Directing a Marcellus Shale Drilling Program Using High Resolution Aeromagnetic Data*

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Abstract

Typically, aeromagnetic surveys are used to find deep-seated faults that can give rise to shallower structures. In most cases, these features are identified with a focus on drilling areas closely associated with them. In the continuous shale play, however, this is exactly the opposite of what should be done. It has been pointed out that in Marcellus Shale exploration, one of the geologic hazards to be avoided is structurally complex areas with deep-seated faulting.

The presence of open natural fractures is of primary importance in Marcellus exploration, as they can lead to superior well production performance. However, while natural fracturing can aid production, it can also cause significant problems in drilling, completion, and production. This is especially true if the natural fractures are part of a bigger, deeper-seated basement fault system. Heavily naturally fractured areas often result in poor fracture stimulation, which in turn leads to a poor well.

Secondary natural fractures in the sedimentary cover are also associated with deep basement faults. These are often expressed as surface lineaments and as intra-Marcellus natural fractures. It is these secondary intra-Marcellus natural fractures that are beneficial. Many of the more than 20,000 penetrations of the Marcellus had reported natural flows of gas from it. These natural flows of gas are indicative of natural micro-fracturing of the rock, as the low permeability would not allow for natural production without enhancement by natural fracturing.

Previous work has found there is a relationship between the EUR per stage and fault intensity in the immediate area around a well. This is most likely due to faults absorbing the hydraulic fracturing energy. Hence, greater faulting can lead to more potential leak-off per stage. Even small faults can divert a large amount of the stimulation energy. As a result, understanding the locations of basement block edges is of primary importance, as the areas adjacent to these fault boundaries are highly fractured. Getting inside, and staying within, the boundaries of individual basement blocks is critical to ensure that deep-seated faults are less likely to be encountered. In fact, when designing a program, it will be optimal to find the most magnetically quiet areas possible. By incorporating aeromagnetic data into a shale exploration program, the greater the chance of avoiding faults and large-scale fractures that lower peak well deliverability.

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Directing a Marcellus Shale Drilling Program Using High Resolution Aeromagnetic Data

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Objectives

- Review “conventional” aeromagnetic processing.
- Discuss what the experts have said about the Marcellus Shale.
- Using these observations, explain the need to alter the frame of reference regarding the use of magnetics.
- Show an example from northeastern PA that ties it together.

How its always been done

- Since the sedimentary column is generally non-magnetic, aeromagnetics is a tool to see the basement.

- In most cases, structural relief on the basement surface is only nominal. What is more relevant is the juxtaposition of different lithologic domains in the basement. These boundaries are fault controlled and the contrast in their properties is observed by aeromagnetics.

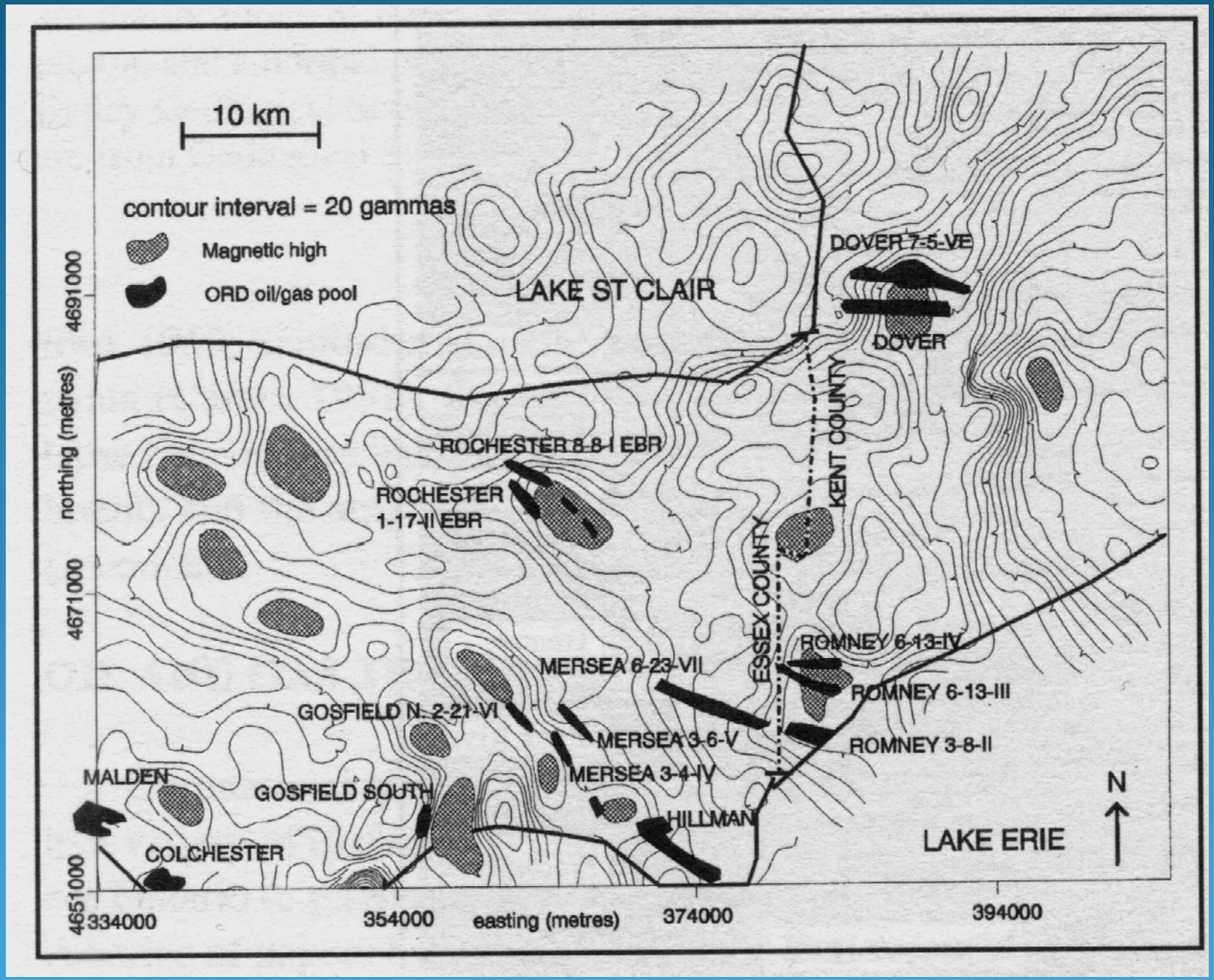
How its always been done

- Aeromagnetic data provide information about faulting patterns in the basement.
- As basement is brittle, lithologic contacts also can become the loci for fracturing.
- Reactivated basement faults can propagate fractures upwards through the sedimentary column.

In summary…

- When tectonic stresses are re-applied throughout geologic time, the pre-existing basement faults will become reactivated. This will have a direct effect upon sediment deposition, structural fabric in the sedimentary cover, and reservoir quality adjacent to these reactivated basement faults.
- Typically, aeromagnetic surveys are used to find the deep-seated faults which can give rise to shallower structures. In most cases, we find these features and want to drill areas closely associated with them.

Total magnetic intensity--Essex County, ON



Southern Ontario summary

"The structural grain of the Precambrian basement, as reflected in magnetic maps, is an important tool for prediction of the likely orientation of faults and fractures in the Paleozoic strata."

"Consequently, Precambrian basement mapping should be useful in interpretation of the probable location and orientation of these pools, especially *when used in conjunction with traditional structure, isopach, and facies mapping.*"

Carter, Trevail, and Easton---GSA Special Paper 308

Is there a use for magnetics in shale?

- Do these relationships extend to the Marcellus?
- If so, how can we use this tool to help drive an exploration program?

Is there a basement-Marcellus link?

- "Geologic hazards to be avoided include structurally complex areas with deep seated faulting and the lack of upper or lower frac boundaries."

Greg Wrightstone, AAPG Eastern Section Meeting, Pittsburgh, PA 2008

Is there a basement-Marcellus link?

Recurrent basement movement has created distinct crustal blocks. The edges of these blocks can exhibit both vertical and strike-slip movement. Northwest striking cross-structural discontinuities are well-documented in western Pennsylvania. These include the Tyrone-Mt. Union, Lawrenceville-Attica, Home-Gallitzen, and Pittsburgh-Washington faults. Research at SUNY-Fredonia and Penn State has shown that block movement appears to have been reinitiated in late Early Devonian time. Hence, depositional and erosional patterns of the Marcellus Shale were controlled by basement block movement.

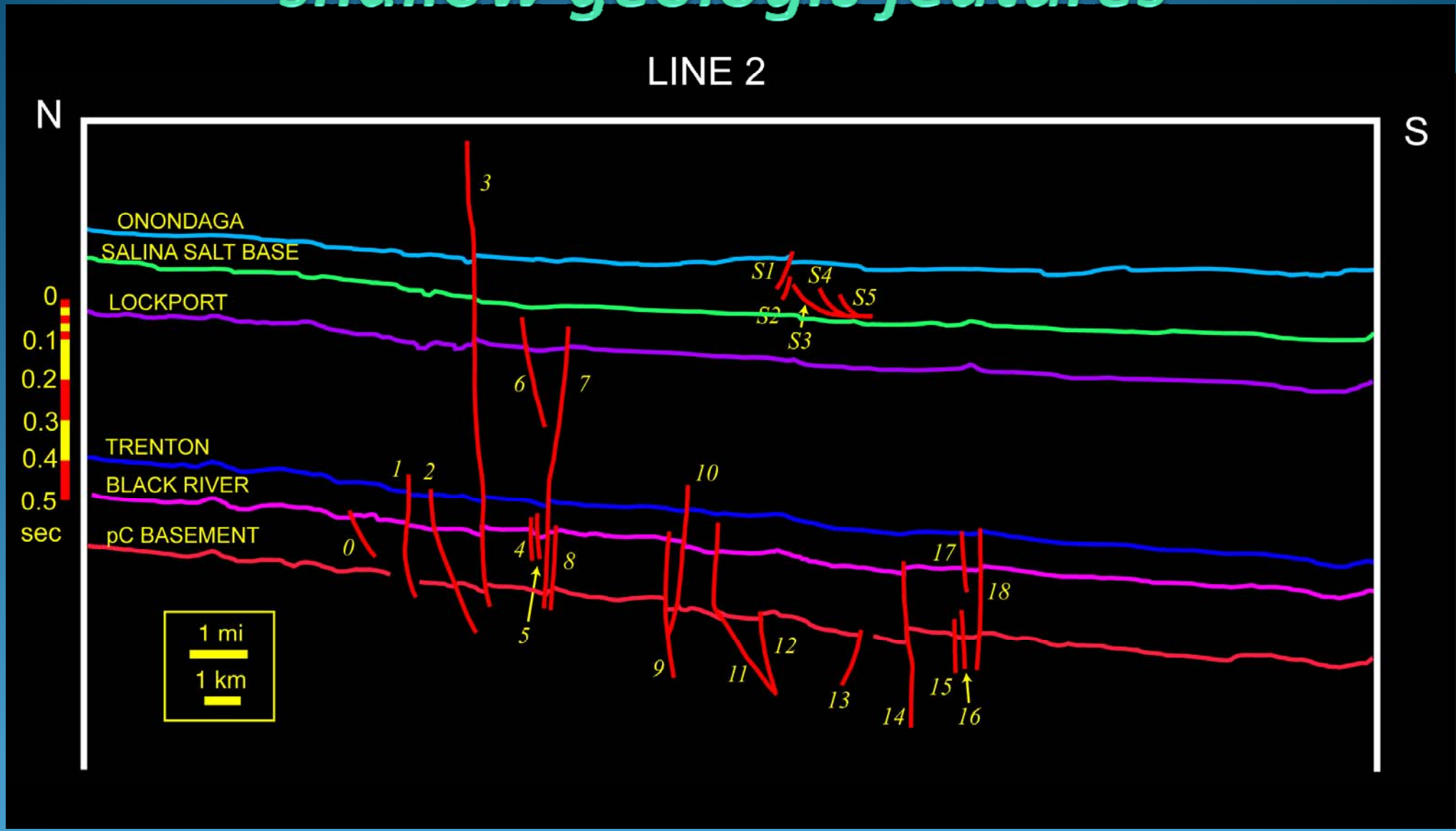
Lash and Engleder, AAPG Bulletin, V. 95, No. 1 (January 2011), P. 61–103

Is there a basement-Marcellus link?

Research at the New York State Museum has shown that there are natural fractures in the sedimentary cover associated with deep basement faults. Some of these are expressed as surface lineaments, as well as intra-Marcellus natural fractures. The intra-Marcellus natural fractures may be beneficial, but those related to basement faults may complicate drilling, completion, and production.

Smith, Nyahay, Leone, and Martin, AAPG Eastern Section Mtg., 2008

Relationship between deep and shallow geologic features



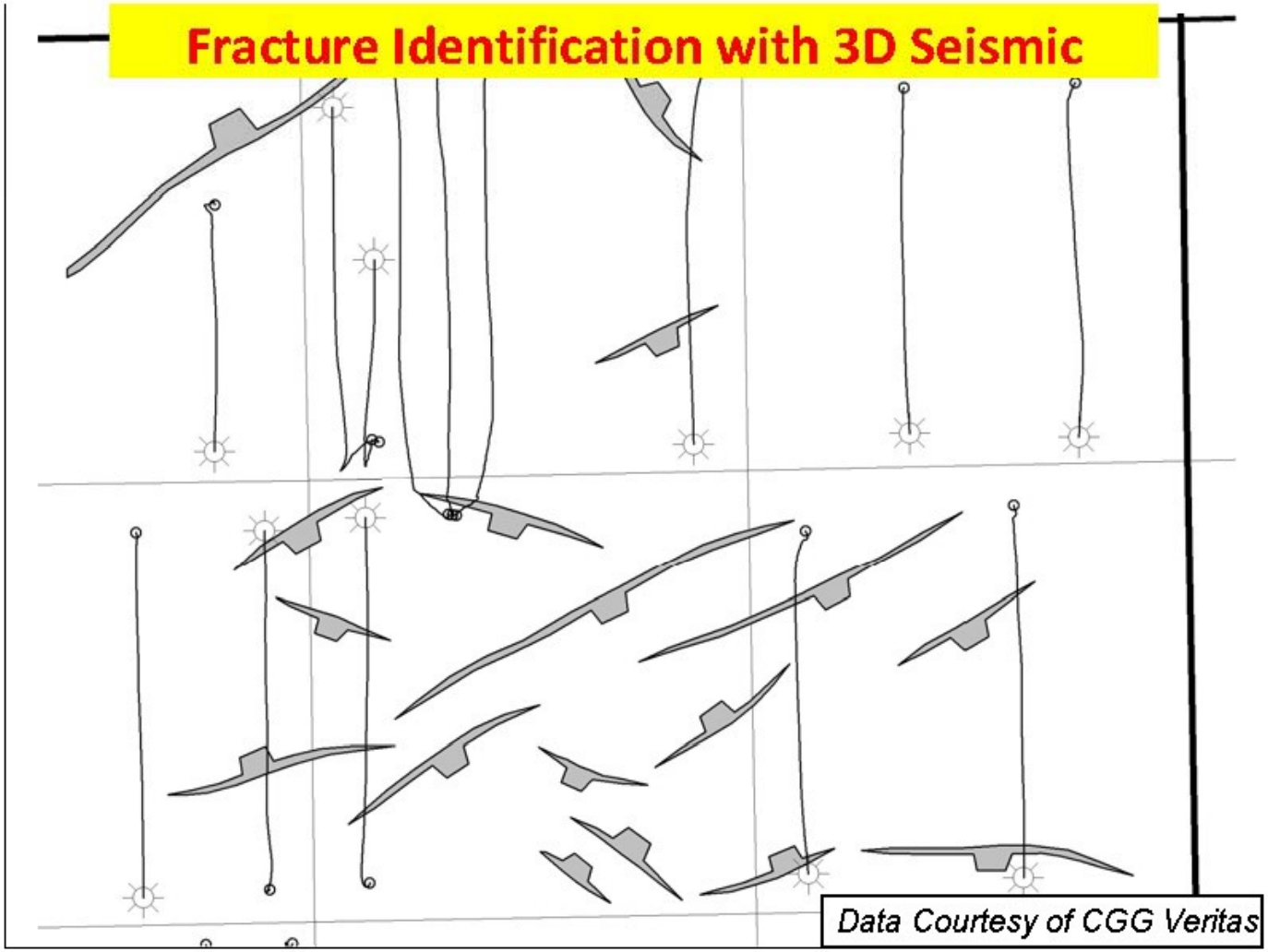
Data courtesy of SUNY-Buffalo

Is there a basement-Marcellus link?

"In addition to other basinal faulting associated with the Rome Trough, there also are NW-SE trending basement faults that influence or disrupt all of the thermal maturity and depositional patterns that appear to have bearing on exploration approaches in each of the two Marcellus core areas."

Bill Zagorski in AAPG Explorer

The engineer perspective



Gilman and Robinson, AAPG International Conference and Exhibition, Calgary, Alberta, September 12-15, 2011

The engineer perspective

- In lightly faulted regions there are good and poor wells, but in heavily faulted areas, there are only poor wells.
- When the data are binned in order to try to reduce the scatter, it becomes clear that being close to numerous faults, i.e., fractures, results in poorer EUR/Stage. We think this is due to faults "stealing" the frac energy and causing ineffective fracturing of the shale; the more faulting, the more potential leak-off zones. We have seen this occur in several micro-seismic surveys run during stimulation. Even small faults can divert a large amount of your stimulation.

Paradigm Shift

- We typically use an aeromagnetic survey to find deep-seated faults and look for structures associated with these faults.

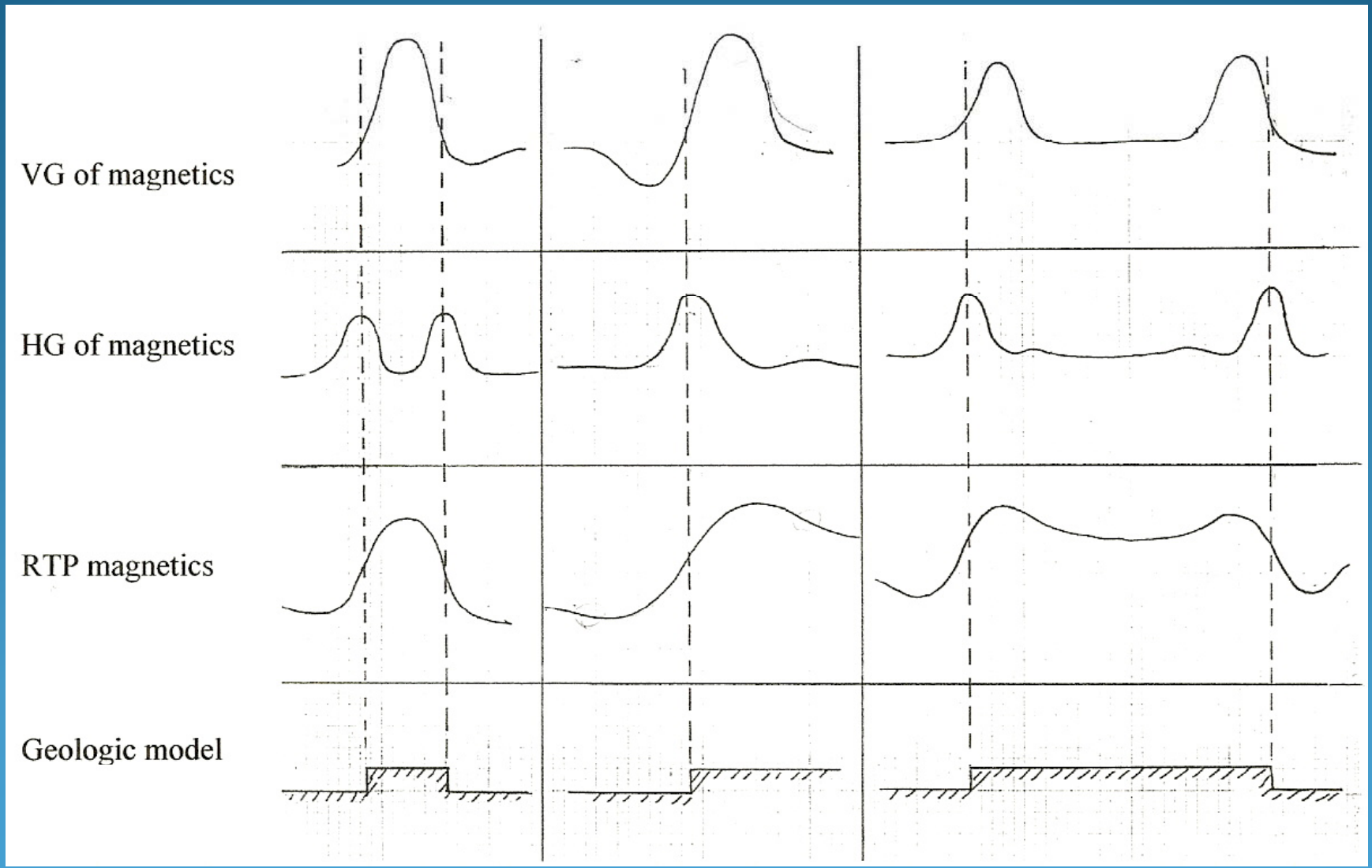
- In the Marcellus, we must use the survey first to locate basement faults and then, more importantly, to avoid them.

Paradigm Shift

- One of the tools that we use in conventional processing is to map the horizontal gradient. It is essentially the rate of change of the magnetic field in the plane of the ground.

- Maximum gradients generally occur over the basement fault.

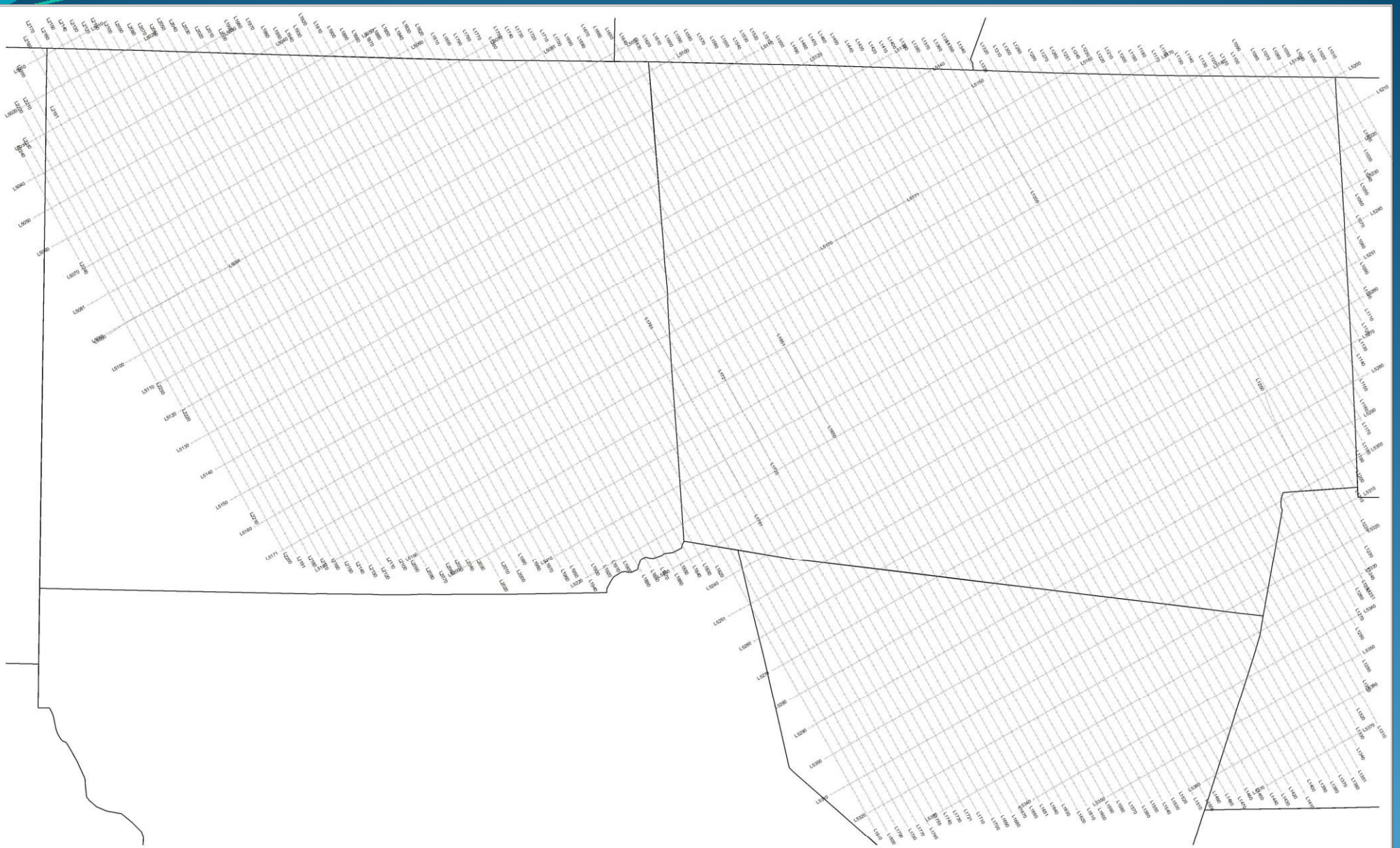
Horizontal gradient illustrated



Paradigm Shift

- Using high resolution aeromagnetic data, perform many of the standard processing techniques.

- Instead of searching for maximum horizontal gradients, search instead for areas with low gradients. These quiet areas should be away from basement block edges, which can be faults.



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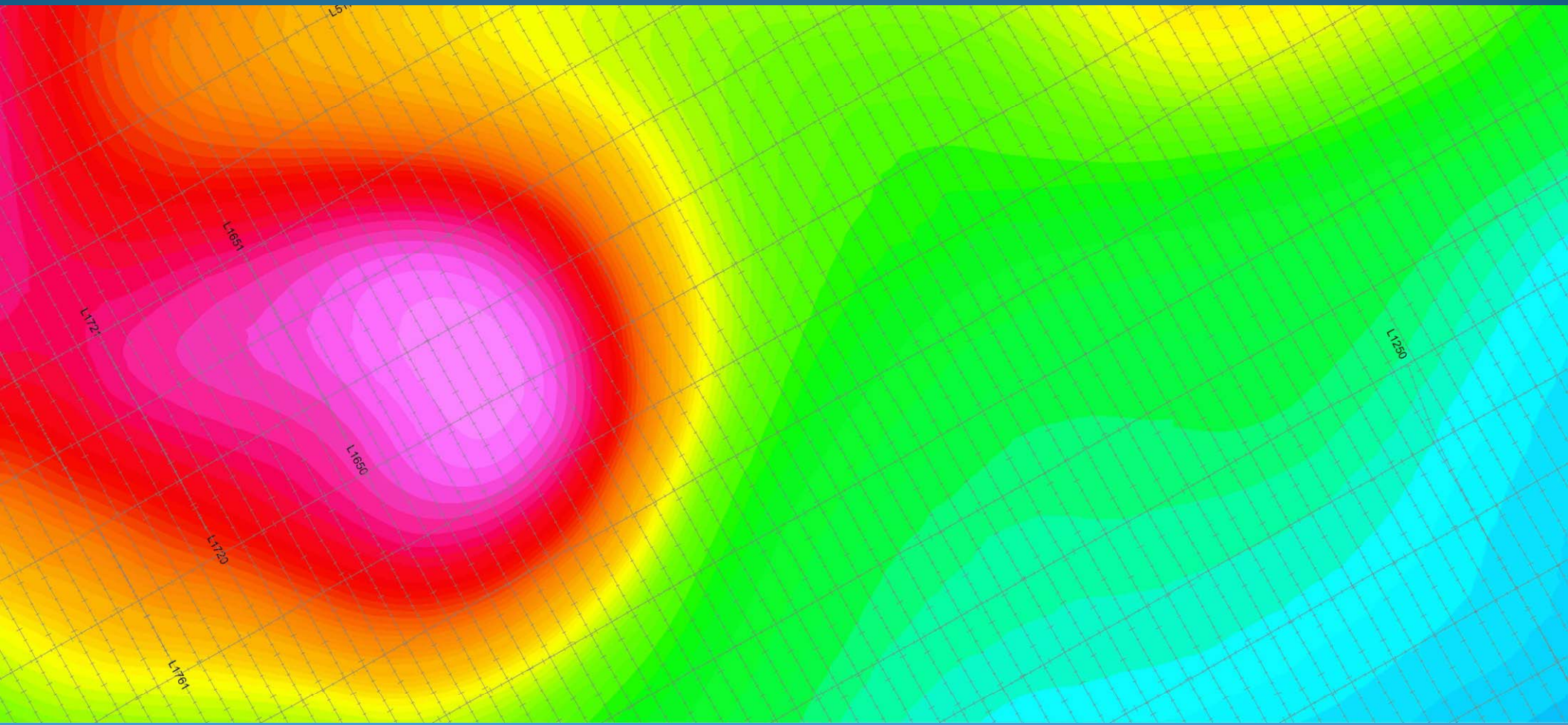
Scale 1:126720

2000 0 2000 4000 6000 8000

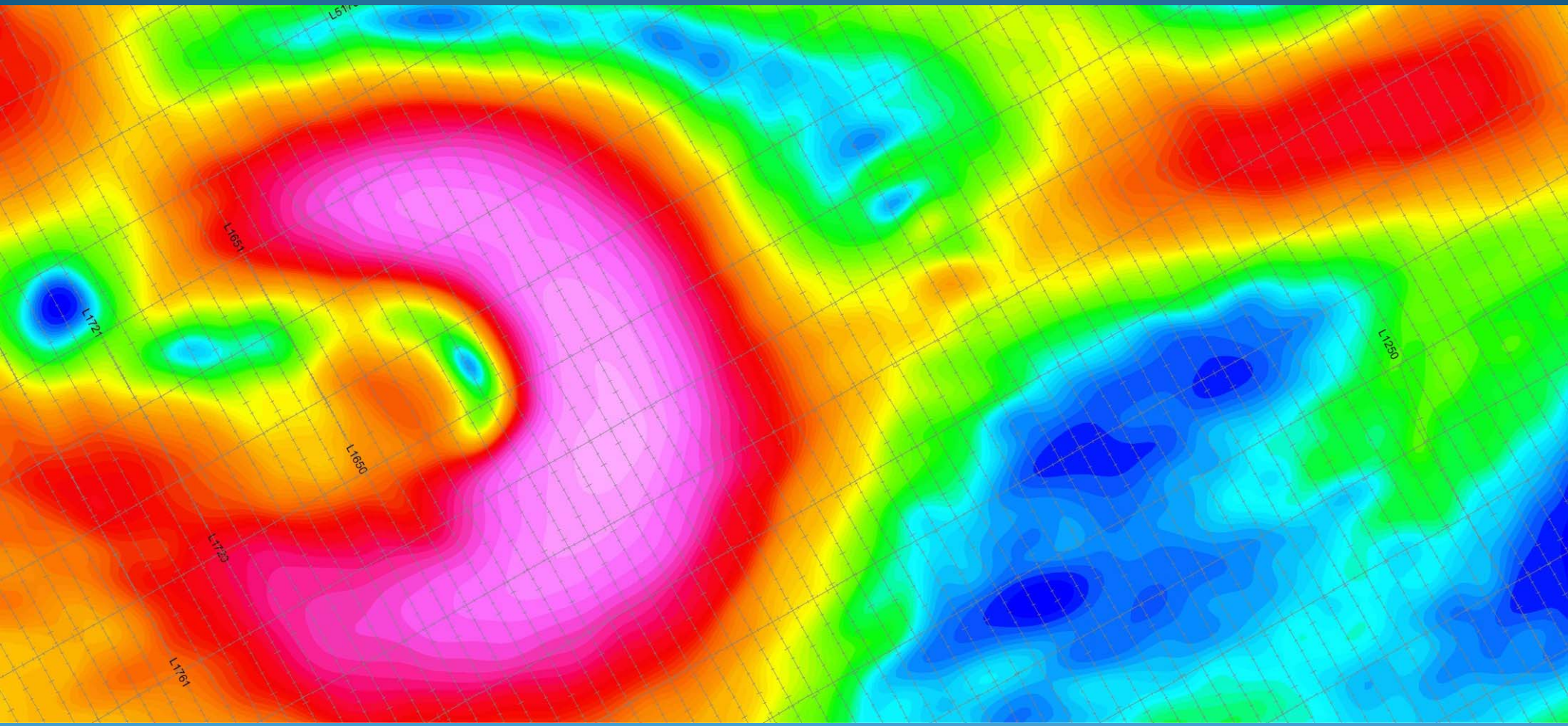
Bradford/Tioga County Survey

Total Magnetic Intensity

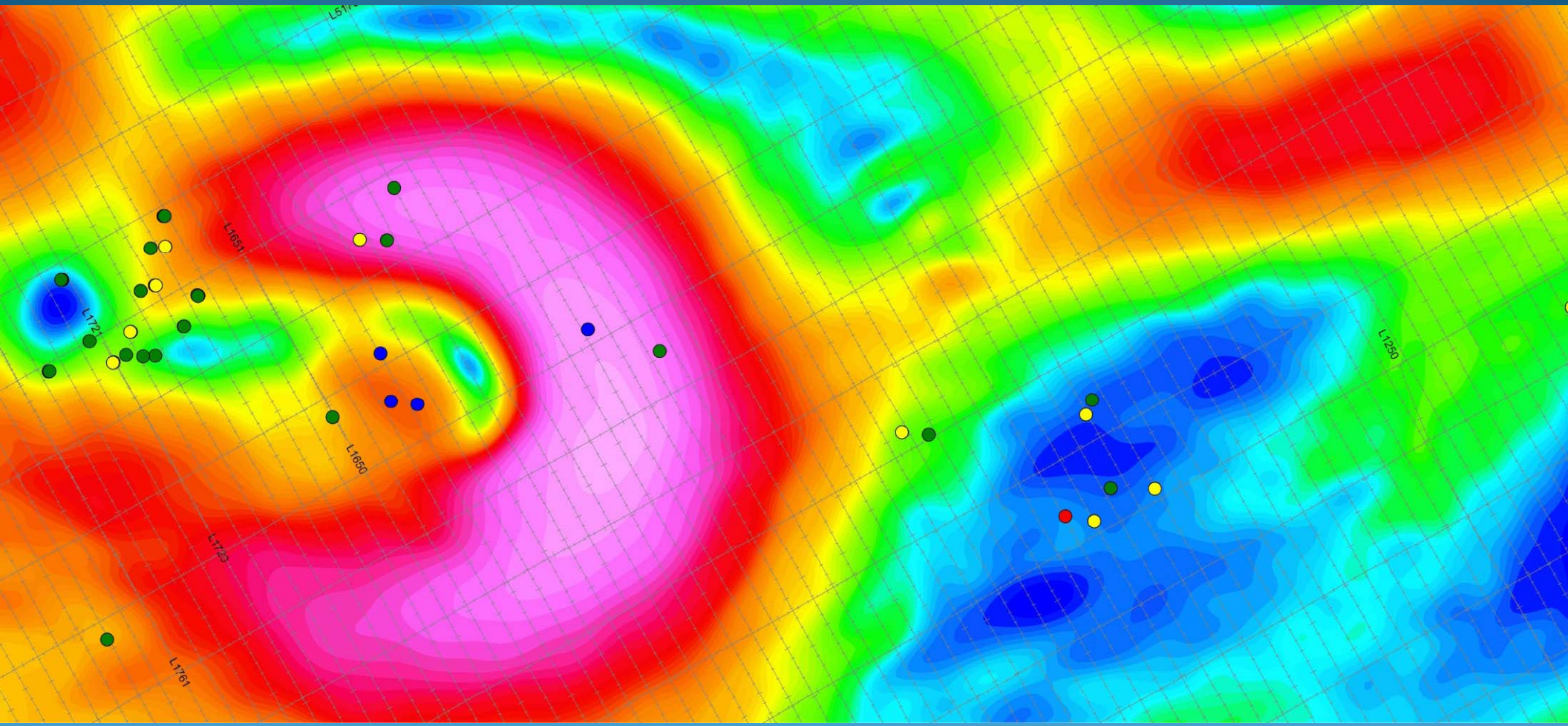
Reduced to pole magnetics



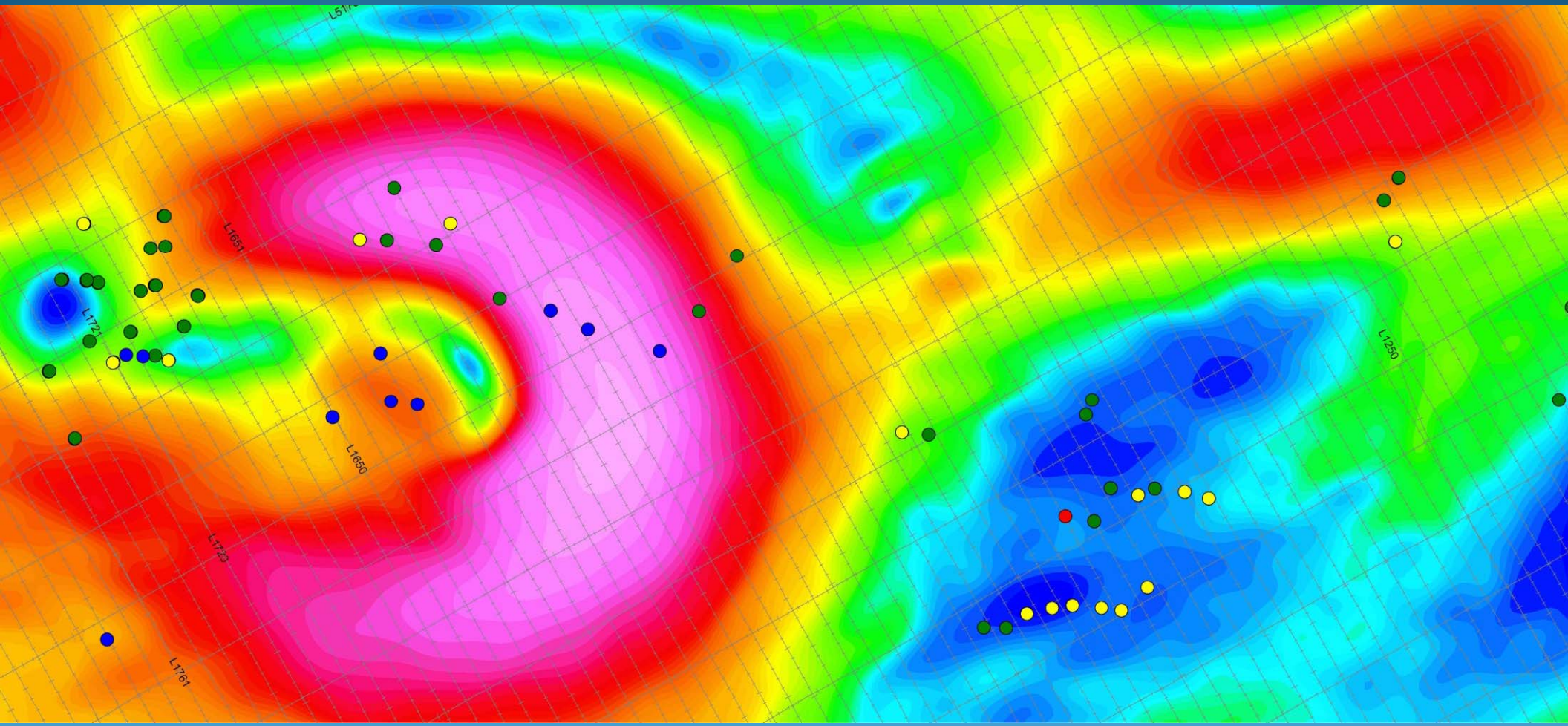
Horizontal gradient of RTP magnetics



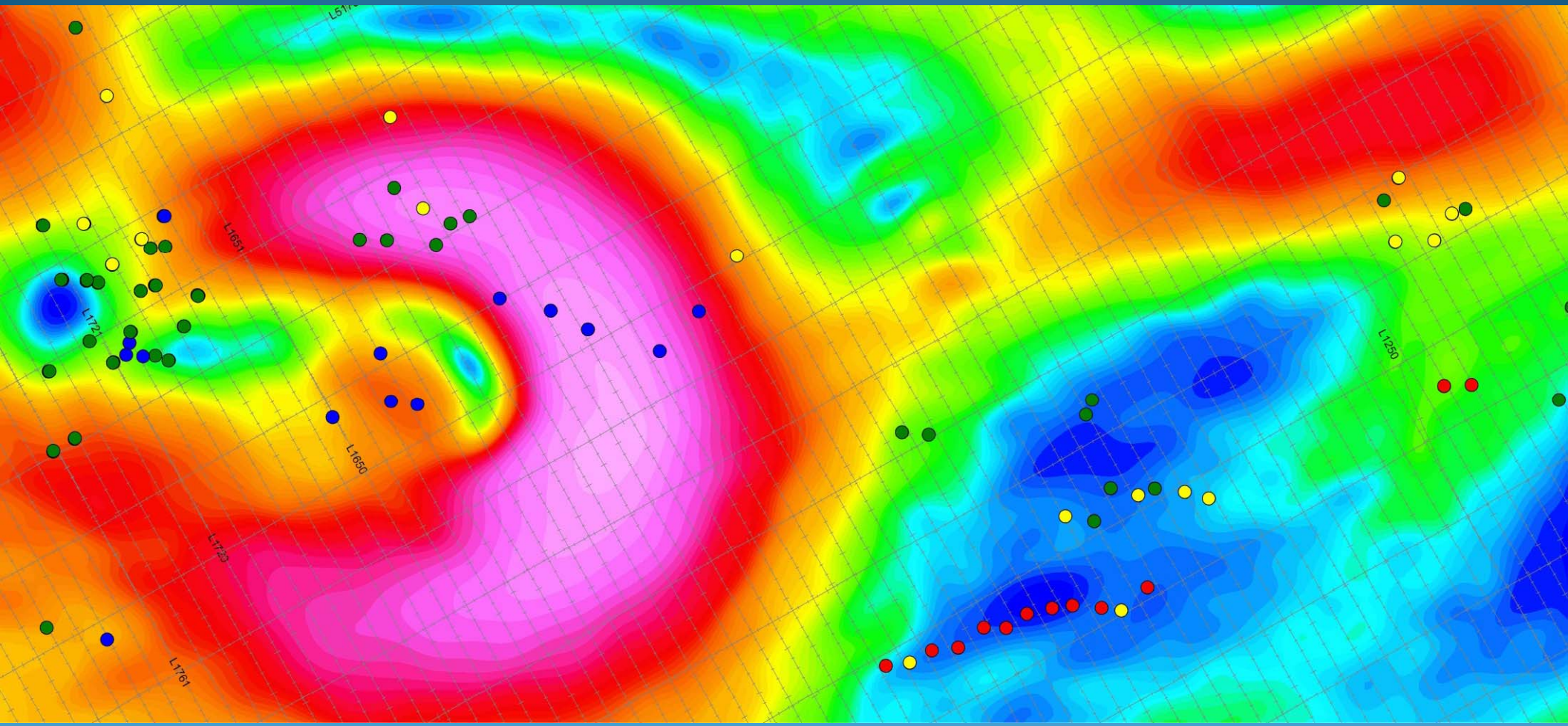
Daily production (7/09-6/10)



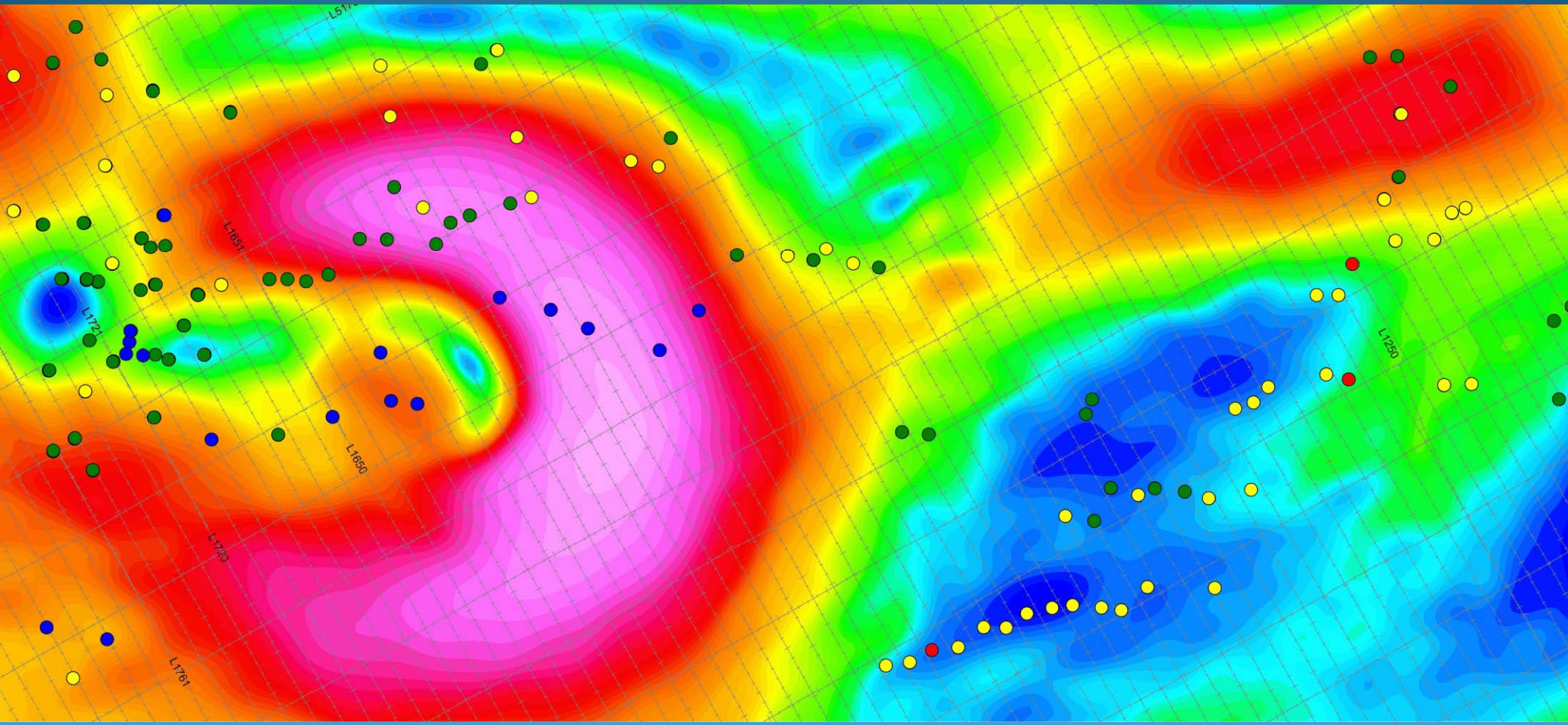
Daily production (7/10-12/10)



Daily production (1/11-6/11)



Daily production (7/11-12/11)



Summary of results

- Over a three year period, there is a very good correlation between average daily production and the horizontal gradient of the magnetics.
- Wells that start off average tend to stay average; wells that start off good tend to stay good.
- EUR should therefore be better on those wells that are drilled where the HG is lower (i.e. away from basement faults.)

Conclusions

- Aeromagnetic surveys are a very cost-effective tool to help in locating the basement faults that can sap well deliverability. Don't drill the areas that are more likely to yield poorer wells due to faulting.
- Aeromagnetic data can help direct leasing programs and to manage existing land holdings.
- For the unconventional plays, aeromagnetic data can prioritize which areas to drill.

Conclusions

- Drilling a well on sub-average acreage to hold leases to allow you to drill more sub-average wells in the future is foolhardy.
- As much as people want to make these plays simple, "flat and black, work everywhere plays," they are not. You need geological thinking and a critical eye.
- With some work and thought, you do not drill the poor wells—then you are exceptional.