Influence of Paleozoic Arches on Structural Style and Stratigraphy in the Madre de Dios Basin in Southern Peru and Northern Bolivia

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SUMMARY

This paper addresses the impact that transcontinental uplifts (cross-basinal arches) have had on the extent, stratigraphic development, and structural styles of the Madre de Dios Basin of southern Peru and northern Bolivia. The Madre de Dios Basin is located on the eastern side of the Andes and is separated from the Ucayali basin to the northwest by the recently identified Manu Arch, and, further to west, by the previously described Fitzcarrald Arch. To the south and east the Madre de Dios Basin is bounded by the Madidi Arch, which trends west-northwest along the current edge of the Andean fold and thrust belt from northern Bolivia into southern Peru (Figure 1).

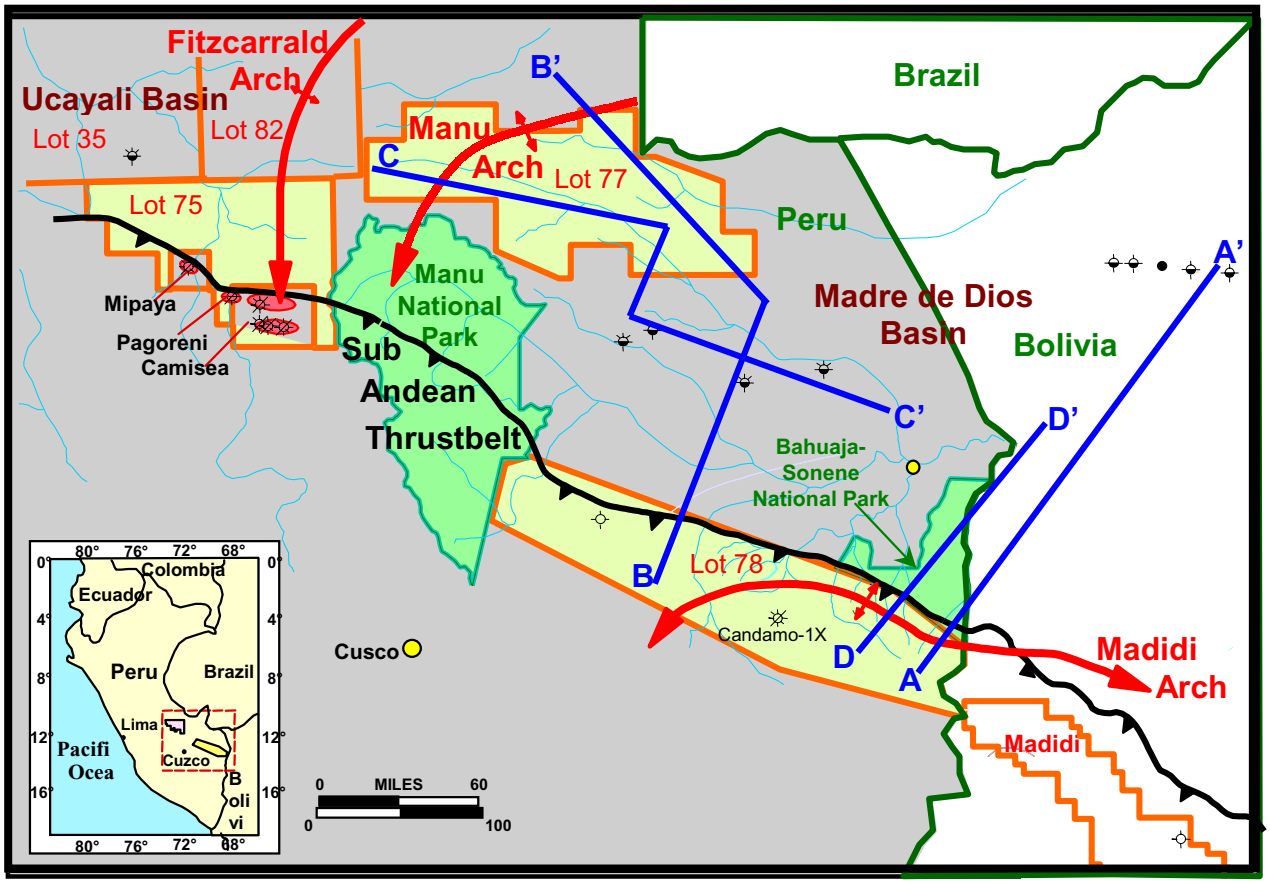

Figure 1. Major tectonic elements of the Madre de Dios basin in Peru and Bolivia. The Madidi, Manu and Fitzcarrald arches are highlighted in red.

Influence of Paleozoic Arches on Structural Style and Stratigraphy

The **Fitzcarrald Arch**, located on the western margin of the Madre de Dios Basin, was initially identified by drainage patterns on areal photography and Landsat images. The arch is a drainage divide that separates the tributaries to the Urubamba River to the northwest and the Madre de Dios River to the southeast. Oil companies came to regard the Fitzcarrald arch as a major fault zone and uplifted area trending north-northeast from the Camisea structures in the southern Ucayali Basin through the middle of block 82 (Phillips). The Fitzcarrald Arch exhibits thinning relations in Upper Permian formations that suggests it developed in the Late Paleozoic. However, it also exhibits present day seismicity that suggests it is being partially reactivated along old structural weaknesses.

The **Manu Arch** was recently identified on seismic data recorded by Mobil Oil and partners in the former Lot 77 area. It extends southwest from the Brazilian shield curving southwards into Manu National Park.

The **Madidi Arch** extends from northern Bolivia westwards into the Madre de Dios foldbelt of southern Peru where it has been further delineated by recent seismic data and surface geologic studies associated with evaluation of Lot 78.

THE MADIDI ARCH

In studies evaluating the hydrocarbon potential of the Madre de Dios basin in Peru, a series of regional late Permian to late Cretaceous Age unconformities were identified. The regional late Permian subcrop map below (Figure 2) illustrates the basin wide subcrop relationships that expose continuously older Paleozoic sediments nearer the center of the axes of arches surrounding the basin. Both the Manu and Madidi arches have been completely stripped of Paleozoic sediments, exposing crystalline basement rocks along their axes during the late Permian to late Cretaceous period. The subcrop relationships along the Manu and Madidi arches are easily recognized as angular unconformities on seismic data recorded in the 1970's and more recently in 1996-97. (Figures 3-7: Cross-sections A-A', B-B', C-C', and D-D').

The Madidi Arch is interpreted as the southern-eastern boundary of the Madre de Dios Basin trending westwards from northern Bolivia towards the Andean foothills in southeastern Peru. The arch appears to be late Permian in age based on seismic data which highlight stratigraphic truncation of pre-Permian sediments and thinning of late Permian followed by downlap of Jurassic to late Cretaceous age sediments. The angular nature of this unconformity is easily recognizable on seismic as shown cross-section A-A' (Figure 3).

The Madidi arch has been denuded down to crystalline basement during the late Permian period near the frontal Tambopata fault in southern Peru. The removal of deeper Paleozoic sedimentary horizons by erosion near the axis of the Madidi Arch, coupled with a local buttress formed by the arch itself, forced the decollement level of the major thrusts in the southern half of the Madre de Dios foldbelt to climb up-section to the base of the Tertiary. This is shown in cross-section D-D', demonstrating localization of frontal Tambopata Thrust along denuded Madidi Arch (Figure 4). In this area the structural style is expressed as a triangle zone whose location is controlled by the Madidi Arch to the east where no Paleozoic sediments are preserved and the high Andes to the west where younger foreland vergent thrusts have overridden the structures created by the buttressing effects of the Madidi Arch as seen in cross-section A-A" and D-D' (Figures 3 and 4).

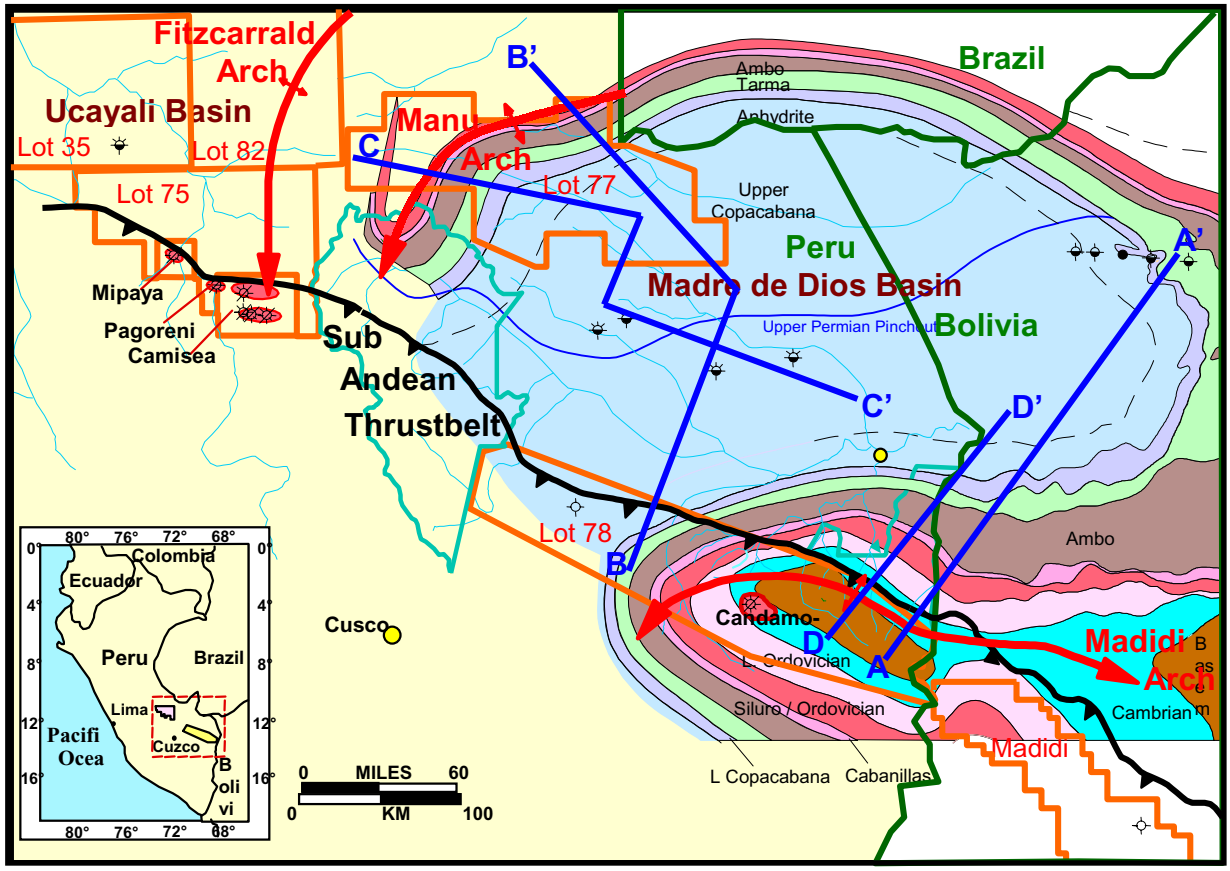

Figure 2. Regional Sub-crop map below late Permian unconformity, Madre de Dios basin, Peru and Bolivia. Four regional seismic cross-sections are highlighted in blue (A-A', B-B', C-C' and D-D').

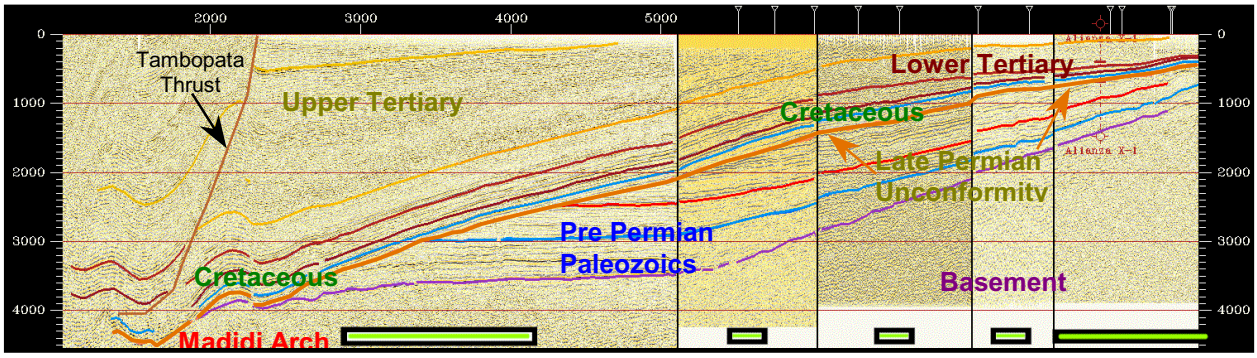

Figure 3. Regional seismic cross-section A-A' illustrating location of Madidi Arch relative to the frontal edge of the sub-Andean fold and thrust belt (Tambopata thrust fault).

NOTE: In this and all other seismic cross-sections found in this monograph, the length of the pale green bar at the bottom of each seismic section is equivalent to 25 km. These cross-sections are composites of various different data sets and, due to size limitations, it was not possible to fit all sections in at the same scale.

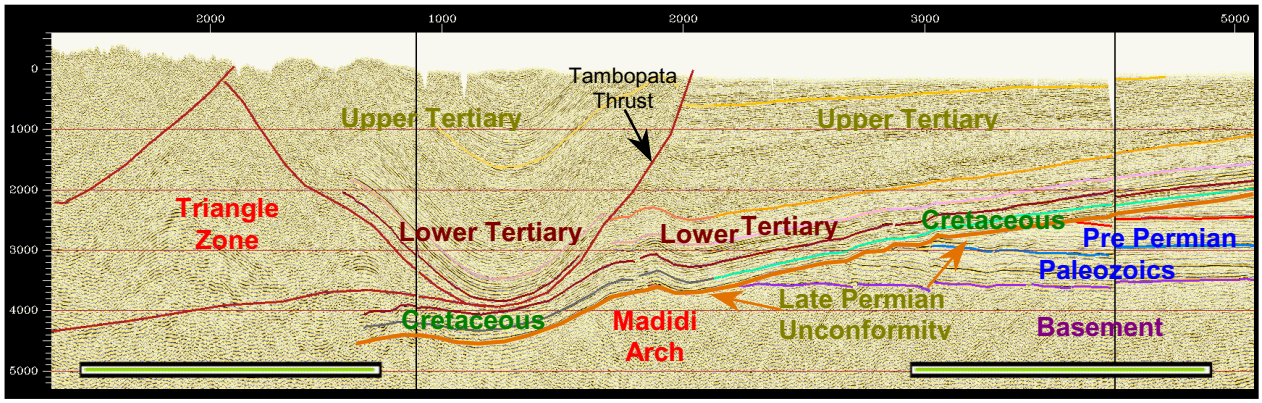

Figure 4. Regional seismic cross-section D-D', illustrating the localization of the frontal Tambopata thrust above denuded Madidi Arch..

Approximately in the center of Lot 78, the Madidi Arch changes direction, trending nearly due west into the Andes. Northwest of this area significantly more of the Paleozoic section is preserved beneath the Permian unconformity as seen in cross-section B-B' (Figure 5). A smaller more compact triangle zone with more numerous, yet smaller, structures characterizes this portion of the foldbelt. Here the Paleozoic sediments provide a greater number of glide planes for thrust fault occurrences.

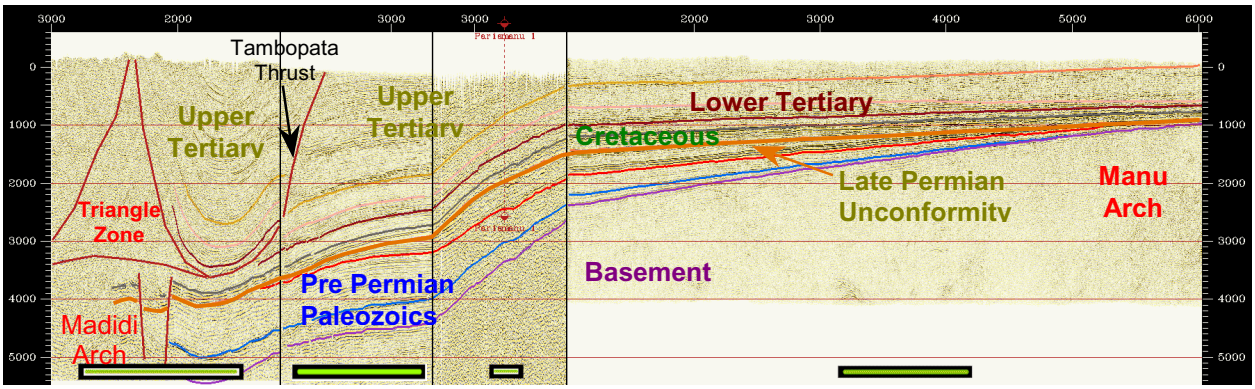

Figure 5. Regional seismic cross-section B-B' illustrating Andean foldbelt zone west of the Madidi Arch showing preserved Paleozoic section.

While lower Tertiary units are relatively uniform in thickness throughout the basin, thickening slightly towards the current basin axis, the upper Tertiary units are thickest near the Madidi arch axis, and thin gradually to the foreland. The upper Tertiary sediments can be interpreted as syn-tectonic, commencing deposition at the onset of the Andean orogeny.

Thus, the Madidi Arch has controlled the location and structural style of the compressional structures of the sub-Andean foldbelt in the Madre de Dios Basin in southern Peru.

THE MANU ARCH

Early indications of the Manu Arch were present on Bouguer gravity and magnetic maps in the foreland portion of the Madre de Dios basin. Wide Aperture Reflection and Refraction Profiling (WARRP) data, recorded in 1994 to determine gross structural features of the basin, also indicated that the sedimentary section thinned towards the northwest.

The seismic data recorded in Lot 77 in 1996 shows the Permian unconformity cutting down to crystalline basement in the northern most portion of the lot in the direction of the Brazilian Shield. Cross-section C-C' (Figure 6) is a regional composite

seismic line illustrating the regional late Permian unconformity as it cuts through Paleozoic units down to the crystalline basement of the Manu Arch in the northwest portion of Lot 77.

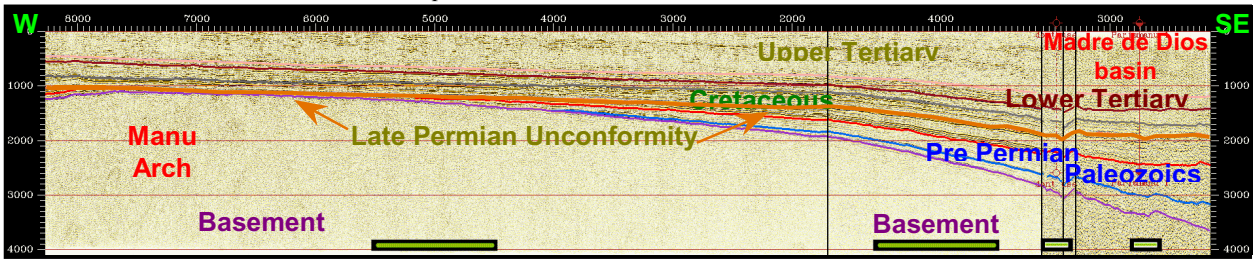

Figure 6. Regional seismic cross-section C-C' illustrating Manu Arch and the western limit of the Madre de Dios basin.

The foreland portion of the Madre de Dios basin is characterized by a gentle dip from the Manu arch to the south and east. Nevertheless, the presence of the late Permian unconformity is easily recognized by the angular truncation of pre-late Permian, Paleozoic units down to crystalline basement near the axis of the arch to the north and west as seen in the regional seismic cross-section above. The late Permian through late Cretaceous thin gradually toward the Manu Arch and beyond northwards. Further to the west, this portion of the sedimentary section begins to thicken gradually towards the Ucayali basin.

CONCLUSION

Data recently acquired indicate that both the Madidi and Manu arches were uplifted beginning in the late Permian as evidenced by erosional truncation of Paleozoic units from crystalline basement through Permian carbonates along a regional unconformity. Both of the arches have controlled the lateral extent of the current Madre de Dios basin and late Tertiary deposition and burial. The Madidi Arch and Manu Arch have controlled the location and development of different structural styles in the sub-Andean foldbelt and foreland portions of the Madre de Dios basin in Peru.

Most of the hydrocarbon source rocks in the Madre de Dios Basin are Paleozoic in age, and there is some evidence that the Permian age Madidi and Manu arches controlled the deposition of late Permian source rocks. The presence, burial depth, and preservation of these source rocks below the Permian unconformity and the depth of burial in the Tertiary foreland basin control the extent of hydrocarbon generation as well as migration pathways. Improvements in the understating of major cross-basinal arches are critical to future hydrocarbon exploration in the Madre de Dios Basin in Peru.

ACKNOWLEDGEMENTS

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