APPENDIX A: Magnetotelluric Data in Relation to San Pedro Mesa Structural High

The San Pedro Mesa structural high (discussed in main text of paper) was originally interpreted to be rooted Precambrian basement on the basis of magnetotelluric (MT) data collected at the Precambrian outcrop (located on Fig. 2) on the mesa surface. Those data show resistive material extending from the surface to great depth (> 5 km), interpreted to represent Precambrian rocks that are not over- or underlain by sediments. A gravity high at the same location supports the interpretation of a narrow horst composed of Precambrian rocks (Fig. 13). The MT profile presented in the main text of the paper (Fig. 12) is located several kilometers to the south. A local two-dimensional MT model (Fig. A1) is presented here to show evidence for the Precambrian rocks on the surface being rooted at depth. This two-dimensional model was derived by inverting only the transverse magnetic-mode observed response because the observed data at each MT station indicated a three-dimensional electromagnetic response (Rodriguez and Williams, 2007; Williams and Rodriguez, 2007). This model is only meant to show geologic relationships in a qualitative sense, as precise thicknesses of conductors have not been tested. Neither has the model been tested against the gravity model, but was computed completely independent of any a priori information.

An electrical resistor, consistent with Precambrian rocks, extends from the Precambrian outcrop on the surface downward, with no intervening conductors that would indicate the presence of sediments. This structural high separates conductive sediments underlying the Costilla Plains from those underlying the Sanchez graben. As stated in the main text, this interpretation was explicitly built into the three-dimensional
gravity model as a constraint, forcing the Precambrian outcrop at the surface to be modeled as rooted at depth.

References

Figure A1: MT sounding locations and qualitative model in vicinity of San Pedro Mesa structural high. A, Location of MT stations (red triangles) in relation to San Pedro Mesa and surrounding physiographic features. Note location of outcropping Precambrian rocks near station 119. B, Two-dimensional finite-difference inversion resistivity profile model with geologic interpretation.
Figure A2A: Resistivity data for model shown in Fig. A1. Observed (TE-black circle, TM-black cross) and calculated (TM-orange cross) magnetotelluric (MT) apparent resistivity sounding curves at stations for two dimensional finite difference inversion resistivity profile model (Fig. A1). MT station number label is the number appearing in the upper right corner of each individual plot. Horizontal axis is log frequency where lower frequencies (left) correspond to greater depths and higher frequencies (right) to shallower depths. Vertical axis is log apparent resistivity in ohm m.
Figure A2B: Phase data for model in Fig. A1. Observed (TE-black circle, TM-black cross) and calculated (TM-orange cross) magnetotelluric (MT) apparent resistivity sounding curves at stations for two dimensional finite difference inversion resistivity profile model (Fig. A1). MT station number label is the number appearing in the upper right corner of each individual plot. Horizontal axis is log frequency where lower frequencies (left) correspond to greater depths and higher frequencies (right) to shallower depths. Vertical axis is degrees.
APPENDIX B: Magnetotelluric Data, Processing, and Modeling

Acquisition of magnetotelluric (MT) data involves recording of the natural electric and magnetic fields in two orthogonal, horizontal directions (the vertical magnetic field is also recorded). The resulting time-series signals are used to derive Earth-tensor apparent resistivities and phases after first converting them to complex cross-spectra using fast Fourier transform (FFT) techniques and least-squares, cross-spectral analysis (Bendat and Piersol, 1971) to solve for a tensor transfer function. Apparent resistivity is the approximate ratio of the electric-field strength to the magnetic-field strength at a given frequency. The impedance phase is proportional to the slope of the apparent resistivity curve on a log-log plot, but from baselines at ±45 degrees (Vozoff, 1991). If one assumes that the Earth consists of a two-input, two-output, linear system in which the orthogonal magnetic fields are input and the orthogonal electric fields are output, then the calculated function relates the observed electric fields to the magnetic fields. Before it is converted to apparent resistivity and phase, the tensor is normally rotated into principal directions that usually correspond with the direction of maximum and minimum apparent resistivity. For a two-dimensional Earth, the MT fields can be decoupled into transverse electric and transverse magnetic modes.

Two-dimensional (2-D) resistivity modeling is generally computed to fit both modes. When the geology satisfies the two-dimensional assumption, the MT data for the transverse electric mode is assumed to represent the electric field along geologic strike, and the data for the transverse magnetic mode is assumed to represent the electric field across strike. The MT method is well suited for studying complicated geological environments because the electric and magnetic relations are sensitive to vertical and
horizontal variations in resistivity. The method is capable of establishing whether the
electromagnetic fields are responding to subsurface rock bodies of effectively one, two,
or three dimensions.

Thirteen MT soundings (Rodriguez and Williams, 2007; Williams and Rodriguez, 2007) along an east-west profile (B-B', Fig. 3) were acquired in 2006 and 2007 in the survey area. Horizontal electric fields were sensed using copper-sulfate electrodes placed in an L-shaped, three-electrode array with dipole lengths of 30 m. The orthogonal, horizontal magnetic fields in the direction of the electric-field measurement array were sensed using induction coils. Frequencies sampled ranged from about 0.01 to 100 Hz by use of single-station recordings of both orthogonal horizontal components of the electric and magnetic fields and of the vertical magnetic field. Sampling these frequencies in the San Luis basin region allowed us to probe the subsurface from depths of tens of meters to tens of kilometers (Rodriguez and Williams, 2007; Williams and Rodriguez, 2007).

The recorded time-series data were transformed to the frequency domain using Fourier analysis and processed to determine the impedance tensor, which was used to derive apparent resistivities and phases at each site. The MT “Tipper” is calculated from both horizontal components and the vertical component of the magnetic field. The observed data were rotated to match Tipper strike directions (Fig. B1) so that propagation modes for the signals were decoupled into transverse electric (TE) and transverse magnetic (TM) modes. We also sorted cross-power files to select optimal signal-to-noise data sets. Figure B2 shows observed data values of the transverse electric and transverse magnetic modes from the MT soundings (Rodriguez and Williams, 2007; Williams and Rodriguez, 2007).
The MT data were initially modeled through inverting the data by a 2-D inversion of the TM mode data using a finite-difference resistivity algorithm called RLM2DI (Mackie and others, 1997; Rodi and Mackie, 2001). This was followed by the application of a 2-D finite-element resistivity algorithm called PW2D (Wannamaker et al., 1985). The results of the RLM2DI resistivity inversion were used as the initial input model for the forward resistivity modeling using PW2D, where conductive structures derived from the inversion results were tested for their minimum and maximum thicknesses. The 2-D forward resistivity model is constructed by adjusting the resistivity values beneath the profile of MT stations, so that for all stations the calculated 2-D response agrees with the measured data that is one- or two-dimensional. MT profile B-B’ (Fig. 3) trends east-west. MT station offsets from profile A-A’ range from 0.5 to 10 km south except for MT station 1, which is offset about 1 km north. The finite-element grid used in this model consisted of 105 by 63 variable dimension cells that extend over 800 km horizontally beyond the profile end points and 300 km vertically to minimize edge effects. In the finer part of the mesh, the horizontal element size was between 0.3 to 1 km. The vertical element size ranged from 10 m near the surface to 1 km below 5 km depth. We forward-modeled the two-dimensional models (Fig. 12), attempting to fit the calculated response primarily to the transverse magnetic-mode observed response (Wannamaker et al., 1984), because the observed data at each MT station indicated a three-dimensional electromagnetic response (Rodriguez and Williams, 2007; Williams and Rodriguez, 2007). The calculated fits of the two-dimensional resistivity models are shown in Fig. B2.


Figure B1: Magnetotelluric strike data of profile B-B’ (Fig. 3). Sounding number is in upper right corner. ZRot (green circle symbol) is forced rotation of magnetotelluric data, Z Strike (orange triangle) is impedance strike data, and Tip Strike (pink diamond) is Tipper strike data determined from three-dimensional measurement of magnetic field (Rodriguez and Williams, 2007; Williams and Rodriguez, 2007). Horizontal axis is log frequency. Vertical axis is degrees.
Figure B2A: Resistivity data for model shown in Fig. 12a. Observed (TE-black circle, TM-black cross) and calculated (TE-green circle, TM-orange cross) magnetotelluric apparent resistivity sounding curves at all stations for two dimensional finite element resistivity profile models (Fig. 12). Magnetotelluric station number label is the two digit number appearing in the upper right corner of each individual plot. Horizontal axis is log frequency where lower frequencies (left) correspond to greater depths and higher frequencies (right) to shallower depths. Black vertical lines on observed data are RMS error estimates. Vertical axis is log apparent resistivity in ohm m.
Figure B2B: Phase data for model in Fig. 12a. Observed (TE-black circle, TM-black cross) and calculated (TE-green circle, TM-orange cross) magnetotelluric apparent resistivity sounding curves at all stations for two dimensional finite element resistivity profile models (Fig. 12). Magnetotelluric station number label is the two digit number appearing in the upper right corner of each individual plot. Horizontal axis is log frequency where lower frequencies (left) correspond to greater depths and higher frequencies (right) to shallower depths. Black vertical lines on observed data are RMS error estimates. Vertical axis is degrees.
Figure B2C: Resistivity data for model shown in Fig. 12b. Observed (TE-black circle, TM-black cross) and calculated (TE-green circle, TM-orange cross) magnetotelluric apparent resistivity sounding curves at all stations for two dimensional finite element resistivity profile models (Fig. 12). Magnetotelluric station number label is the two digit number appearing in the upper right corner of each individual plot. Horizontal axis is log frequency where lower frequencies (left) correspond to greater depths and higher frequencies (right) to shallower depths. Black vertical lines on observed data are RMS error estimates. Vertical axis is log apparent resistivity in ohm m.
Figure B2D: Phase data for model in Fig. 12b. Observed (TE-black circle, TM-black cross) and calculated (TE-green circle, TM-orange cross) magnetotelluric apparent resistivity sounding curves at all stations for two dimensional finite element resistivity profile models (Fig. 12). Magnetotelluric station number label is the two digit number appearing in the upper right corner of each individual plot. Horizontal axis is log frequency where lower frequencies (left) correspond to greater depths and higher frequencies (right) to shallower depths. Black vertical lines on observed data are RMS error estimates. Vertical axis is degrees.