A Gravity Study Performed over a Silurian Pinnacle Reef in Western Indiana

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ABSTRACT

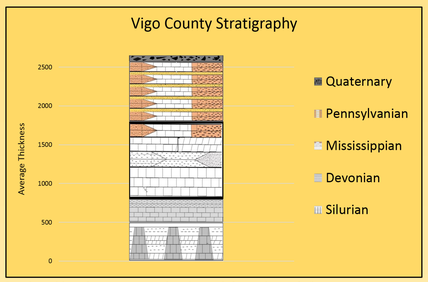
The objective of this study is to show whether gravity measurements are able to identify a petroleum-bearing Silurian pinnacle reef structure situated beneath the Indiana State University (ISU) campus in western Indiana. In the 1800's the campus and downtown areas of Terre Haute was the site of several prolific oil wells that were eventually abandoned. In 2012, Pioneer Oil Company explored the area with the idea that this old oil field, like many others in this part of Indiana, might be associated with the drape of Devonian and younger sedimentary strata over a Silurian reef. As a result of their seismic exploration, several production wells were drilled beneath the campus. The gravity study presented here consists of 44 stations distributed along two crossing profiles (N-S and E-W) centered on campus to examine whether such a reef and its overlying draped strata might exhibit a gravity anomaly associated with the subsurface density variations. Given that the average density of limestone (2.55 g/cm^3) is greater than the average density of shale (2.40 g/cm^3), the expected gravity anomaly for the region would be positive. The resulting Bouguer anomaly for these profiles after the regional gravity gradient is removed is a ~0.16 mgal positive gravity anomaly, which is very well defined on the N-S profile. The anomaly is similarly developed (but with more variation) on the E-W profile, which was limited to the west by the Wabash River. This result matches the expected gravity anomaly, and its magnitude and scale is very similar to that found across the reef structure of the Terre Haute East Field in an ISU Senior Thesis (Hauser, 1976) and for gravity across the Silurian reef beneath the Wilfred gas storage facility in Sullivan County to the south (Dana, 1980).

PURPOSE OF STUDY

The goal of this study is to determine whether gravity methods can be used to identify the petroleum reservoir associated with a pinnacle reef located in the middle of ISU campus.

BACKGROUND

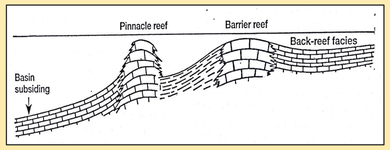
Oil and gas production is associated with a large Silurian reef archipelago extending in a north-northwest by south-southeast trending facies known as the Terre Haute Bank that developed along the eastern edge of the Illinois basin. The reefs range in size from small pinnacle reefs to larger reefs and atolls (Rupp, 1988). In the study area, these Silurian carbonates are overlain by Devonian shale and limestone followed by Mississippian carbonate rocks, shale, siltstone, and sandstone overlain by a sequence of Pennsylvanian shale, siltstone and sandstone (Hartke and others, 1983). This sedimentary sequence dips gently to the southwest (Drost and Shaver, 1980), and the average depth of the Silurian strata in the Vigo County area is 2152.5 feet (Hartke and others, 1983). Overlying the Paleozoic sedimentary sequence is a thick layer of glacial till measuring up to 125 feet thick in some areas (Hartke and others, 1983).



Stratigraphic column representing the rock formations of Vigo county according to their age and thickness (J. Hartke, 1983).

Representation of the Bank of Terre Haute (from Drost and Shaver, 1980).

Oil was first discovered in Terre Haute, Indiana, in 1865 during the construction of a water well, which was later abandoned due to poor water quality. The first commercial oil well in Terre Haute was completed in 1889 with five additional wells being installed in what became known as the Terre Haute Field (Hartke and others, 1983). Recently, Pioneer Oil Company completed a seismic survey of the downtown Terre Haute area, including the ISU campus, to map the structure of the Terre Haute Field and the suspected reef. Based on their results, Pioneer installed a deviated well to safely extract petroleum from a reef structure under the ISU campus.



Silurian reefs in the Michigan Basin.

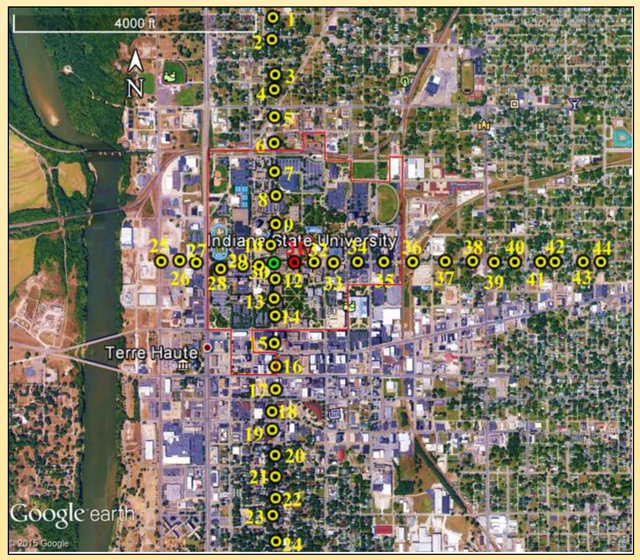
METHODS

The gravity survey was conducted over a two day period in December 2014 during the early morning and late evening when traffic flow was at a minimum. A LaCoste&Romberg gravimeter from Wright State University was used to measure gravity along a set of stations extending N-S and E-W centered on the ISU campus. Lateral variations in gravity were anticipated to be likely associated with lateral differences in the relative density of the rocks of the Silurian pinnacle reef and the overlying strata draped over the reef. The location and elevation of each station was measured RTK (real time kinematic) to ~1 cm precision using a Trimble 5800 GPS device connected via wifi cell phone hotspot to the INDOT GPS base station system, and all data were entered into an Excel spreadsheet.

LaCoste&Romberg gravimeter.

Trimble 5800 GPS

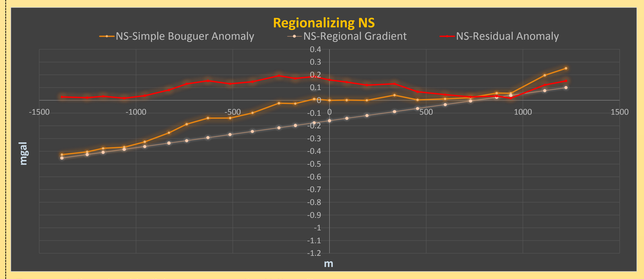
The survey sites consisted of forty-four stations along two profiles centered on the ISU campus, twenty-four in a 2.6 km-long N-S profile and twenty in a 2.2 km-long E-W profile. Station 31 near the intersection of the profiles was used as the gravity base station because of its accessible location for repeated measurements in a relatively quiet area of the survey. The gravity data were corrected for drift, latitude, free-air, and Bouguer. The resulting simple Bouguer gravity values were then graphically corrected for a regional gravity gradient, with the remaining shorter wavelength variations representing the Bouguer anomaly along each profile.



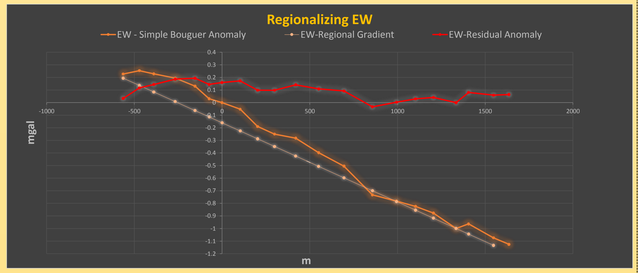
Profiles NS and EW, and the 44 stations in their real location, including the base station (in red).

RESULTS

The result of this study shows a well-defined anomaly of ~0.16 mgal on the N-S line and an anomaly of the same magnitude but less well-defined on the E-W line. In the graphs below, the regional gradient (rose straight line) was calculated by the following equation y = ax+b and that was subtracted from the Simple Bouguer anomaly (orange curve), resulting in the Residual anomaly (red curve). The residual anomaly associated with such a reef may be from the density contrast of (1) the draped strata that are structurally higher over the reef, and/or (2) the lateral variation in density of the dolomite reef core and the laterally surrounding shaly inter-reef sediments.



Representation of residualizing process on the N-S profile.



Representation of residualizing process on the E-W profile.

CONCLUSION

This study demonstrates that a distinct positive gravity anomaly of ~0.16 mgal is spatially associated with the Silurian reef beneath the ISU campus. Although proprietary gravity surveys have been used by industry (especially in the 1940s-50s) to find reefs along the Terre Haute Bank in Illinois Basin and in the Michigan Basin, this study suggests that careful gravity studies may yet still aid in the exploration for these reefs and the associated oil and gas reservoirs in the overlying draped strata.

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