Use of Public-Source Data to High-Grade Areas For Detailed Exploration: An Example From Offshore SW Africa

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Offshore gas discoveries at Kudu (Namibia) and Ibhubesi (South Africa) foretell a promising new exploration frontier along the southwest African continental margin. Further exploration in this or other frontier areas can be optimized by undertaking a relatively low-cost interpretation of available public-source geophysical and geologic data, then using the findings to high-grade areas for more concentrated and expensive surveys. This poster illustrates the results of using such data to produce a viable, integrated, first-pass interpretation of the Orange Basin area, offshore South Africa (Figure 1). Although the Orange Basin itself is located within the passive continental margin and extends from the Kudu Arch (northern boundary) to the Agulhas-Columbine Arch (southern boundary), development of its regional framework required that the actual area of investigation extend north into offshore Namibia and south past the Cape Town area.

Initial Impressions

For generalized qualitative gravity interpretation, sedimentary basins are often assumed to correlate with large gravity minima. Figure 2, a free-air gravity map, shows that the Luderitz and Orange basins as outlined by Hirsch et al (2009) do not have consistent gravity signatures. The Luderitz Basin is a

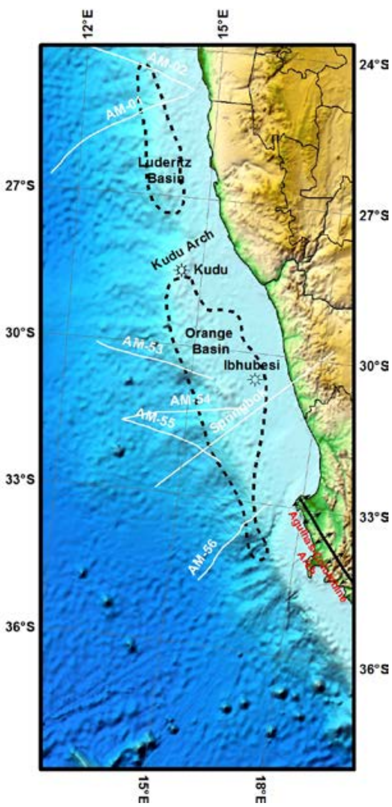

Figure 1. Offshore South Africa and Namibia. Basin outlines after Hirsh (2007)

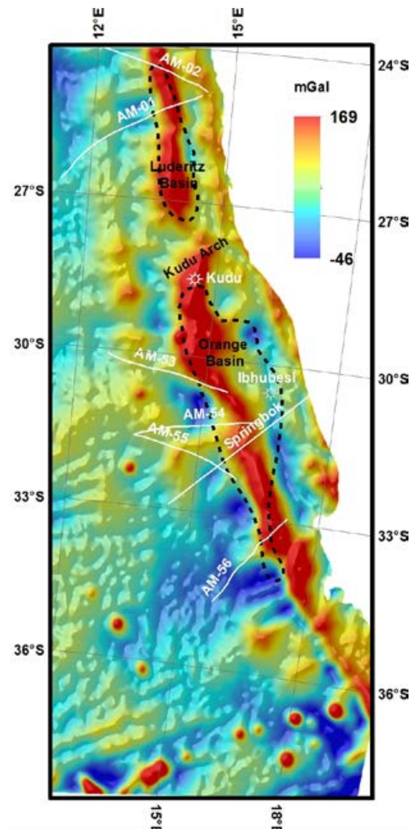

Figure 2. Satellite-derived free-air gravity (Sandwell 20.1). Seismic line locations after Austin and Uchupi (1982)

[1] Note: only selected poster figures were used in this expanded abstract

maximum, while the Orange Basin is a maximum with a minimum on the east flank. The maxima can be referred to as “edge-effect anomalies” (Watts, 1988, and others) and may disguise anomalies from deeper and more interesting geologic sources. Both basins appear as Bouguer minima, although the Orange Basin has a more complex max-min signature, thereby suggesting local structural or stratigraphic features at depth.

Many published regional crustal studies consider the crustal domains south of Walvis Bay, Namibia, to be representative of the entire offshore southern African crust. We view the crust as segmented by northeast-trending shears and varying in style from north to south. Each major crustal segment therefore requires a unique interpretation in terms of both crustal structural style and the style or location of overlying basement and/or sedimentary structures.

Depth and Configuration of the Mohorovičić Discontinuity

The initial phase of our interpretation was the derivation of a depth and configuration map of the crust/mantle (Mohorovičić, or Moho) discontinuity offshore South Africa, specifically the Orange Basin area. Two simple, complementary steps were taken to achieve the goal. The first step was to obtain a first-pass Moho configuration through an isostatic calculation (Airy Root) based on Sandwell’s version 20.1 satellite- derived free-air gravity (Figure 2, above) and version 15.1 bathymetry/topography. The second step was to adjust that first-pass configuration by using a 3-dimensional inversion of the computed Bouguer gravity field. Our prior experience with Gulf of Mexico data had demonstrated the importance of constraining the configuration surface by use of refraction or long-offset seismic, but there was little suitable published data offshore South Africa. A velocity model of the offshore South Africa *Springbok* seismic reflection/refraction line (Hirsch et al, 2007, 2009) provided some constraint; however, the deepest velocity interface modeled (7.5 km/s) is considered by studies in the South Atlantic (Schnabel et al, 2006), the Gulf of Mexico (Ewing et al, 1955; Ibrahim et al, 1981; Ebeniro and Nakamura,1988) and in the Somali basin (Coffin et al, 1986) to represent oceanic crust, rather than top of the mantle. We therefore chose to extrapolate downward and build a deeper 8.0 km/s velocity/density layer to represent the Moho surface (Figure 3). The final Moho map (Figure 4) shows subsea depths ranging from 15 km to 35 km, deepening from 19 km at the western end of the *Springbok* profile to over 35 km near the coast. An onshore point at Ezelfontein, just east of the profile, places the Moho with velocity of 8.0 km/s at 40 km (Green and Durrheim, 1990). That depth fits an extrapolation of our Moho surface depth (Figure 3).

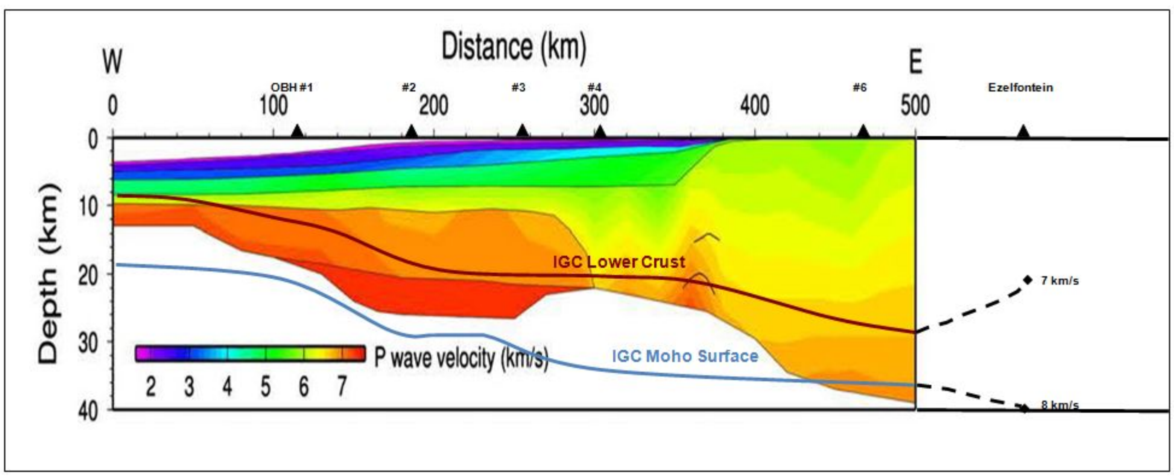

Figure 3: The colored interpretation by Hirsch (2007) is along the *Springbok* line.
IGC’s interpretation of the Lower Crust and Moho profiles are shown for comparison.

Crustal Elements

The second phase of the interpretation was the development of a regional crustal map (see Figure 4) of the offshore area. We interpreted the areas of steep contour gradients on the Moho surface map as zones where oceanic crust bounds transitional or continental crust; this concept is compatible with the velocity/crustal *Springbok* profile of Hirsch et al. The oceanic crust boundary is approximately 200 miles from shore north of Luderitz, then shifts seaward along northeast-southwest shears to a distance of 300-350 miles in the Orange basin area. The boundary shifts shoreward again to a zone 100-150 miles off Cape Town. We interpreted the seaward edge of continental crust as marked by the lip of the Moho trough, with crustal width ranging from 50 miles in the north, to 150 miles near the *Springbok* line, and to 25 miles near Cape Town. That crustal boundary correlates well with a major velocity anomaly on Hirsch's 2007 *Springbok* model.

Geologic Features

A third phase of the interpretation, identifying local gravity anomalies for more detailed investigation, required removal or attenuation of long-wavelength, regional anomalies. Rather than calculating a residual by digital filtering, we chose to develop an isostatic residual. The gravity effect of our Moho surface was calculated, and those values were subtracted from the Bouguer data. A bandpass filter was applied to the resultant isostatic residual to enhance anomalies having a higher probability of further exploration interest. The filtered residual map (Figure 5), integrated with the limited reflection seismic data available in publications, was used to refine the initial crustal structure interpretation and to interpret local structures.

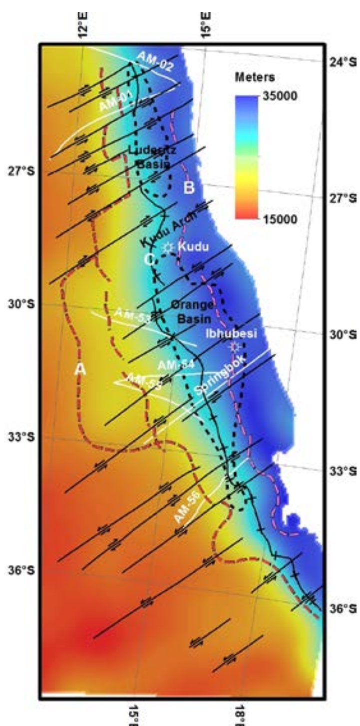

Figure 4. Interpreted depth to Moho surface and crustal elements
Crustal boundaries:
A = oceanic/transitional
B = transitional/continental
C = hinge line

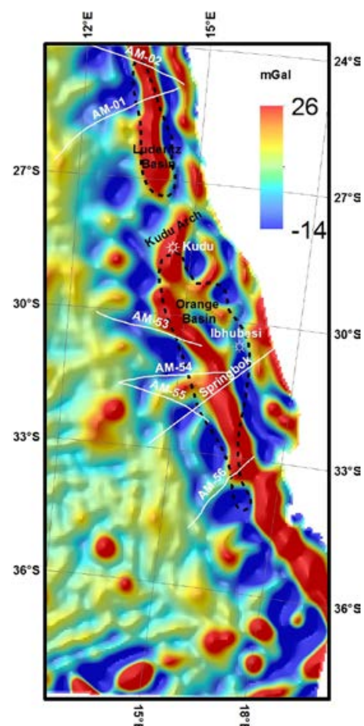

Figure 5. Filtered isostatic Residual gravity

The filtered isostatic residual provides sharper definition of the location and probable offset of northeast-southwestern shears. An alignment of gravity maxima trending north from the Cape Town area, through the Orange and Luderitz basins and into offshore Namibia, is a dominant feature of the isostatic residual map. The maxima appear to define an Agulhas-Columbine Arch (ACA) trend, with the Kudu gas field sitting on the crest of one maximum. A series of residual minima located between the shoreline and the Arch would then represent local syn-rift basins. Ibhubsi Field is located on the flank of one of the elongate minima. Kudu Field therefore appears to have been drilled as the result of a structural play and Ibhubesi was a stratigraphic play.

Integrated Interpretation

Although the primary geophysical coverage of the Orange Basin area is gravity data, our integrated interpretation includes seismic, magnetics, and published geologic structure/stratigraphy cross sections. These additional datasets provide important constraints to any gravity interpretation and produce a more robust, geologically sound final product. Several papers describing the Orange Basin area include a limited number of old seismic profiles along with accompanying analog magnetic profiles that could be used for such integration. A digital grid of total magnetic intensity (TMI) values is available from WDNAM.NGDC and we used it to extract magnetic values corresponding to five of the published seismic lines.

We made integrated interpretations of both seismic line AM-01 (Figure 6) across the Luderitz Basin and line AM-56 across the Orange Basin. On each line, the residual gravity maximum considered to be an expression of the ACA correlated with a TMI maximum, and a qualitative interpretation of a

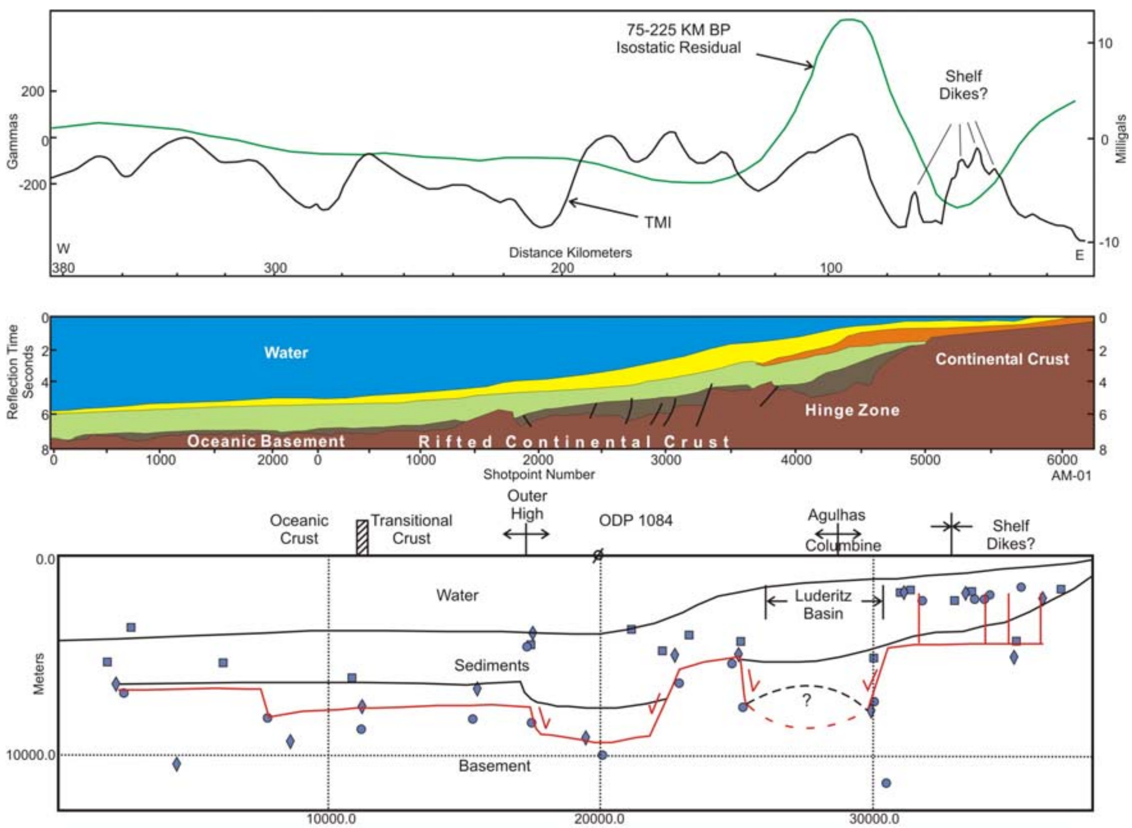

Figure 6. Integrated interpretation, seismic line AM-01
Seismic interpretation after Austin and Uchkopi (1982)

basement-supported arch seemed feasible. However, on both lines the gravity/magnetic maxima correlate with seismic deeps, and rough depth estimates for the maxima place their source bodies at or below the deepest published seismic interpretation. The most plausible interpretation of the gravity/magnetic source bodies then became that of elongate, deep-seated, high-density and highly-magnetic intrusives, and the ACA would not be a basement-supported structure. A further examination of the uninterpreted seismic data (Plate 2, Austin and Uchupi) on AM-01 further reveals that chaotic events at marker 100 km may contain shoreward-dipping reflectors which could be the east flank of a deep arch or fold, and the ACA could therefore be interpreted as a sedimentary feature.

Conclusions

We have demonstrated that some cautions must be observed in the use of public-source data. They are, in and of themselves seldom an end product, but are rather a set of building blocks for an integrated interpretation. Use of these data requires expertise in evaluating their quality. For example, our comparison of the analog and the digitally extracted magnetic profiles led us to believe that data integrity was damaged in the process of compiling the digital grid and much of the digital data had to be used with caution. Unconstrained qualitative interpretation of any one data set, such as the gravity, may provide a seeming logical solution, but that solution must be compatible with and supported by other data.

Despite such limitations, an integrated interpretation of various public-source geological and geophysical data sets can provide both an initial working hypothesis regarding the exploration value of a frontier play and guidance as to where to concentrate more detailed and expensive exploration efforts. For example, the correlations of the Kudu and Ibhubesi fields with certain types gravity anomalies can be extrapolated to predict where to concentrate the search effort for similar fields on passive margins. This would have time- and cost-effective value as an exploration method.

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