Reducing the risk: Integrating gravity, magnetic, and seismic data in Papua New Guinea

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In early 1992 a combined seismic and gravity survey was conducted in Petroleum Prospecting License (PPL) 123 on the central coast of the Gulf of Papua, Papua New Guinea, to delineate existing structural leads where Mesozoic sandstones were expected to be well developed. One lead, the Veiru structure, was originally observed on surface geological mapping as a large anticline located near the edge of an outcropping limestone plateau.

As part of the 1992 seismic survey, several lines were recorded over the Veiru feature. Local surface conditions consist of rugged karst limestone which typically is a poor seismic data environment. T91-18 was the first seismic line recorded over the structure and surprisingly good data quality was achieved. However, despite the better-than-expected data, the interpretation of the subsurface structure and faulting remained ambiguous; two significantly different but valid seismic interpretations were possible (Figure 2). The Veiru feature is bounded to the north and south by two major west-northwest-trending faults, but the correlation across the northernmost fault was inadequate to determine the direction of throw with a high degree of confidence.

Interpretation A suggested the fault throw was up to the north, which would indicate that the Veiru structure is a fault-bounded anticline formed during two major tectonic episodes. The major normal faulting occurred during early Tertiary extension and would have been followed by an extensive period of limestone deposition. Flexure and development of four-way dip closure would likely have taken place during a period of compressional tectonics in the Pliocene.

In interpretation B, the throw of the northern fault is down to the north. This interpretation describes the Veiru feature as a large pop-up anticline formed during the Pliocene compression, possibly as part of a major wrench-restraining bend. Interpretation B is supported to some degree by a Bouguer gravity map (Figure 1) which has a gravity high approximately centered on the Veiru structure and also by the possible flower structure evident in the shallow limestone section. Additionally, the general surface expression of the exposed limestone anticline also demonstrates that a localized area of uplift is associated with the feature.

Determining the structural configuration of the Veiru feature was important because the associated faulting significantly influenced the prospectivity of the feature — the

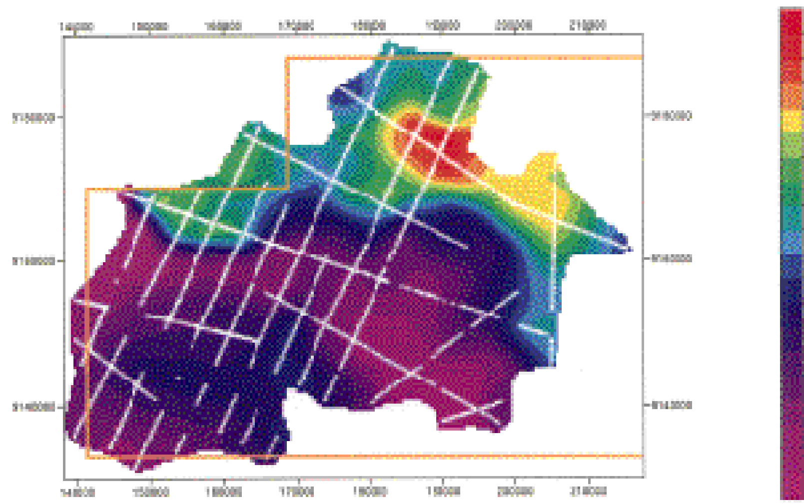

Figure 1. Bouguer gravity and Kairi survey station location map.

Table 1. Estimated density values for the model shown in Figure 2.

Layer	Geologic Age	Lithology	Density Range gm/cm³	Initial Model Density Estimate	Final Model Density Value
1	Pliocene	Clastics-Siltstones and Shales	1.90-2.20	2.00	2.05
2	Miocene	Carbonate-Porous Platform Limestone (Darai)	2.20-2.40	2.30	2.30
3	Miocene	Carbonate-Deepwater Argillaceous Limestone (Puri)	2.50-2.70	2.65	2.55
4	Mesozoic	Clastics-Siltstones and Shales	2.00-2.40	2.30	2.25
5	Triassic Basement	Volcaniclastics Metamorphic and Rock	?	2.60	2.60

faulted anticlinal dome of interpretation B being the more prospective scenario.

Surface topography. As can be seen in Figure 2, the exposed limestone reaches an elevation of 100 m on line T91-18 over the Veiru structure (up to 160 m off-line on the crest). The effect of this surface topography was modeled for various limestone densities to determine if it was possible to attribute the gravity anomaly in this region solely (or primarily) to the outcropping limestone. The effect of topography was found to be relatively insignificant. The surface relief may be expressing the structural deformation at depth, but the relief itself is only a minor component of the total gravity anomaly.

Several density values were modeled with similar results; i.e., only high-frequency effects in the gravity can be subdued with alterations in the near-surface densities. This leads to the conclusion that the broader and higher amplitude features must be caused by structure at greater depth and larger areal extent than the outcrop relief.

Gravity modeling. In a gross sense the subsurface stratigraphy can be divided into five major lithological units: (1) a shallow layer of relatively low-density Pliocene-age clastics (siltstones and shales); (2) platform (Darai) limestone of middle Miocene age; (3) higher-density deepwater argillaceous (Puri) limestone; (4) Mesozoic clastics, all underlain by (5) Triassic-age metamorphic basement rock (Figure 3).

Depths and thickness estimates were calculated along line T91-18 every 100 to 400 shotpoints, depending on geological complexity, to provide sufficient time-to-depth control. Density data were obtained by studying 19 wells within and adjacent to the license area. These results, summarized in Table 1, provided the initial unbiased input parameters for the first-pass models (Figure 4).

Model A provided a reasonably good initial match between the observed or field-measured gravity measurements and the modeled gravity profile, except at the south end of the line. Model B also had a similarly poor match at the southern end of the line but, more significantly, did not match as well as model A at the north end over the Veiru structure where the two interpretations

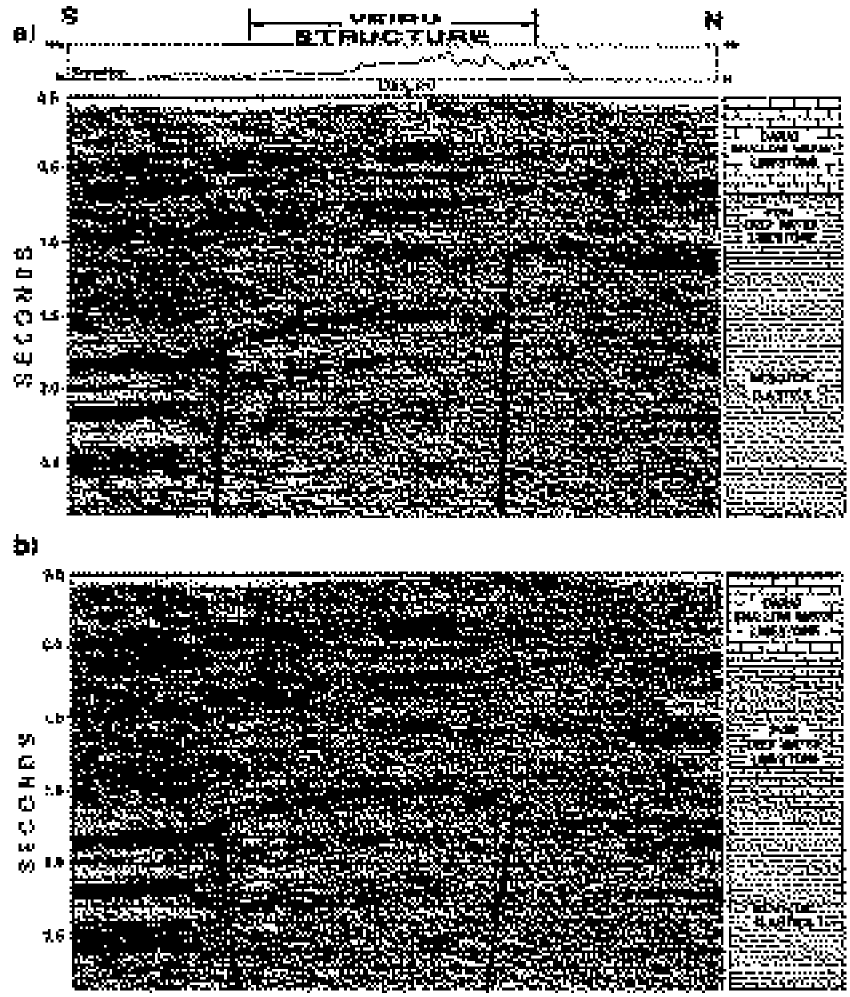

Figure 2. Portion of seismic line T91-18 with (a) Interpretation A superimposed and (b) Interpretation B superimposed. Note surface topography reflecting rugged karst limestone outcrop.

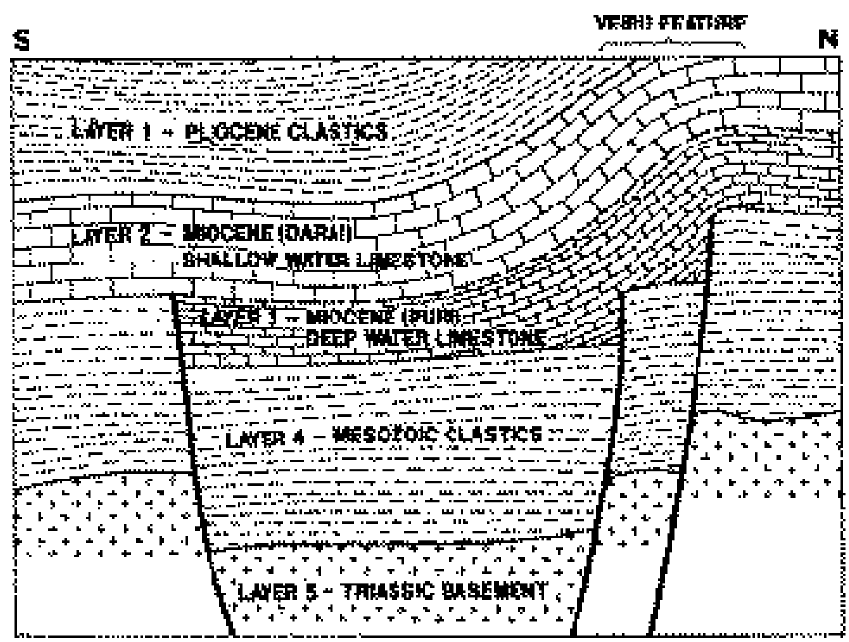

Figure 3. Cross-section of layer-cake geological model along line T91-18 (Interpretation A).

differ structurally. The divergence of observed and modeled gravity at the south end of both models was interpreted to be due to an oversimplification of the input structural parameters. The effect of the high-density Puri limestone was initially underestimated, and the southern extent of this deep-water limestone had been limited to simplify the model. Extending the Puri limestone farther to the south over the top of the horst block, as interpreted on seismic data, provided an improved match between observed and modeled gravity profiles over this portion of the line.

Similarly, over the Veiru feature, the high-density Puri limestone was acknowledged as having a more significant effect on the gravity profile than the deeper basement structure.

Several models were produced iteratively to improve the match for both interpretations. In the case of interpretation B, this required significant alterations to basement. A deeper high-density basement structure, not visible on seismic, had to be introduced.

What was most convincing about the validity of Model A was that a good character match was achieved using the initial unbiased parameters (i.e., using a best-guess structural and density model without thought to the outcome).

Magnetic modeling. Although a magnetic survey was not acquired as part of the Kairi survey, regional magnetic data were available and could be interpolated along the strike of line T91-18. The calculated magnetics from Model A provided a good match with no structural edits. However, the calculated magnetics from Model B were quite different from the observed. The magnetic anomaly coincident with the Model A Veiru structure has a range of about 40 nT, suggesting a suprabasement origin (relief on basement) as opposed to an intrabasement origin (large change in basement susceptibility). The magnetics supported Model A(i.e., large basement normal faulting as opposed to an uplifted anticlinal structure in Model B).

Gravity modeling revisited. The proof of any experimental result is in the ability to reapply the same input parameters to another data set and come up with similar conclusions. In this manner the final derived density values from Models A and B on line T91-18 were applied to different structural interpretations of line T91-03 along the strike of the Veiru structure. The main fault bounding the north side of the Veiru feature also intersects the west end of line T91-03, providing another test of interpretations A and B.

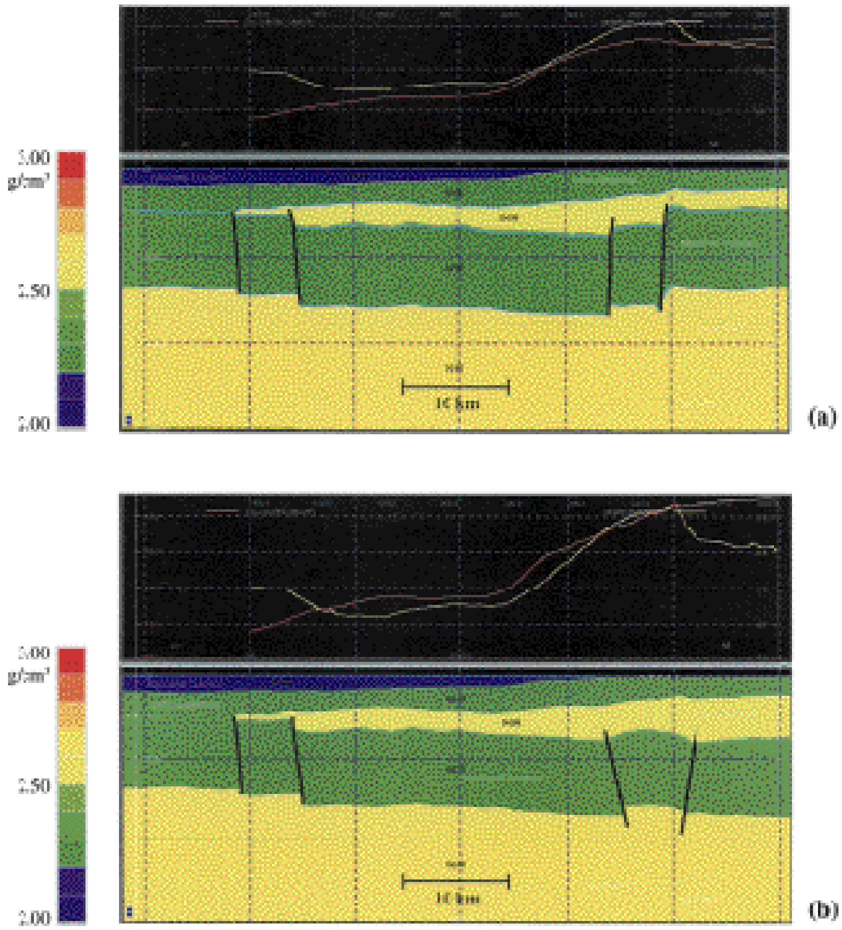

Figure 4. Initial results of Veiru gravity modeling on line T91-18. (a) Model A with the north-bounding Veiru fault upthrown to the north, and (b) Model B with the Veiru fault downthrown to the north. Note the improved match between measured and modeled gravity curves, over the Veiru structure, in Model A.

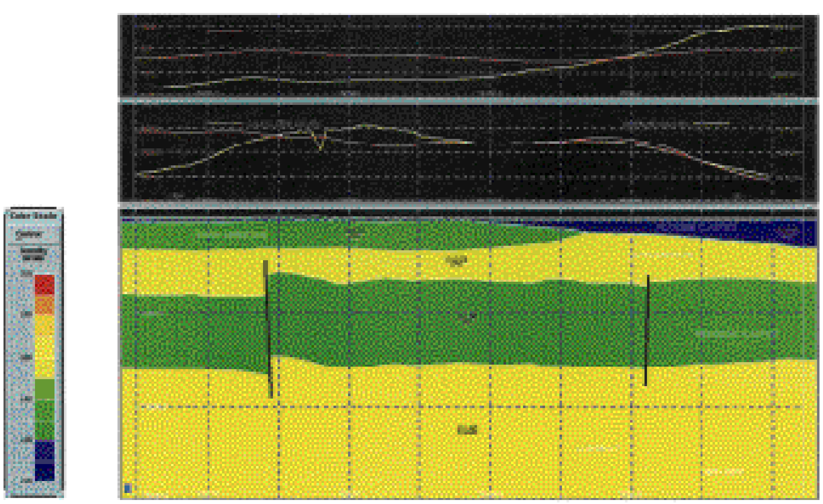

Figure 5. Gravity models of T91-03, incorporating lateral limestone facies change.

Interpretation A was modeled and produced a fairly good gravity profile match except in the eastern end of the line where the modeled gravity profile diverged considerably from the measured profile. Increasing the density for the shallow Pliocene clastics, which increases in thickness toward the east, was considered as this would resolve the profile mismatch. However, the density of this geological interval is quite well known from well and surface data and could not be varied significantly from the original value. The model had been kept fairly simple with the platform-type limestone and underlying deepwater limestone assumed to be separated by a regional seismic time line. Well and outcrop data indicate, however, that the shallow-water Darai limestone undergoes a lateral facies change into deepwater type limestone near the center of line T91-03. Introducing this change into both Models A and B, as shown in Figure 5, produced an excellent match between measured and modeled gravity for the eastern portion of the line. Through iterative modeling, the location of the facies change was more accurately defined than had been possible using only well, outcrop, and seismic data.

On the west portion of this line where the two models are structurally different, Model A produced a better fit of both the gravity and magnetic curves. Further structural adjustments to the base of the platform limestone, which could be supported by the seismic data, produced a near-perfect gravity fit (Figure 6).

Supporting evidence. So how conclusive are results from gravity modeling? Obviously, an unconstrained inverse solution for any given gravity profile is nonunique. Any number of structural and density configurations can produce a given gravity signature. However, using reasonable structural constraints from seismic and well density data to produce a good match between observed and modeled gravity provides a high degree of confidence in the integrated geophysical results. The addition of magnetic data improves this confidence.

The above modeling conclusions can only be proved by drilling a well on either side of the fault. However, other evidence can be considered that, when taken in total, further confirms the modeling results.

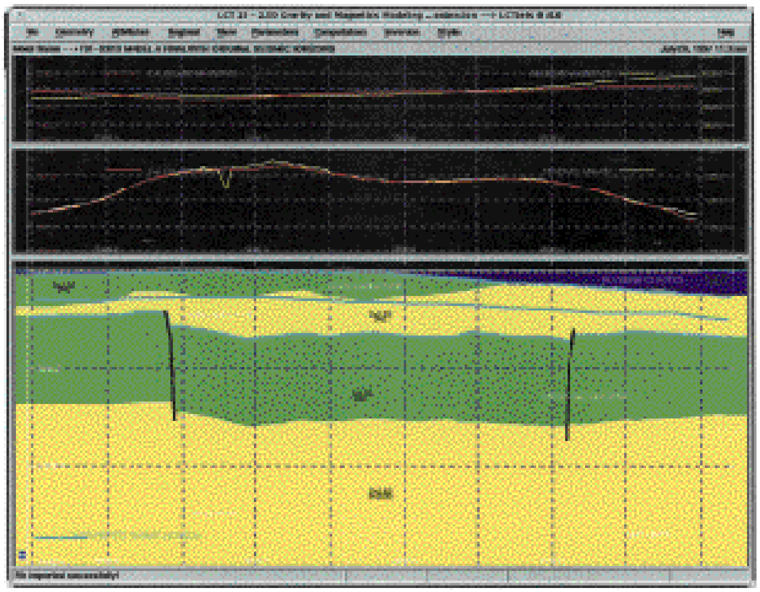

Figure 6. Final version of Model A along line T91-03.

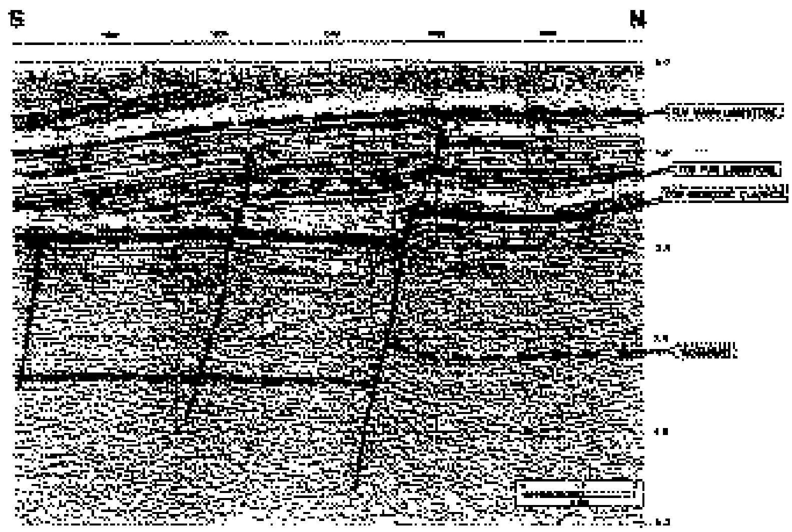

Figure 7. Line T91-20, depicting major faults.

Asignificant structural difference in the two models is the vertical section thickness of limestone that exists on the north side of the Veiru fault. Model B predicts a similar depth to the base of limestone immediately north and south of the Veiru structure. In model A the base limestone has been moved up 700 ms relative to model B and replaced by lower velocity clastics. Interval velocities derived from the seismic stacking velocities within this interval (1150-1850 ms) are slower north of the fault than those in the equivalent interval to the south. This suggests that a slower velocity rock (clastics) exists on the north side as compared to the limestone section interpreted south of the fault.

Line T91-20, southeast of line T91-18 and oriented in a north-south direction, intersects what is likely an eastward extension of the same fault trend. Lying east of the outcropping limestone, the seismic data quality is better and the nature of the faults unambiguous. The main north fault clearly throws down to the south (Figure 7). Similar deformation of the limestone strata above the main fault can be observed, suggesting some recent (Pliocene-age) compressional strike-slip motion.

Conclusions. Of the two interpretations available in the Veiru area, the integrated seismic, gravity and magnetic modeling supports interpreta-

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