A Middle Pleistocene Lacustrine Delta Lobe in the Kern River Alluvial Fan and its Close Association with Groundwater Arsenic Concentrations:
One Outcome of USDA-CREES Grant #2001-01170

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Introduction

USDA-CREES Grant "2001-01170 was awarded to the Department of Geology at CSU Bakersfield in the Fall of 2001 for a project entitled "Fundamental Processes Governing the Aquifer Characteristics of the Kern Water Bank: Implications for other Alluvial Fan-type Aquifers in Agricultural Regions with Arid to Semi-Arid Climates." The subject of this project is the Kern Water Bank, a ~ 40 square-mile groundwater storage and management facility on the Kern River Alluvial Fan with a capacity of ~1,000,000 acre-ft (Figure 1). The principal goals of the project included the following:

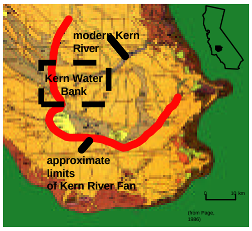


Figure 1. Location of Kern Water Bank, Kern River Alluvial fan and other localities discussed in text:

Project Goals

I. 3-D computer-based mapping of the sedimentary layers containing the aquifers of the Kern Water Bank (KWB), an optimal case study.

II. Development of depositional models from results of Goal #1.

III. Refinement of depositional models to allow for prediction of aquifer characteristic (e.g., water quality, permeability, etc.).

Why map sedimentary layers?

Sedimentology ultimately is main control on hydraulic conductivity, effective storage capacity, and groundwater quality.

Why bother with depositional models?

Depositional models allow one to predict stratigraphy into unknown areas (e.g., beyond the limits of the study area or between far-spaced wells). They also foster associated models regarding water quality. See 2nd page of this presentation for example of how a depositional model led to a better understanding of groundwater quality.

I.1 Defining Mapping Units

Sedimentary units were defined in 162 wells by electrical resistivity from electric logs in these wells which reflects grain-size/clay content (Figure 2).

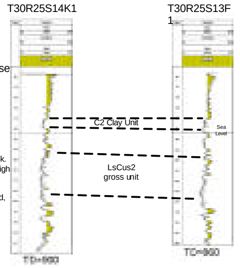


Figure 2. Sample electric logs from two wells ~one-half mile apart in the Kern Water Bank. Higher resistivity generally indicates coarser grains and/or less clay content (Figure 3). High resistivity units were identified as sand intervals, low resistivity as silts/clays (e.g., "C2" shown above). Gross units were also defined. The gross units consisted of systematic packages of individual units (e.g., the coarsening upward sequence shown). Once defined, tops and bottoms of units were picked on the electric log yielding two sets of x, y, z, data for each unit.

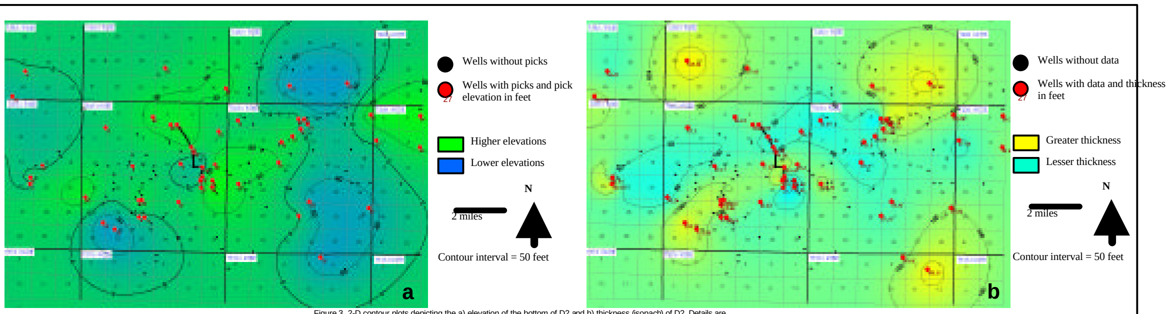


Figure 3. 2-D contour plots depicting the a) elevation of the bottom of D2 and b) thickness (isopach) of D2. Details are discussed in text on the left.

I.2 Mapping Results: 2-D Contour Plots of Sedimentary Units

Each mapped sedimentary unit contains two sets of *x*, *y*, *z* data. The *x* and *y* values are the same for both sets; they define the map location of all of the wells in which the unit was found. The *z* data in one case is elevation of the bottom of the unit; in the other case it's that of the top of the unit. ***For every unit each set of location and depth data can be represented on a map wherein colors represent a range of elevation values.*** For example, Figure 3a shows the elevation of the bottom of the D2 unit (see Figure 2 for definition of unit names). This map is commonly referred to as a *structure* map on the bottom of the unit. Figure 3b shows the thickness *(aka isopach)* of unit D2. A set of such maps plus structure maps on the tops of the units were constructed for all mapped units using Geographix™ geological interpretation software from Landmark, Inc.

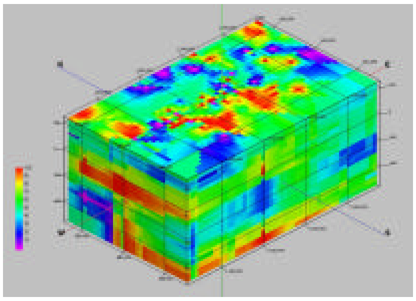


Figure 4. 3-D block diagram showing distribution of sands and silts/clays throughout the Kern Water Bank down to a depth of ~800-900 ft below ground surface. Details are discussed in text on the left.

I.3 Mapping Results: 3-D Block Diagram of Sedimentary Units

The positions and thicknesses of all sedimentary units can be shown in one 3-D diagram (Figure 4). In this case each unit at each location was given an arbitrary number corresponding to unit type (silts/clay=1; sands=100). This 3-D distribution of 1's and 100's was then interpolated throughout the rectangular prism representing the Kern Water Bank and the resultant values assigned colors within a ten-unit range. This model was constructed in the RockWorks™ geological interpretation software from RockWare, Inc.

II.1 Depositional Models for the Kern Water Bank Sediments

The sediments of the Kern Water Bank have been deposited over the past million years or so by an alluvial fan-delta system built by the Kern River (Figure 1). In such cases, stacked packages of sediments characterized by coarsening-upward grain-sizes are common. If the packages are predominantly fine-grained (e.g., silts and clays) they likely were deposited at the distal end of the alluvial fan as part of a prograding delta into a terminal lake. If they are coarse-grained (e.g., gravels and sands), then they were likely deposited near the top of the fan close to where the river emerges onto the valley floor (e.g., Prothero and Schwab, 2004).

II.2 A Prograding Delta Depositional Model for the “LsCus2” Unit

One of the “gross” units (Figure 2) mapped in this project is a sequence of coarsening-upward units that thickens toward the southwest of the study area (Figure 5). This is the second-highest-elevation coarsening-upward unit found in the Kern Water Bank, hence, its name “LsCus2” (**L**arge-**s**cale **C**oarsening-**u**pward **s**equence **2**). For reasons discussed in the previous paragraph, ***we propose that this unit was deposited several hundreds of thousands of years ago as a delta built basinward starting at the then-distal end of the Kern River Alluvial Fan (Figure 6).***

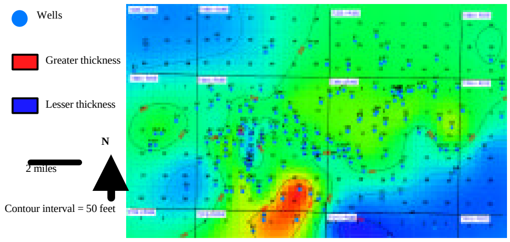
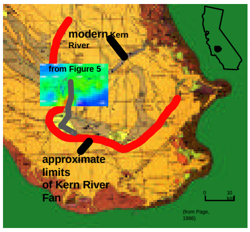


Figure 5. Contour plot showing thickness (isopach) of LsCus2 prograding delta deposit.



(from Page, 1986)

Figure 6. Contour plot of thickness of LsCus2 prograding delta deposit superimposed on map of Kern River alluvial-fan system. LsCus2 thickens toward terminal Buena Vista Lake at the toe of the alluvial fan. This spatial relationship supports the interpretation of a lacustrine environment of deposition for the LsCus2 sediments.

II.3 Testing the Prograding Delta Depositional Model: Stepping Out from the Water Bank

If the LsCus2 unit was deposited in a prograding delta, then it should be related spatially to a sequence of sediments deposited in a terminal lake. This is indeed the case as shown in Figure 7 where the LsCus2 was bulit upon a lacustrine clay deposit that is likely correlative to the “Corcoran Clay”, a clay layer found throughout most of the Central Valley that was deposited in an enormous lake (Figure 8) 800,000-650,000 years ago (Sarna-Wojcicki, 1995; Harden, 2004; Negrini et al., 2004).

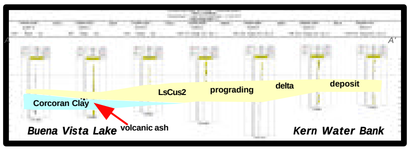


Figure 7. Cross-section showing stratigraphic relationship between LsCus2 deltaic deposit (yellow) and “Corcoran Clay” (blue), a unit deposited in a Central Valley-wide lake several hundreds of thousands of years ago. Profile line for this cross-section (A-A’) is shown in Figure 6.

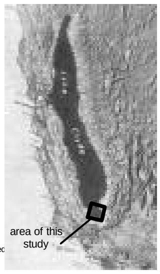
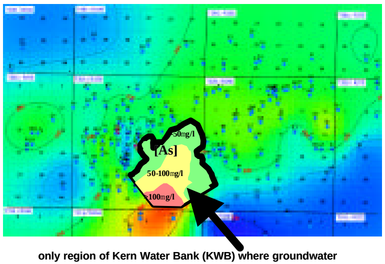


Figure 8. “Lake Clyde,” the lake in which the Corcoran Clay (and LsCus2?) were deposited (from Harden, 2004).

II.4 Spatial Association of the LsCus2 Unit with Elevated Groundwater As

The LsCus2 Unit is closely associated, both in map view (Figure 9) and with respect to depth (Figure 10) with the only occurrence of elevated groundwater As in the Kern Water Bank.

Figure 9. The only region of elevated groundwater As concentrations in the Kern Water Bank superimposed on the LsCus2 map from Figure 5.



only region of Kern Water Bank (KWB) where groundwater arsenic concentrations [As] are >5 mg/L
(note: in general, quality of KWB water is exceptionally high)

III.1 Incorporating Elevated Groundwater As into the LsCus2 Depositional Model

Deltaic sediments, as opposed to those deposited in stream channels farther up alluvial fans, are deposited under the surface of a lake and, as a result, are likely to undergo reducing rather than oxidizing geochemical conditions. Such a scenario is supported by higher total organic carbon (TOC) and lower magnetic susceptibility (MS) in the LsCus2 interval as shown in Figure 10. Under reducing conditions organic matter is commonly preserved and, also, a series of chemical reactions take place that reduces minerals and ionic species that start out in the oxidized state. These reactions progressively destroy Mn-oxide minerals, Fe-oxide minerals, and then sulfates (e.g., Cohen, 2003; and Evans and Heller, 2003; and references therein). ***If the reducing geochemical conditions are extreme enough and if sulfate is present, sulfate reduction occurs resulting in the formation of pyrite. Arsenic substitutes for sulfur in pyrite. Thus pyrite, if it is present, can serve as an arsenic reservoir. A later change to oxidizing geochemical conditions can potentially dissolve the pyrite and release the arsenic into the groundwater.***

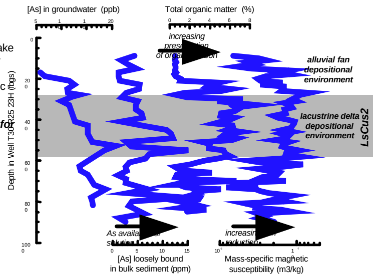


Figure 10. Geochemical data from Well T30R25S23H. Depth range of LsCus2 prograding delta unit is represented by shaded region. a) Concentration of arsenic in groundwater. b) Concentration of easily exchangeable arsenic in sediment grab samples. c) Percentage of total organic carbon in sediment grab samples. d) Mass-specific magnetic susceptibility (MS) of grab samples. Elevated groundwater and sediment arsenic are found at base of LsCus2. The high values of total organic carbon found with the LsCus2 unit are indicative of the anoxic, reducing geochemical conditions common to lacustrine rather than alluvial fan depositional environments. Extremely low values of MS within LsCus2 suggest that the iron reduction phase of the LsCus2 reducing environment eliminated the available iron-oxides and that the geochemical environment likely progressed to the sulfate reduction phase depending on the availability of sulfur.

III.2 Testing the LsCus2 Depositional Model: Groundwater Arsenic

The previous paragraph outlines a model for high groundwater arsenic in association with the LsCus2 prograding delta deposit. This model predicts that 1) pyrite is present in the LsCus2 deposit, 2) pyrite exhibits dissolution textures, and 3) pyrite has concentrations of As high enough to produce the groundwater arsenic concentrations found in association with the LsCus2 deposit. ***As shown in Figure 11, model predictions 1) and 2) are consistent with observations.***

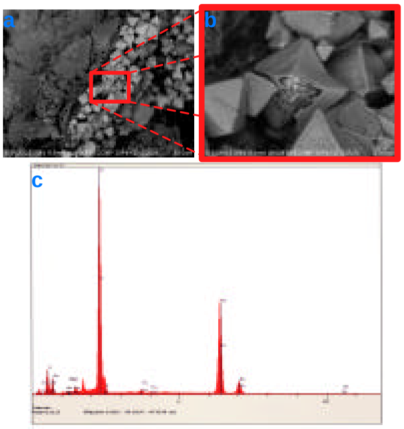


Figure 11. a) SEM photograph of pyrite crystals in clay matrix from the LsCus2 deposit. Sample is from a depth of 550 ft in Well T30R25S23H. b) Closeup view of a pyrite crystal from 11a) exhibiting dissolution. b) Energy dispersive x-ray spectrum indicating that the Fe and S contents are consistent with pyrite.

Future Work

Preparations are under way to measure the arsenic concentration in the pyrite shown in Figure 11 with the microprobe facilities at UC Davis. We are also inspecting additional samples from other units in Well 23H and from another well which has low groundwater arsenic concentrations.

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