In Search of Pre-Andean Depocentres – Integrated Geophysical Study in Peru and Bolivia*

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Abstract

The Andean foreland basin formed throughout the Cenozoic in a retro-arc setting in front of the advancing orogen. A 2,500-km-long segment of this basin system passes through eastern Perú and Bolivia and is comprised of, from north to south, the Marañon, Ucayali, Madre de Dios, Beni and Chaco Basins.

The Andean foreland basin contains substantially thick units of Cenozoic sediments, which overlie Mesozoic and Paleozoic successions and Precambrian crystalline basement. In the deeper parts of the foreland basin, no wells have penetrated the full, pre-Andean sedimentary section and the sheer thickness of the sediments makes it difficult to seismically image crystalline basement in some areas. Thus, the thickness of the pre-Andean sediments and the existence of basins that pre-date the Andean Orogeny are partly obscured.

Areally extensive gravity and magnetic data sets have been used to build a structural and tectonic framework for the area. Gravity and magnetic 2D forward modelling and 3D inverse gravity modelling, constrained by seismic interpretation and well data, enabled base Cretaceous and top crystalline basement horizons to be derived. This approach allowed lateral extrapolation of the detailed but localised seismic interpretation into areas without seismic coverage and it also extended this interpretation by including the depth to top crystalline basement.

The results of this analysis indicate the presence of large pre-Cretaceous depocentres underlying the Andean foreland basin. These include a major depocentre extending from the central Marañon Basin north-northeastwards across the Iquitos Arch, two depocentres underlying the Madre de Dios Basin and four depocentres beneath the Beni/Chaco basins.

2D Forward Modelling

Two-dimensional gravity and magnetic modelling was performed using GM-SYS^{TM} (Geosoft Inc.). The aim of the 2D modelling was to test and refine the structural interpretation and to investigate the depth to base Cretaceous and top crystalline basement, and hence the pre-Cretaceous sedimentary thickness. By adequately defining the depths to these two horizons, the 2D modelling results could be used as constraints for the 3D gravity inversions that followed. The sedimentary section was divided into two main units: Cenozoic/Cretaceous sediments and pre-Cretaceous sediments. This means that this study only resolves pre-Andean depocentres of Jurassic age and older. An analysis of almost 20 well density logs in the Marañon, Ucayali and Madre de Dios basins indicate that, while there was some variability, there are no obvious, large-scale density steps within the tested Cenozoic and Cretaceous sediments. Therefore, it was deemed sensible to model these sediments as a single layer with a density equal to the average density seen in the wells (2.33 g/cc). Density logs indicate a clear density increase in the pre-Cretaceous sediments to an average density of 2.56 g/cc.

Five 2D models were constructed for the study area. Where possible these models were constrained by well and seismic data and followed the best available gravity and magnetic data. Figure 1 shows the results from one of the 2D models across the Marañon Basin. A number of basement grabens and a half-graben have been modelled between 170 and 480 km along the profile (Figure 1). These structures show some correlation with upper Paleozoic features seen in the seismic interpretation, and they presumably formed as a result of pre-Cretaceous extensional tectonics (Sempere et al., 2002; Spikings et al., 2016). North of 480 km along the profile, the basement starts to shallow, and consequently we see a thinning of the pre-Cretaceous section. A positive gravity anomaly at 600 km along the profile is generated by a basement structural high where pre-Cretaceous sediments are absent or at least very thin. This structure has been identified as the Iquitos Arch (Roddaz et al., 2005; Wesselingh et al., 2006; Barragan et al., 2008; Hermoza et al., 2009;) and is thought to represent the Andean forebulge in this area. A gravity low between 610 and 675 km along the profile is presented here as being due to the presence of a small, pre-Cretaceous basin with a maximum basement depth of around 6.5 km.

3D Gravity Inversions

Three-dimensional gravity inversions were performed using a modified version of the iterative technique of Cordell and Henderson (1968). Here, the subsurface is represented as an array of vertical rectangular prisms, and their gravity effect is calculated at the surface; the mismatch between the observed gravity anomaly and the modelled gravity anomaly is used to iterate the model. Separate inversions, constrained by outcrop data and by well, seismic, and 2D model depths were performed to produce base Cretaceous and top crystalline depth surfaces for the foreland areas of Perú and Bolivia. The difference between these two surfaces indicates the thickness of pre-Cretaceous sediments (Figure 2).

Although thick, localised accumulations of pre-Cretaceous sediments can be seen beneath the foreland basin of Perú and Bolivia, the thickest sediments are to be found in the central Marañon Basin of Perú and in parts of the Beni and Chaco basins of Bolivia. A number of basement arches appear to separate these pre-Cretaceous depocentres. A number of less well-known depocentres have been revealed by the gravity inversion. These include the small basins seen to the northeast of the Marañon Basin and Iquitos Arch in northeast Perú, and a possible north-eastward continuation of the Madre de Dios Basin towards the Bolivia/Brazil border.

Discussion

The thickest accumulations of pre-Cretaceous sediments follow the NW–SE to N–S trend of the Andean front, being located directly east or northeast of it (Figure 2). Therefore, the Paleozoic and Mesozoic subsidence pattern in Peru and Bolivia must have been controlled, besides by basement heterogeneity, by tectonic processes related to the South American active plate margin. Thus, the pre-Cretaceous subsidence pattern observed replicates to a large extent the geometry of this long-lasting plate boundary and the strike of the present-day Andean Belt.

The significant thickness of pre-Cretaceous sediments (Figure 2) and their stratigraphic inventory (McGroder et al., 2015) suggest that the development of the pre-Andean basins was a long-lasting process that spanned the entire Phanerozoic. By implication, the present-day size of the pre-Cretaceous basins in the study area does not necessarily correspond to their original extent. Some basement arches (e.g., the Iquitos Arch) were formed in a Neogene forebulge setting (Roddaz et al., 2005; Wesselingh et al., 2006; Barragan et al., 2008; Hermoza et al., 2009), whereas others (e.g., the Fitzcarrald Arch) may have originated because of latest Paleozoic contractional events (House et al., 2000). In both cases, they did not exert any control on pre-Permian depositional systems.

Our data confirm a possible extension of thick Upper Paleozoic sedimentary successions, hosting the most important source rocks in southern Peru and Bolivia, into central and northern Peru. We can speculate that the extensive Mesozoic overburden in this area, which is primarily comprised of a thick Cretaceous succession, might have partly deteriorated the Paleozoic petroleum systems.

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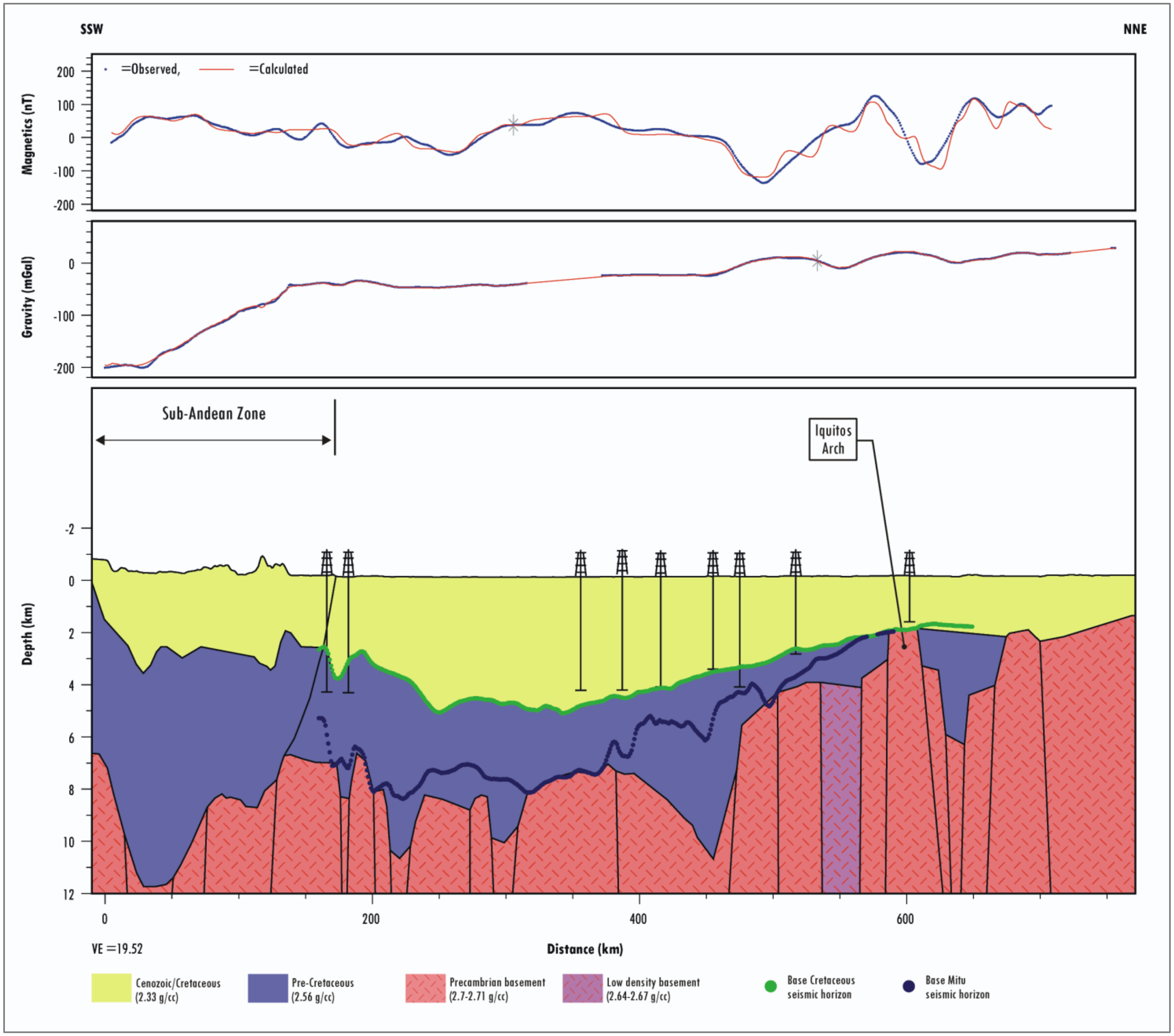

Figure 1. Marañon 2D model. Observed and calculated magnetic and gravity profiles are shown above the best fit 2D model. This model has good constraint from seismic and well data. The thickest pre-Cretaceous sediments may be located within the Sub-Andean Zone. A number of large pre-Cretaceous depocentres can be observed within the centre of the basin and another can be seen to the north of the Iquitos Arch.

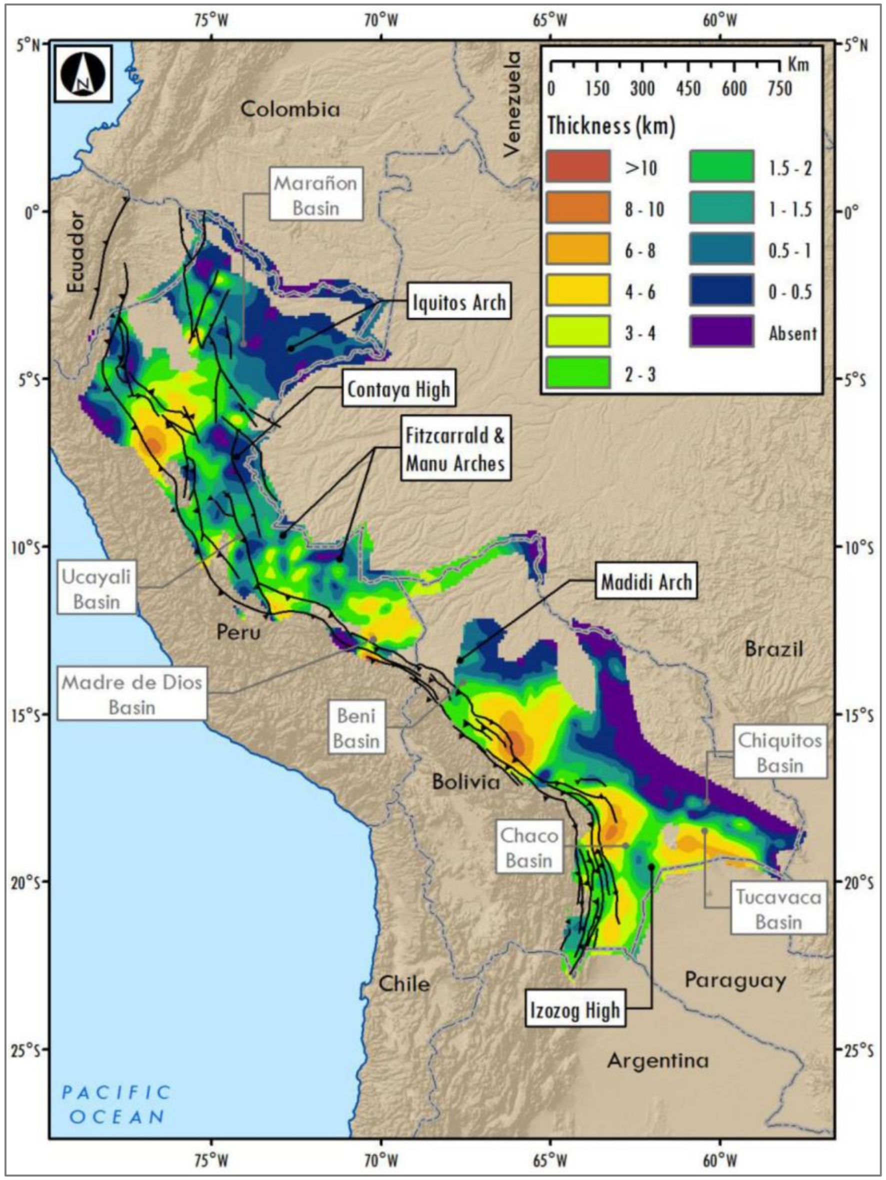

Figure 2. Pre-Cretaceous sedimentary thickness. The locations of the principal structural elements are after Mathalone and Montoya (1995), Isaacson and Díaz Martínez (1995),and McGroder et al. (2015).