of the facility, through pumping by surrounding residences and the local municipality, the historical CSM suggested that the observed increases in total dissolved solids likely originated from the base.

Site Logistics/Contacts

This section contains the basic contact information for the project, such as.

Lead Agency : U.S. Navy
Oversight Agency:

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MEDIA AND CONTAMINANTS

The purpose of this section is to describe the types of contaminants present at the site, and the characteristics of the matrices in which they are found. Include information on the listed topics as needed to aid case study coherence:

Matrix Identification

Type of Matrix Sampled and Analyzed: **Groundwater, surface water, and subsurface soil.**

PRELIMINARY CONCEPTUAL SITE MODEL

In the early stages of the construction of a revised CSM for NAWS China Lake, an extensive literature review was conducted. Geologic, hydrogeologic, structural, and geochemical data was uncovered for nearly 2000 existing wells in the area during the literature review. Data was used from nearly 300 of these wells to create maps, cross-sections, and geochemical plots (Stiff and Piper diagrams). Borehole logs when available were used to create geologic cross-sections, structure contour, and isopach maps. Stiff and Piper diagrams were used to identify water types based on the major ion chemistry. Geologic cross-sections helped identify the hydrogeologic units present in IWV. A structure contour map was made on the top elevation of a low permeability lacustrine clay dominated intermediate hydrolgeologic unit and an isopach map was made of its thickness. The examination of these diagrams and maps helped the CSM team identify the presence of three discrete geologic and hydrogeologic water bearing units in IWV previously thought to be a single inter-connected system. The project team designated these zones as the Shallow Hydrogeologic Zone (SHZ), the Intermediate Hydrogeologic Zone (IHZ), and the Deep Hydrogeologic Zone (DHZ).

Further study of the literature from surrounding areas also revealed that IWV is located in the southwestern part of the Basin and Rasin Physiographic Province, IWV is a half-graben structural depression bounded by pre-Tertiary igneous and metamorphic rocks that also underlie the basin. Faulting of two major styles and ages are present and continue to keep the area tectonically active. The structural depression is filled with consolidated continental deposits of Tertiary age and over 1,500 feet of Pleistocene unconcolidated sediments that mostly represent alluvial fan, alluvial, and lacustrine deposits.

The depositional environment changed dramatically during wetter periods of the Pleistocene. During these wetter periods, much of the basin fill consisted of lacustrine sediments that were related to glacial epochs, subsequent basin flooding, and ancestral Owens Lake overflow. While the mid valley sediments are typically fine-grained and lacustrine, basin margin sediments are more coarsely grained and more poorly sorted.

Based on historical and previous information available from the site geologic it was determined that the IHZ was a potentially bounding clay sequence that could potentially restricted aquifer interactions beneath the facility where combined lacustrine clay sequences were known to exceeded 500 feet in thickness. These lake sediments, as shown in **Figure 3**, where identified by the project team as representing an almost ideal regressive sequence that had come and gone throughout the valley relatively rapidly. It became apparent to the project team, based on this preliminary CSM that understanding the nature and extent of the IHZ would be crucial to determining when and where the contaminated SHZ below the facility might have the potential to impact water in the DHZ, which is the principal source of drinking water in the region.

Primary Contaminant Groups

The primary contaminant groups at NAWS China Lake are volatile organic compounds (VOCs), polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), and metals.

INTRUSIVE SAMPLING AND ANALYSIS TO REFINE THE CSM

A total of 12 borings were initially continuously cored to depths that ranged from 473 to 798 feet bgs. The detailed boring logs filled data gaps and allowed the CSM team to refine and add certainty to the geologic and hydrogeologic understanding of the site. This new geologic data was combined with what was already known to create a number of figures used to communicate the revised CSM to stakeholders. A map showing the estimated extent of the former Pleistocene lakes that where responsible for the development of the IHZ (**Figure 4**), several cartoons showing the relationship between the alluvial, lake, and delta sediments in IWV (**Figures 5, -6, and 7**) where created to communicate the logic used by the project team to the residence of the area. A geologic block diagram of IWV, **Figure 8** (TtEMI 2001a) was also created detailing the primary structural features in the region and their relationship to the geology and hydrogeologic zones . The block diagram (**Figure 8**) is also a schematic representation of the geologic and hydrogeologic features of IWV relevant to the CSM.

Geologic soil samples were collected during the drilling of the exploratory borings. The soil samples were collected at regular and unspecified intervals when lithologic variations were observed. In addition to standard geologic inspections soil samples were analyzed using X-ray diffraction (XRD), X-ray florescence (XRF), thin section petrography, carbon-14 age dating, and physical property testing. The XRF, XRD, and thin section petrography were used to identify the mineralogy and chemical species present in the samples. This data was then used as constraints in the geochemical modeling to determine groundwater residence times. The carbon-14 soil dates were used to examine soil age versus depth profiles. Physical property testing for specific gravity, percent moisture, dry density, bulk density and porosity was also performed to estimate which water bearing units where likely to transmit or block flow.

Groundwater and surface waters were sampled for environmental isotopes. The isotopes sampled in this study included: oxygen, deuterium, carbon, tritium, strontium, sulfur, chlorine, radon, and the intrinsic tracer chlorofluorocarbon (CFC). These isotopes and intrinsic tracers were used to identify groundwater flow paths, hydraulic connection between groundwater zones, recharge sources, and groundwater age.

Groundwater elevations were measured in numerous wells across the site to develop potentiometric surface maps. Water levels were measured on a quarterly basis to determine if the groundwater surface elevation had any seasonal fluctuations. Potentiometric surface maps were created for the shallow and deep hydrogeologic zones. These potentiometric surface maps were used to indicate the directions of groundwater flow and to calculate flow gradients. Potentiometric surface maps indicated areas within the study area where additional water level measurement would be needed to fill gaps in the potentiometric surface map coverage. From these maps flow directions could be mapped and compared with the extent of the clay packages South of the facility to determine where additional investigative work was required.

The new borehole data, isotopic signatures of the water samples, and the age dates of the water and soil samples were used to refine the preliminary CSM. Geochemical modeling was performed with NETPATH and WATEQ4F. WATEQ4F was used to calculate the saturation indexes, chemical activities, and mineralogical phases present in the system. NETPATH was used to calculate the travel times of four different plowpaths in IWV. Changes to the original CSM that resulted from the sampling and analysis program included:

- The likely source of TDS to the DHZ in the area near the Town of Ridgecrest is from deep water within the DHZ and not the contaminated SHZ beneath the facility
- The IHZ appears to be a barrier to communication between the SHZ and DHZ
- Most contaminated water beneath the facility is following towards the center of the playa and away from areas where the IHZ pinches out to the south near Ridgecrest
- Limited communication between aquifers in the area between Ridgecrest and NAWS China Lake is likely influenced by surface water trenches or discharges to the surface (unlined drainage ditches and or impoundments)
- Groundwater age dates indicate that deep groundwater (DHZ) beneath the IHZ does not likely discharge to the surface in the playa as predicted by the previous CSM for IWV.
- Water quality is highly variable across the basin, but is of the highest quality and quantity along the western edge of the basin where fault system may not act to block the flow of modern recharge.

Figure 9 is the revised schematic rendition of the IWV CSM (TtEMI 2001b). These findings were contrary to those that had been made previously and have significantly impacted prioritization of activities to be conducted at the nearly 100 sites located on the facility.

RESULTS

The CSM constructed during this study has met its objectives. The first objective was to gain a fundamental understanding of the hydrogeology across the NAWS China Lake complex. An extensive review of the existing data and literature was used to form a preliminary understanding of the site hydrogeology. Additionally, the mapping of the SHZ's and DHZ's potentiometric surfaces and the geologic descriptions from exploratory borelogs were fundamental in accomplishing this first objective.

An understanding of groundwater recharge zones, flow directions and travel times was also gained through the potentiometric surface mapping. Additionally oxygen, deuterium, and strontium isotopic analysis furthered the understanding of the groundwater recharge zones and flow directions. Tritium, CFC and carbon-14 age dating of the groundwater were used to estimate groundwater travel times. Groundwater travel times from recharge zones in the Sierra Nevada to the well fields in IWV were estimated and used understand potential flow paths and location of better quality water in the region.

Stiff and Piper plots of the major ion geochemistry of the ground and surface waters from IWV were created to evaluate groundwater quality and to distinguish water types based on geochemical characteristics. The influence of groundwater pumping on groundwater quality was investigated by plotting groundwater elevations with oxygen and deuterium isotopic ratio values versus time. This illustrated that as groundwater elevations in the DHZ declined the observed deuterium values became more negative; indicating that groundwater pumping was pulling water from greater depths rather than from the SHZ as shown in **Figure 10** (TtEMI 2001b). This finding was significant because most of the groundwater contamination is located in portions of the SHZ.

Isotopic signatures of the shallow, intermediate, and deep hydrogeologic zones were identified by creating scatter plots of the isotopic values versus the total concentration of the parameter or versus the sample elevation. With the signatures of the different hydrologic zones identified, the amount of mixing between zones was evaluated. This allowed the CSM team to evaluate the impacts that the NAWS China Lake facility has had on the overall groundwater quality and resources in the IWV region. In addition, the revised CSM will provide a basis for any further fate and transport modeling or additional isotopic work to continue to refine the Navy's and the public stakeholder's knowledge of the natural resource and environmental issues in the area.

CONCLUSIONS

This CSM has guided the project team's decisions and actions. Key decisions made during the CSM process include the type and location of additional fieldwork. For example, the CSM was used to determine the location of additional borings, wells, and the screen interval of the wells. The CSM was used as a dynamic tool to plan additional field activities. The next phase of this project is to design a monitoring network to confirm and validate the present CSM. The data returned from the planned monitoring network will be used to further revise the CSM and focus monitoring and measurement activities to be conducted at the site.

A refined CSM will be able to identify hydraulic connection between hydrogeologic zones and groundwater flow lines on a smaller scale that can be applied to individual sites included in the Installation Restoration Program (IRP) within the NAWS China Lake complex. Site prioritization and closure status of IRP sites will be determined by using the CSM as an interactive, dynamic, decision-making tool. This will identify the IRP sites that need further review. Sites requiring further action will continue in the process and will be evaluated based on site closure criteria. Additionally, the CSM process will provide a clear vision on how to most effectively allocate funds for the eventual closure of all IRP sites

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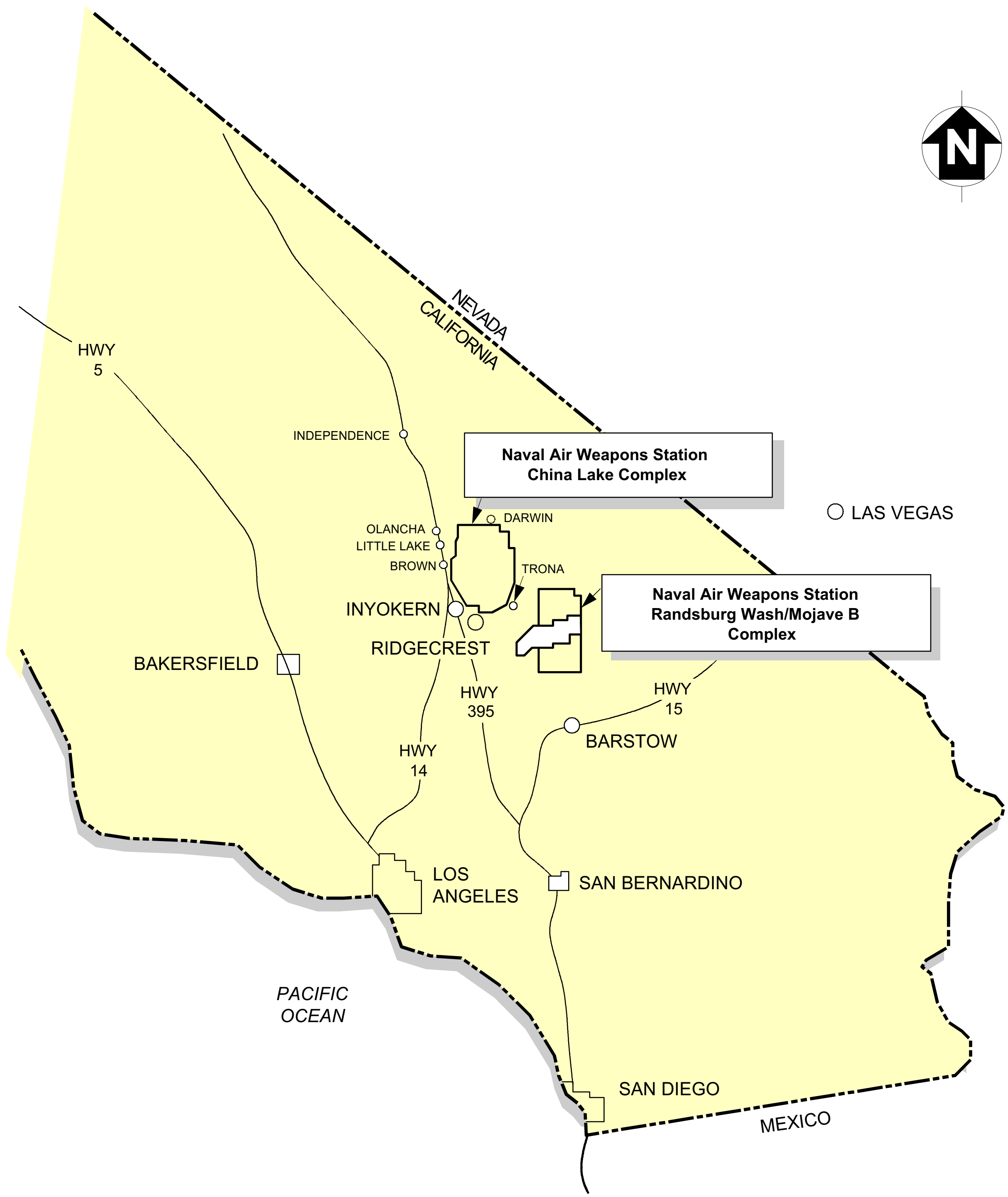
TABLE 1
SUMMARY BHC OBJECTIVES AND DATA COLLECTION ACTIVITIES
NAWS CHINA LAKE, CALIFORNIA

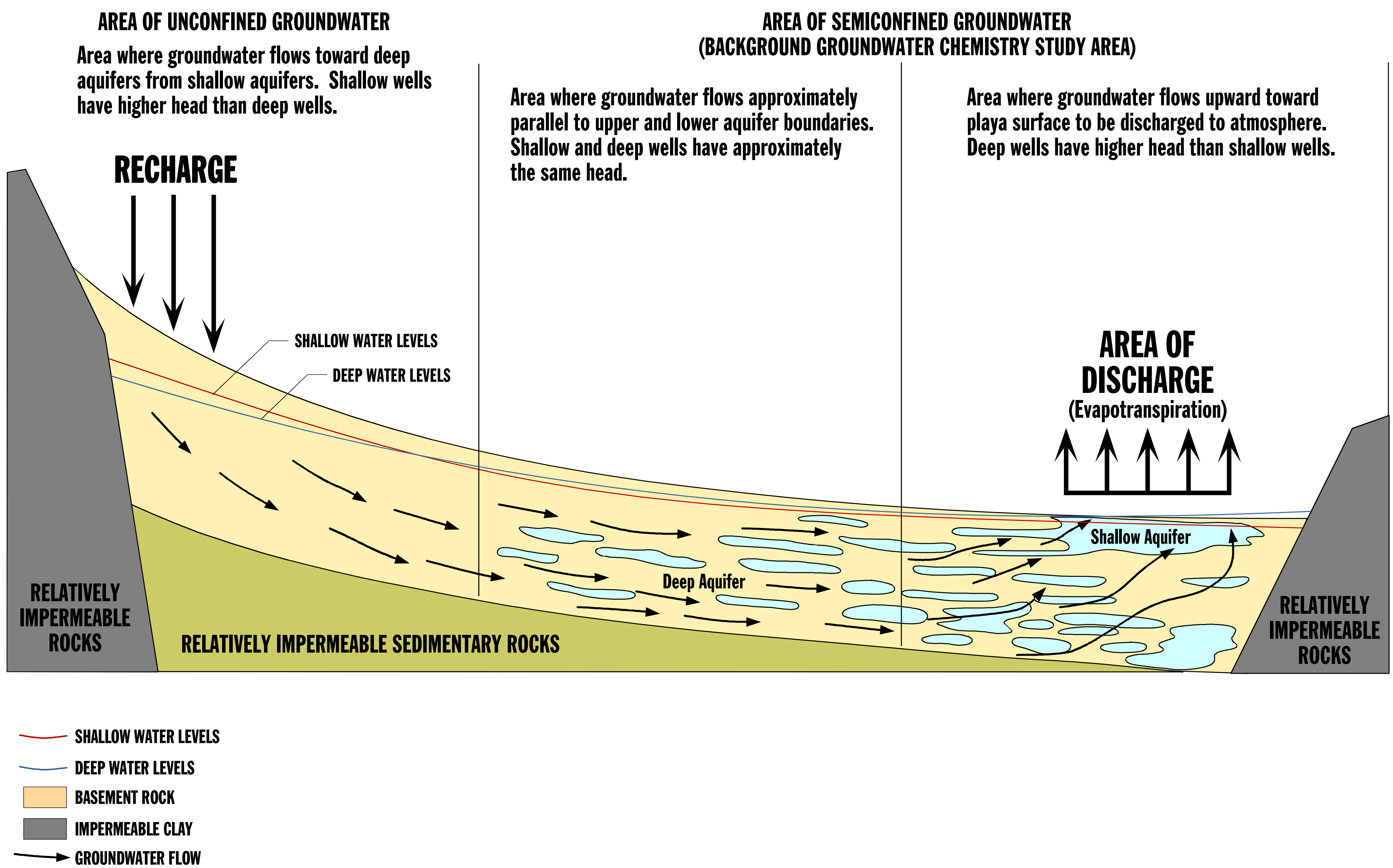
Study Area	Objectives	Type of Data Acquired	Data Collection and Frequency of Acquisition	Data Analysis Summary
Indian Wells Valley	Determine number, availability, and condition of existing groundwater monitoring wells	Basewide inventory of existing monitoring wells, including data regarding well locations, construction, and well screen positions	Visual survey, existing records, and video survey completed at selected wells to determine usability	Determine usability and purpose of each well according to study definition of a usable well
	Establish lithologic definition and control	Borehole logs, downhole geophysical logs, and continuous core data	Leliter Area – 1 borehole drilled to the deep aquifer system, approximately 500 feet in depth	Continuously core and log boreholes according to Unified Soil Classification System
			Main Base Area – 6 boreholes drilled to the deep aquifer approximately 750 feet in depth	Conduct geophysical logging to include spontaneous potential (SP), resistivity, guard, gamma ray, and caliper logs
			Brown Road/Northwest Base Area – 1 borehole drilled to the deep aquifer, approximately 650 feet in depth	Log, label, and archive continuous core samples
			Little Lake Fault Zone/Ridgecrest – 4 boreholes drilled to the deep aquifer, approximately 750 feet in depth	Collect data in accordance with the RI/FS QAPP (TtEMI 1998c) and the QAPP
			Existing well information as available	Construct stratigraphic sections to establish lithologic definition and control
	Determine groundwater mound sources at the Main Gate area	Borehole logs, downhole geophysical logs, continuous core data, and long-term water level monitoring data	Main Base Area – 6 boreholes; approximately 26 wells will be installed in the shallow, intermediate, and deep aquifer systems; water levels will be monitored for 2 years to cover 2 annual cycles of seasonal water use	Use stratigraphic information and water level data trends to locate a potential source for the existing groundwater mound
	Identify water bearing zones (WBZ) and hydrogeologic unit correlation	Borehole logs, downhole geophysical logs, and continuous core data	All 12 boreholes in all 4 areas of Indian Wells Valley; hydrostratigraphic sections will illustrate hydrgeologic units (WBZs) correlated laterally using both existing and new data	Use stratigraphic and downhole geophysical information to identify and correlate WBZs

TABLE 1 (Continued)
SUMMARY BHC OBJECTIVES AND DATA COLLECTION ACTIVITIES
NAWS CHINA LAKE, CALIFORNIA

Study Area	Objectives	Type of Data Acquired	Data Collection and Frequency of Acquisition	Data Analysis Summary
Indian Wells Valley (Continued)	Define groundwater flow directions	Water level measurements	Selected wells in Indian Wells Valley identified for long-term water level monitoring	Use long-term continuous water level monitoring measurements to identify groundwater flow directions; establish seasonal variation, effects of pumping and trends with long-term data
	Define groundwater quality	Groundwater monitoring well installation logs, results for groundwater samples collected during drilling, and quarterly groundwater monitoring data	Installation of approximately 47 wells in Indian Wells Valley; the quarterly groundwater sampling program will include approximately 60 selected wells	Use quarterly sampling results to establish statistically-based population distribution for specified parameters
	Define aquifer response to annual cycles	Long-term water level monitoring data	Quarterly water level monitoring in selected wells, including existing IWVWD wells	Examine quarterly hydrographs foe all wells monitored to identify and correlate trends to annual pumping rates
	Define groundwater flow direction	Long-term water level monitoring data	Quarterly monitoring in selected wells	Examine quarterly flow directions for selected wells and well clusters to establish consistent flow trends
	Evaluate radius of influence of Navy supply wells in Inyokern	Inventory of pumping records from Navy, Inyokern Community Services District, and North American Chemical Company	Existing pumping records, water levels, aquifer hydraulic parameters	Determine radius of influence, long-term effects, and provide wellhead protection program data
	Determine groundwater age and travel times	Carbon –14 and Tritium activities, and CFC concentrations from groundwater samples	Water samples will be collected one time from selected wells and springs	Age date groundwater, determine groundwater travel times and estimate zones of recharge
	Determine hydraulic communication between hydrogeologic zones	^{18}O, D, ^{34}S, $^{87}Sr/^{86}Sr$, Rn, ^{37}Cl, ^{36}Cl, and ^{11}B isotopic data from surface and groundwater	Water samples will be collected one time from selected wells and springs	Isotopic signatures from each hydrgeologic zone will be analyzed to determine if communication and mixing is occurring between zones
	Characterize investigation-derived waste (IDW)	Laboratory analytical data for soil and groundwater samples collected at borehole and well locations	Drilling and purge water will be contained and analyzed; unconfined soil and groundwater will be discharged to the ground surface	Characterize and dispose of IDW according to RI/FS Waste Management Plan (PRC 1993)

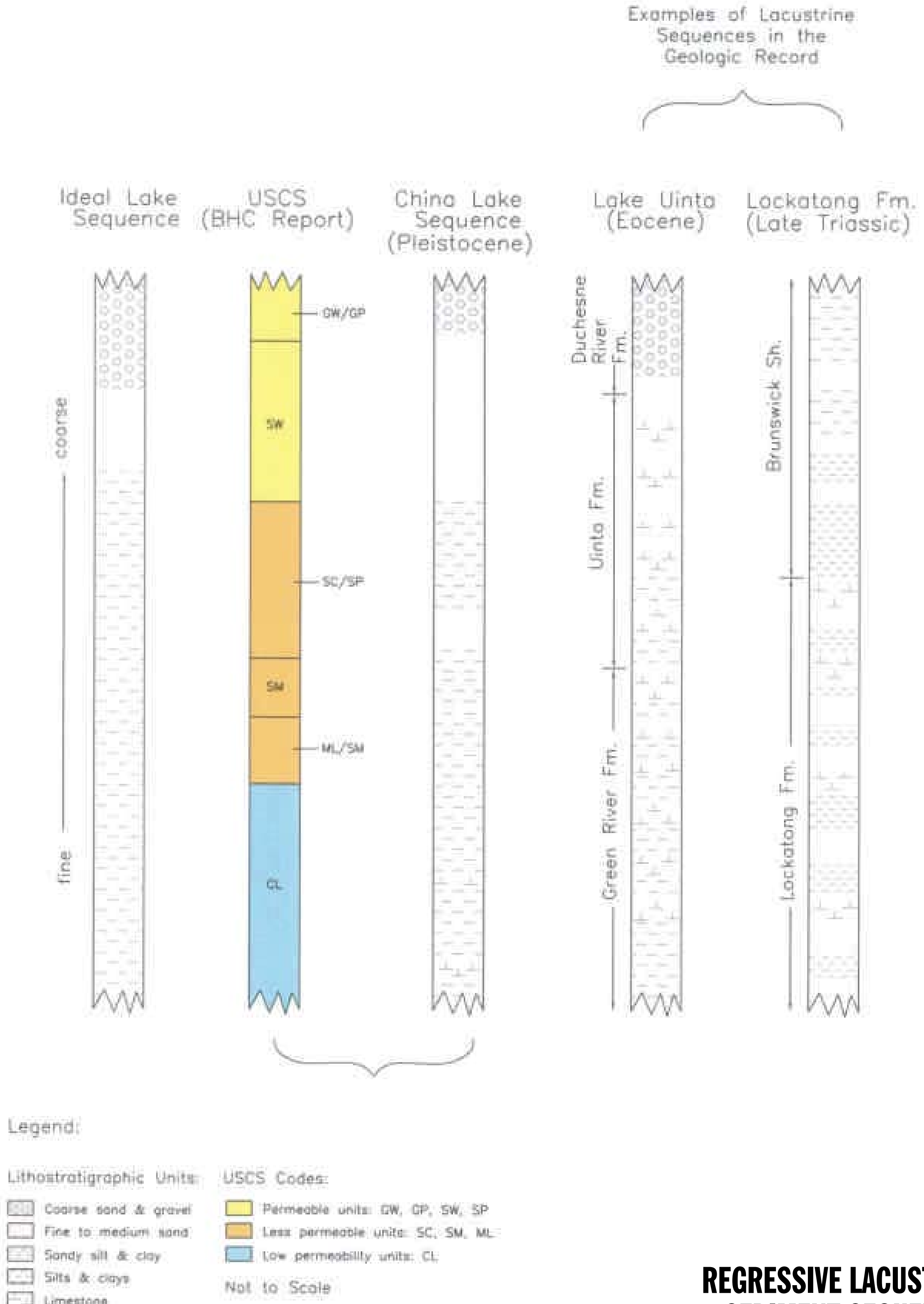


CASE STUDY	CHINA LAKE - LOCATION MAP	FIGURE 1



SOURCE: Redrawn and modified from Dutcher and Moyle (1973) and Berenbrock and Martin (1991)

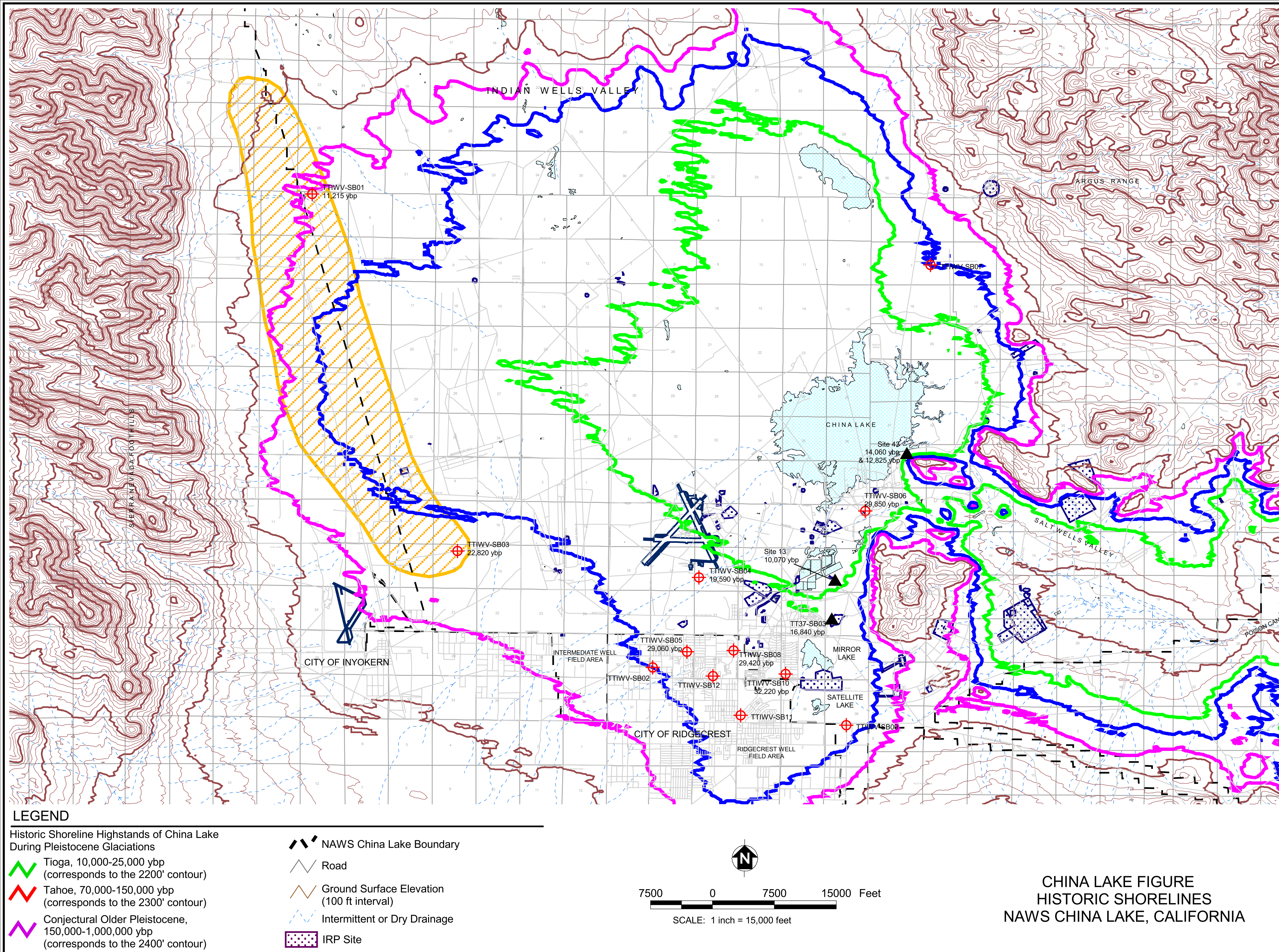
CASE STUDY	CHINA LAKE - CONCEPTUALIZATION OF GROUNDWATER FLOW IN THE INDIAN WELLS VALLEY	FIGURE 2



Source: Modified from Picard and High (1972)

REGRESSIVE LACUSTRINE SEDIMENT SEQUENCE

CASE STUDY	CHINA LAKE - SEDIMENT SEQUENCE	FIGURE 3



CHINA LAKE FIGURE
HISTORIC SHORELINES
NAWS CHINA LAKE, CALIFORNIA

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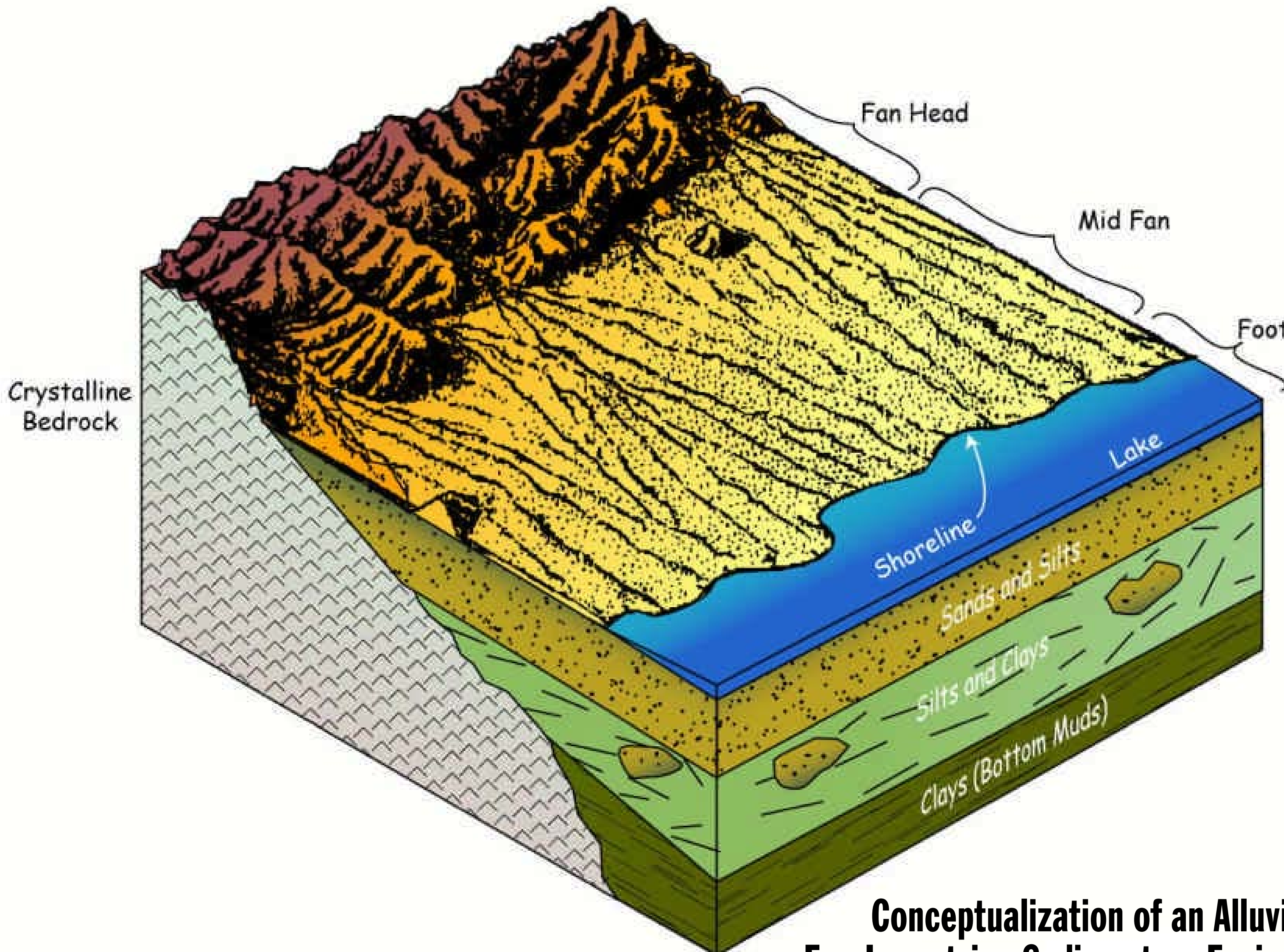
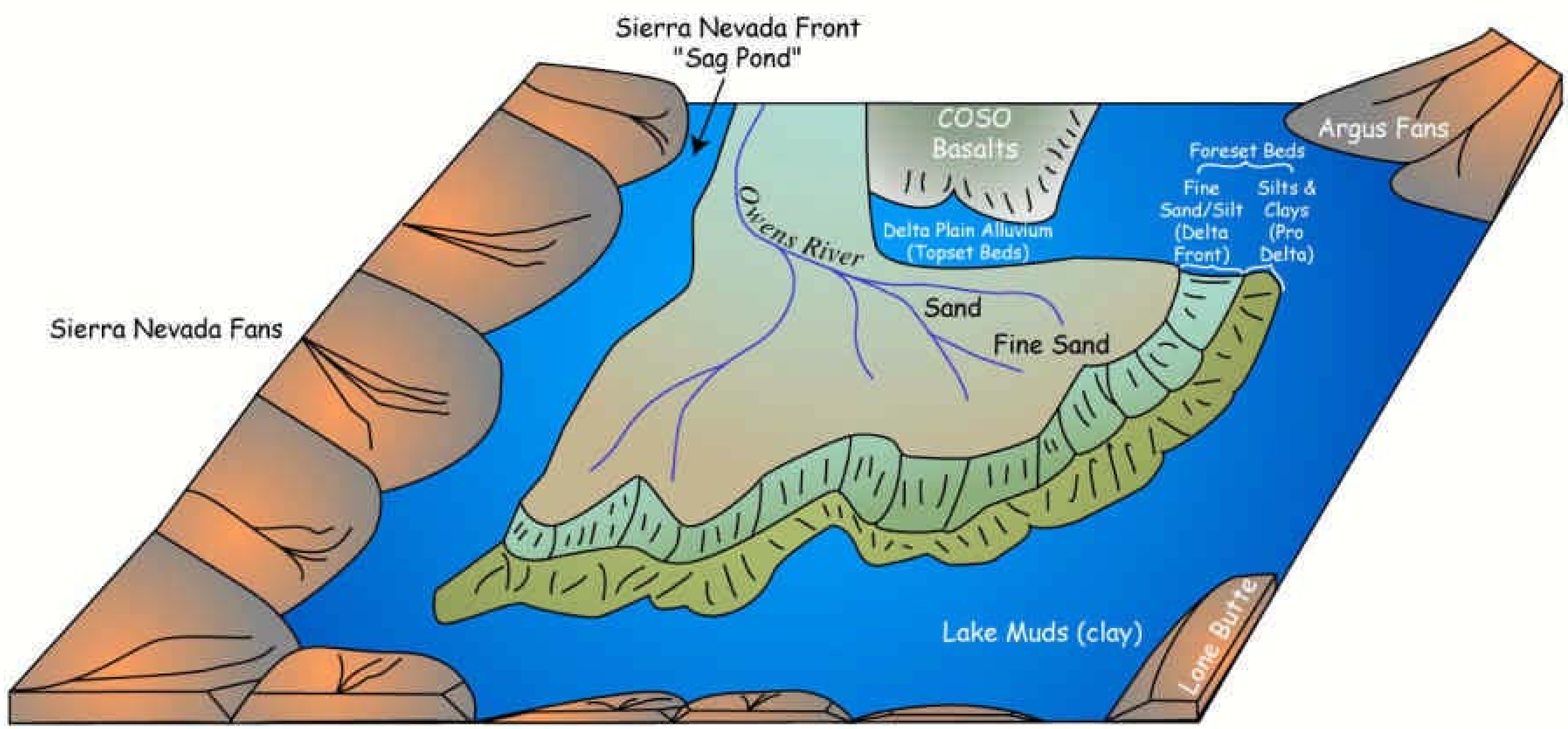


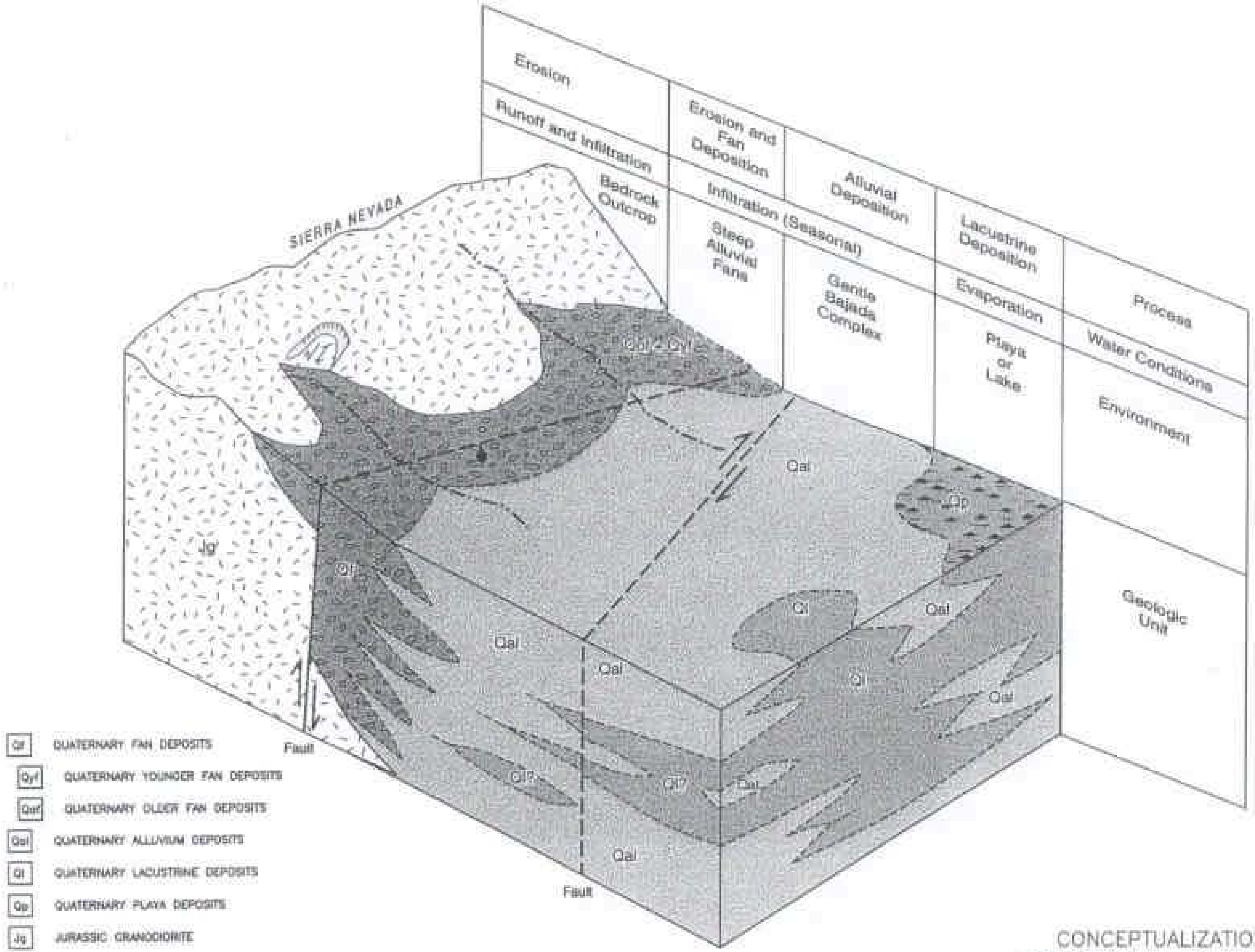
Conceptualization of an Alluvial Fan-Lacustrine Sedimentary Environment

CASE STUDY	CHINA LAKE - CONCEPTUAL ENVIRONMENTAL MODEL	FIGURE 5



Conceptualization of Owens River
Delta Sedimentary Environments

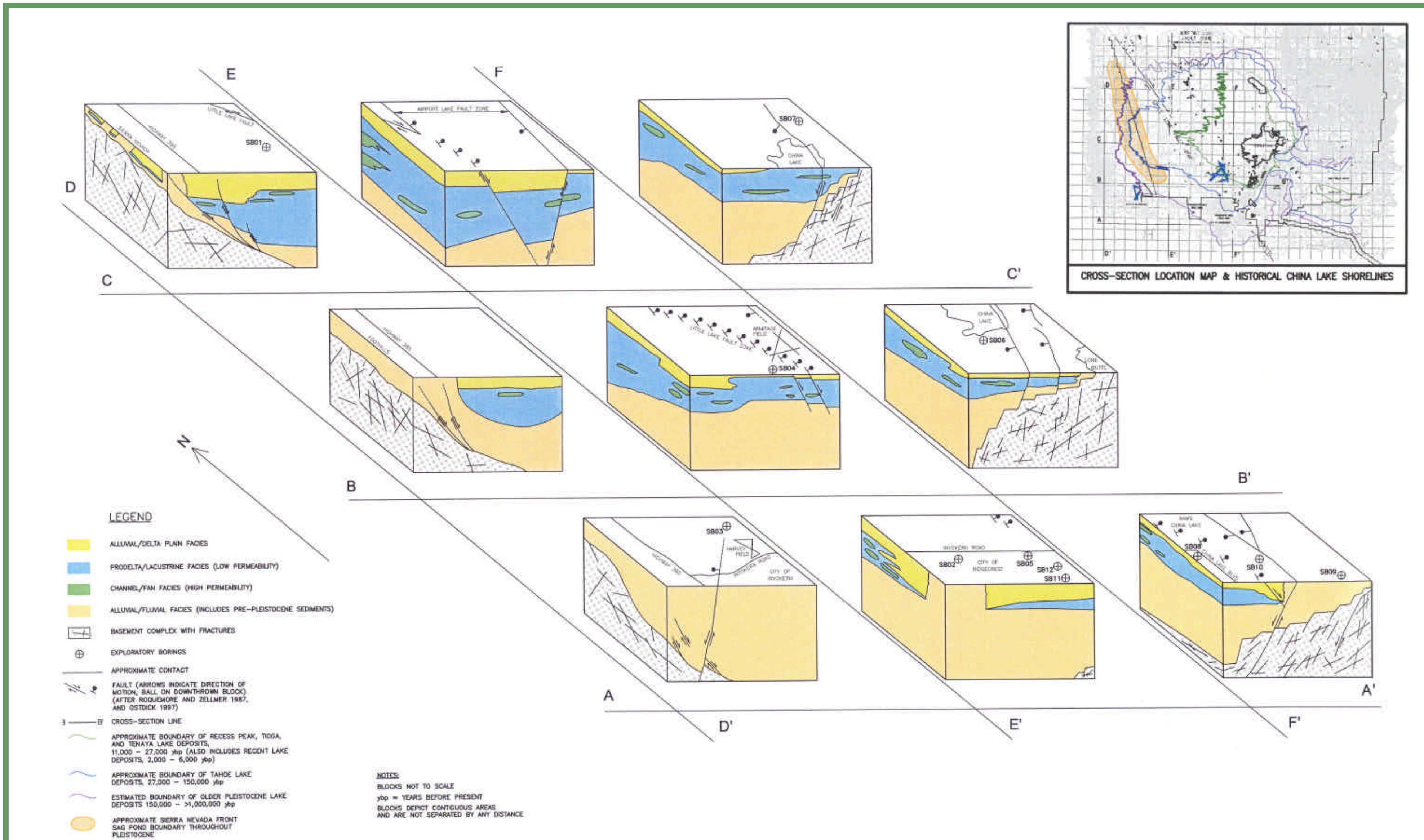
CASE STUDY	CHINA LAKE - CONCEPTUAL ENVIRONMENTAL MODEL	FIGURE 6



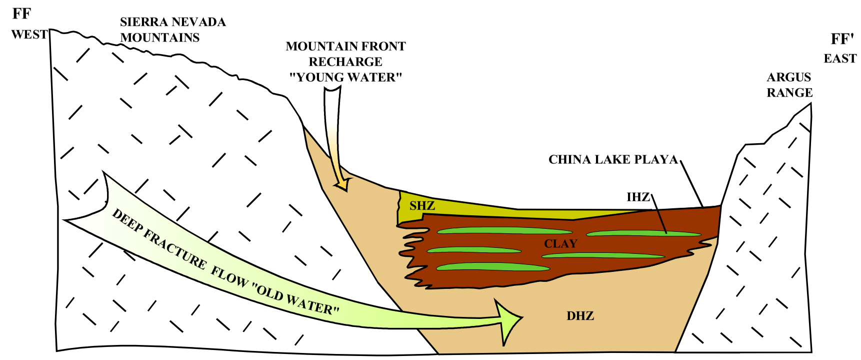
SOURCE: Figure based on geologic descriptions by Kunkel and Chase (1969)

CONCEPTUALIZATION OF DEPOSITIONAL ENVIRONMENTS IN THE INDIAN WELLS VALLEY NAWS CHINA LAKE, CALIFORNIA

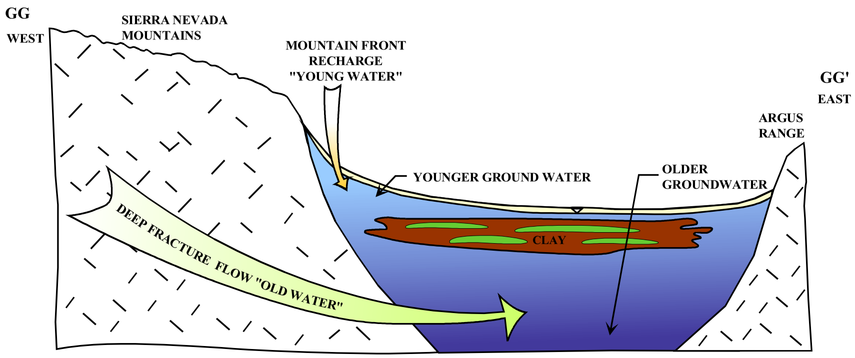
CASE STUDY | **CHINA LAKE - CONCEPTUAL MODEL OF DEPOSITIONAL ENVIRONMENTS** | **FIGURE 7**



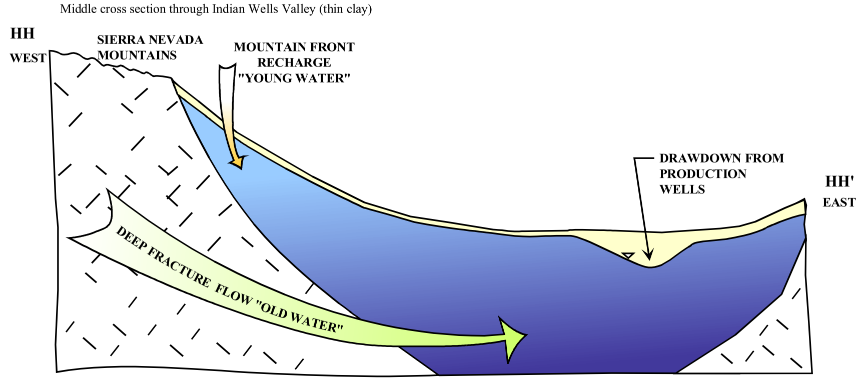
CASE STUDY	CHINA LAKE - CONCEPTUAL BLOCK DIAGRAM OF INDIAN WELLS VALLEY	FIGURE 8



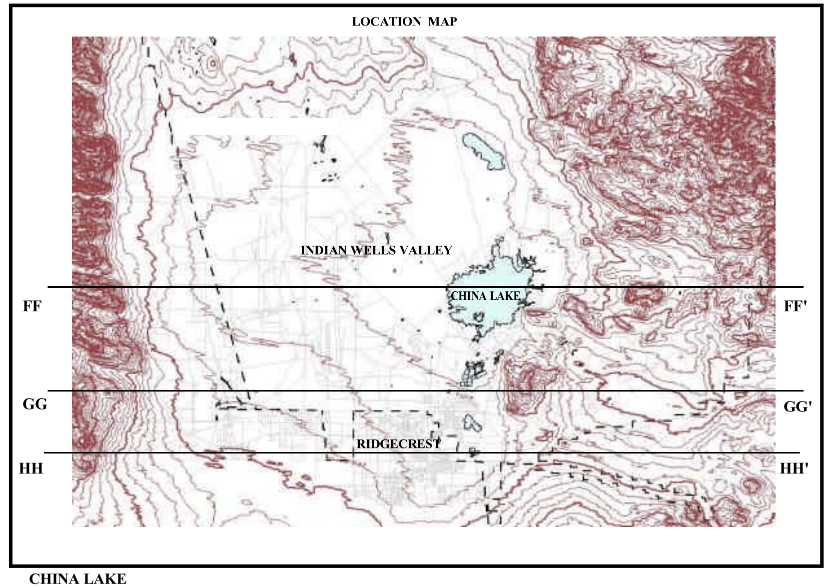
Northern cross section through Indian Wells Valley (thick clay)



Middle cross section through Indian Wells Valley (thin clay)



Southern cross section through Indian Wells Valley (absence of clay)



NOT TO SCALE

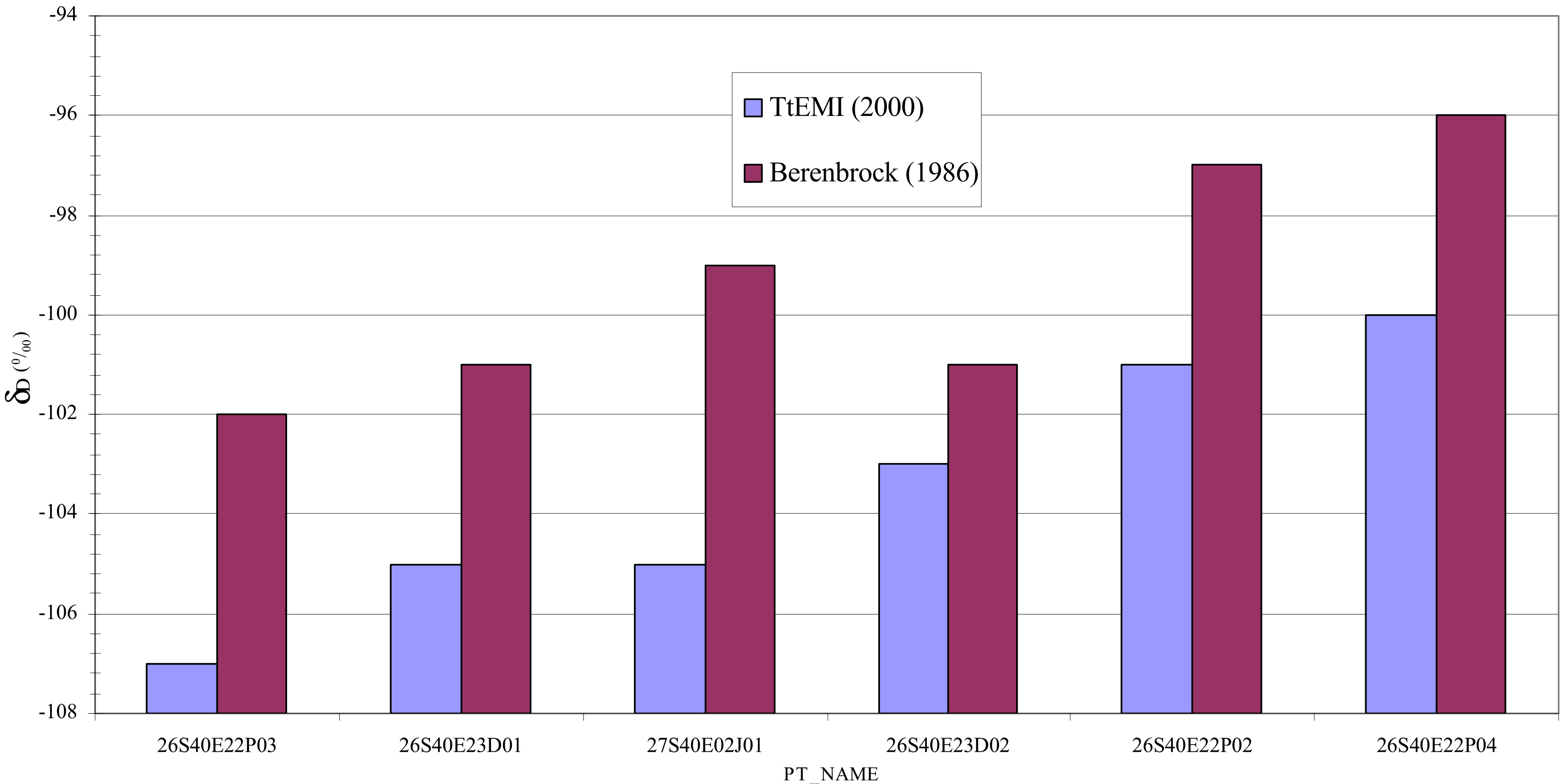
LEGEND FOR FF-FF'

- ALLUVIAL/DELTA PLAIN FACIES SHALLOW HYDROGEOLOGIC ZONE (SHZ)
- PRODELTA/LACUSTRINE FACIES (LOW PERMEABILITY)
- CHANNEL/FAN FACIES (HIGH PERMEABILITY) INTERMEDIATE HYDROGEOLOGIC ZONE (IHZ)
- ALLUVIAL/FLUVIAL FACIES (HIGH PERMEABILITY) DEEP HYDROGEOLOGIC ZONE (DHZ)
- BASEMENT COMPLEX WITH FRACTURES (ALL DIAGRAMS)
- FF FF' CROSS-SECTION LINE

LEGEND FOR GG-GG' AND HH-HH'

- YOUNG GROUNDWATER
- OLD GROUNDWATER
- GROUNDWATER SURFACE
- UNSATURATED ZONE

CASE STUDY | **CHINA LAKE - WATER FLOW CONCEPTUAL MODEL** | **FIGURE 9**



CHINA LAKE FIGURE 11
δD VALUES FROM BERENBROCK (1986)
VERSUS δD VALUES FROM TTEMI (2000)
NAWS CHINA LAKE, CALIFORNIA

CASE STUDY | **CHINA LAKE - BERENBROCK FIGURE** | **FIGURE 10**