DR2004038

Data Repository Item: J. Saleeby and Z. Foster, Topographic Response to Mantle Lithosphere Removal in the Southern Sierra Nevada Region, California

STRUCTURE CONTOUR AND ISOPACH DATA

Seismic reflection data along lines presented in Bloch (1991) and Miller (1999), and which cross Tulare Lake, show that the Tulare Lake basin began forming by ~ 2.2 Ma. Early accounts of the morphology of this basin by structure contour and isopach map construction focused on the Corcoran Clay (an ash bed) which lies in the upper levels of the basin stratigraphy, and which has been dated at 0.615 Ma (Sarna-Wojcicki et al., 1985). Davis and Green (1962), and Page (1986) used drill hole log and core data to contour the surface of the Corcoran Clay, while Frink and Kues (1954), and Croft (1972)used similar data to both contour its upper surface and to construct an isopach map for its total thickness. These data show that at 0.615 Ma the Tulare Lake basin formed a semicircular embayment protruding eastwards ~40 km from the regional NNW-trending depositional trough pattern that typifies the rest of the Great Valley. These data also show a topographic closure to the sub-basin of >300 ft (~100 m) relative to the rest of the Great Valley trough demonstrating the uniqueness of the basin and its greatly accelerated relative subsidence rate. The published structure contour and isopach maps also show sharp changes in slope values and sharp bends in their trends suggesting the presence of unmapped faults. We found such contour patterns suspicious for a broad lacustrine environment, and thus acquired additional well log data (California Division of Oil and Gas) to supplement those used in the published works.

Our new, but preliminary structure contour map for the Corcoran Clay was presented as part of a poster at the 2003 Seattle Geological Society of America meeting (Foster and Saleeby, 2003). This preliminary map is provided here as part of our supplementary data (Fig. DR1). In addition to addressing the complex contour patterns that were published in the original maps that are referenced above, our preliminary map also takes into account; 1. Omissions in section seen in the drill hole log data indicative of normal faulting; 2. Faults that are imaged cutting through the underlying Neogene section in seismic reflection lines presented in Bloch (1991) and Miller (1999); extension of such faults into the shallowest Plio-Pleistocene part of the record section are difficult to resolve solely by the reflection data due to poor shallow-level data quality; and 3. Clusters of low to intermediate magnitude shallow seismicity that occur in the basin (Caltech Seismological Laboratory Catalogue Data). The map that we present here is preliminary because we are in the process of obtaining and processing additional industry seismic data in order to better constrain the three-dimensional geometry of the basin, and to backstrip tectonic subsidence rates for the entire Plio-Pleistocene history of the basin. Our ongoing work also suggests that the basin began forming at ~3.4 Ma in a position that is partially offset to the northeast of its 2.2 Ma to Holocene position, and that maximum subsidence rates were obtained for the entire ~3.4 m.y. history of the basin between 0.9 Ma and 0.6 Ma.

FLEXURAL MODELING OF CRUSTAL RESPONSE TO MANTLE DRIP LOAD

Topographic subsidence affecting the western Sierra Nevada region between 35° and 36°N, and the adjacent Tulare Lake basin is modeled as simple flexure of an elastic plate using the procedures of Angevine et al.(1990), and McQuarrie and Rodgers (1998). Our synthesis of published and unpublished drill hole log data, which are discussed above, and the shallow seismic reflection data of Bloch (1991) show a well-constrained subsidence of ~1200 m in the center and ~1000 m over a broad sector of the eastern part of the basin in post 2.2 Ma sediments. Additional subsidence signals starting at ~3.4 Ma are under current investigation in conjunction with backstripping for tectonic subsidence signals, as are subsidence patterns between the Tulare Lake area and the buried topography of the adjacent western Sierra. It is important to emphasize that the Tulare Lake basin is superimposed over the strongly asymmetric regional subsidence and basement tilting pattern of the Great Valley which produces a much more slowly subsiding linear basin axis strongly offset towards the western margin of the Great Valley (Lettis and Unruh, 1992). This superpositioning pattern renders the westward offset of Tulare Lake, relative to the center of the surface projection of the mantle drip as is evident on Figure 1a of the main article.

Application of the above referenced flexural modeling techniques strictly using the topology and density contrasts for the mantle drip published in Ruppert et al. (1998) and Zandt (2003) yields subsidence values that are an order of magnitude greater than the observed signal. This is consistent with ongoing work on the processing and interpretation of new migrated receiver function data from a dense passive seismic network deployed over the drip structure (G. Zandt, H. Gilbert, T. Owens, M. Ducea, and J. Saleeby, work and manuscript in progress). These data show that the lower crust is behaving viscously, and that in a position that roughly corresponds to the thickened crust above the drip (Fig. 2, main article) a large conical shaped lens of lower crust is being entrained 10's of km into the mantle drip. Ongoing forward dynamic models (M. Gurnis and J. Saleeby) predict a similar pattern of lower crustal entrainment. Thus the crust is not behaving as a rigid plate that is flexing in response to the drip load. We have thus iterated on some of the essential input variables in order to produce the approximate subsidence pattern observed for post-2.2 Ma sediments. These variables include the density contrast between the drip and the adjacent asthenosphere, and the vertical dimension of the drip. A possible rationale for decreasing these values in order to yield a reasonable fit could include: 1. The new seismic data referenced above indicating that a substantial mass of crustal rock is entrained in at least the upper part of the drip, 2. As indicated by the mid-Miocene xenolith data, the lithospheric source for the high-density drip contained a nontrivial amount of mantle wedge peridotite that was interlayered with the eclogitic residue sequence (Ducea and Saleeby, 1998; Saleeby et al., 2003); and 3.

Zandt (2003) has presented an argument that the drip has very recently detached from the residual crust resulting in their partial decoupling. We would argue, however, that the

most likely explanation for the inability of the flexural modeling to more precisely fit the data is that the lower crust is behaving viscously.

The flexural model variables are tabulated below. The load is modeled as a rectangular half space using the equations given below:

$$W\,(0<x<L) = [(\rho_L hL)/2(\rho_a-\rho_s)][2-(\exp-((L+x)/\alpha)(\cos((x+L)/\alpha)] -[(\exp((-L-x)/\alpha)(\cos((L-x)/\alpha)]$$

$$W\,(x>L) = [(\rho_L hL)/2(\rho_a-\rho_s)]\,[(\exp((-L-x)/\alpha)(\cos((L-x)/\alpha)] - [(\exp((-L+x)/\alpha)(\cos((L+x)/\alpha)]$$

$$\alpha = (Xo-L)/[\cos^{-1}(\exp(-2L/\alpha)(\cos(Xo+L/\alpha)]$$

$$D = (\alpha^4(\rho_{lc}-\rho_s)g/4)$$

Flexural modeling works under the following assumptions: (1) A portion of the lithosphere, or residual crust in this application, can be modeled as an elastic solid. (2) Vertical deflections are assumed to be small compared with the horizontal dimensions of the plate. (3) The elastic lithosphere, or residual crust, is assumed to be thin compared to the horizontal dimensions of the plate. (4) Planar sections within the plate are assumed to remain planar after deflection. (5) The load is modeled as a mid-lithosphere rectangular load. The following variables produced the best match to the observed subsidence data.

Variables used in flexure equations

Symbol	Name	Value
α	flexural parameter	6.4 (determined)
Xo	half width of the basin	60 km
L	half width of the load	50 km
hL	height of load	60 km (adjusted from data)
Wo	amount of subsidence	fit to ~ 1000m
ρ_s	density of the basin fill	2.0 g/ cm^3
ρ_a	density of the asthenosphere	3.25 g/cm^3 (with melt inclusions)
ρ_L	density difference of load	0.05g/cm^3 (adjusted from data)
υ	Poisson's ratio	0.25
E	Young's modulus	7×10^{10} N/m^2

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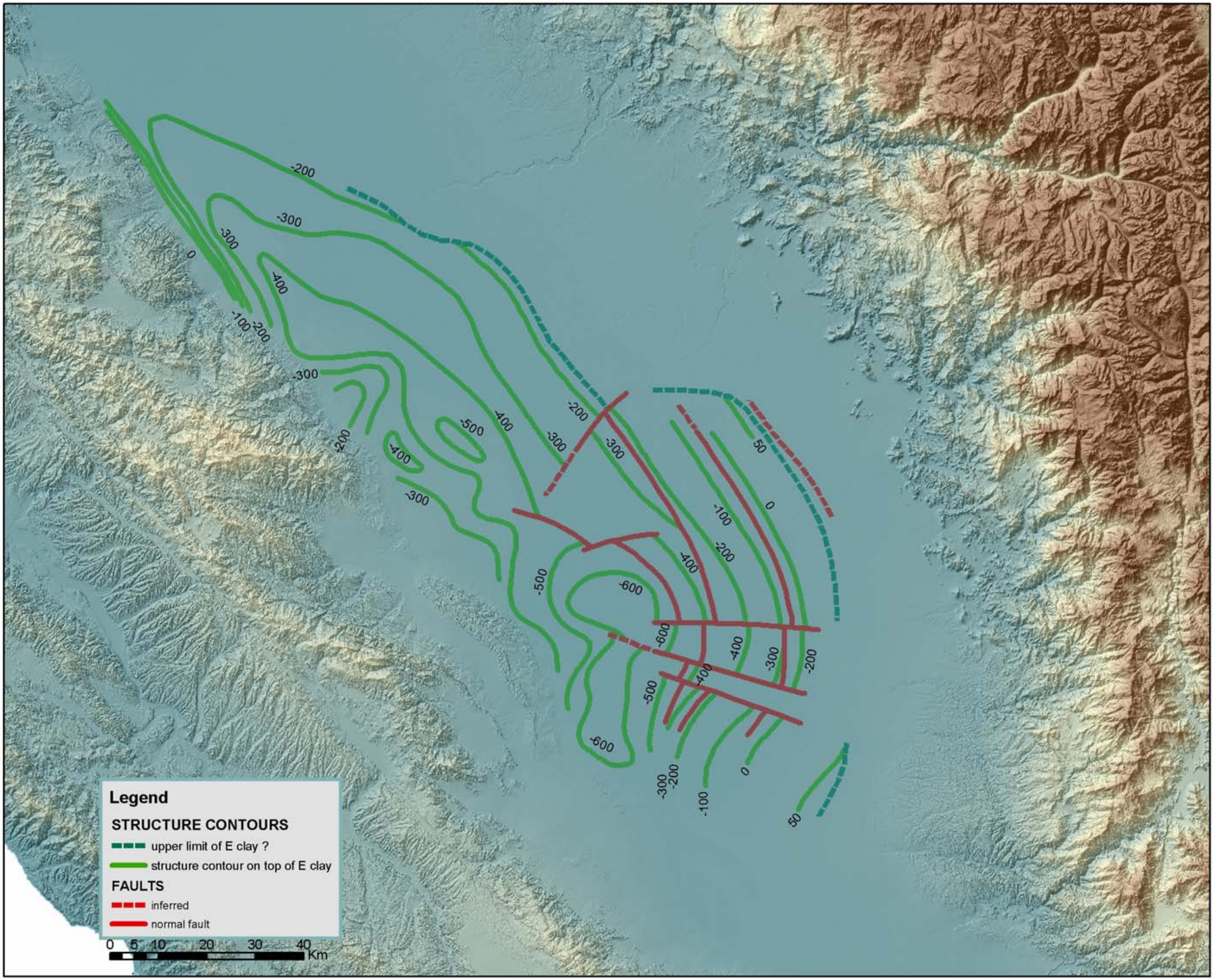
FIGURE DR1 CAPTION: Structure contour map for top of 0.615 Ma Corcoran Clay ("e clay") drawn at 100 ft contour interval based on drill hole log data from Frink and Kues (1954), Davis and Green (1962), Croft (1972), Page (1989) and additional data obtained from California Division of Oil and Gas. Faults are interpreted from sharp changes in slope values, sharp bends in mechanically derived contours, and from missing sections in logs. Some faults are further confirmed deeper in section from seismic reflection data published in Bloch (1991).


Legend
STRUCTURE CONTOURS
upper limit of E clay ?
structure contour on top of E clay
FAULTS
inferred
normal fault
0 5 10 20 30 40 Km