Qualitative Depth Estimation by Differencing Upward Continuations

Jacobsen (1987) made a strong case for using upward continuation filtering as a method for separating causative sources from various depths. There are a number of assumptions involved, and one must keep in mind that magnetic and gravity data contain no inherent information about the depth of source. We can always create any observed field by a distribution of magnetization (or density) on the surface. That is rarely a geologically reasonable solution.

Jacobsen (1987) assumes the observed magnetic field to be the sum of the regional field, the residual field, and aggregate noise. He used assemblages of mutually uncorrelated thin source distributions at various depths to model the field. That is, fields originating at different depths have zero correlation. This is not as restrictive as it may sound, lots of common features may have positive and negative correlations so think of zero correlation as the neutral case. Think of these as equivalent source layers.

The rules of thumb which emerge from this work:

- To extract (isolate) a regional field at a depth of z_0, upward continue the observed field to $2*z_0$. In the wavenumber domain, the optimal filter for that extraction is:

$$B_{reg}(k) = \exp(-2\ k\ z_0)$$

  You can then subtract this regional field from the total field to isolate the residual field.

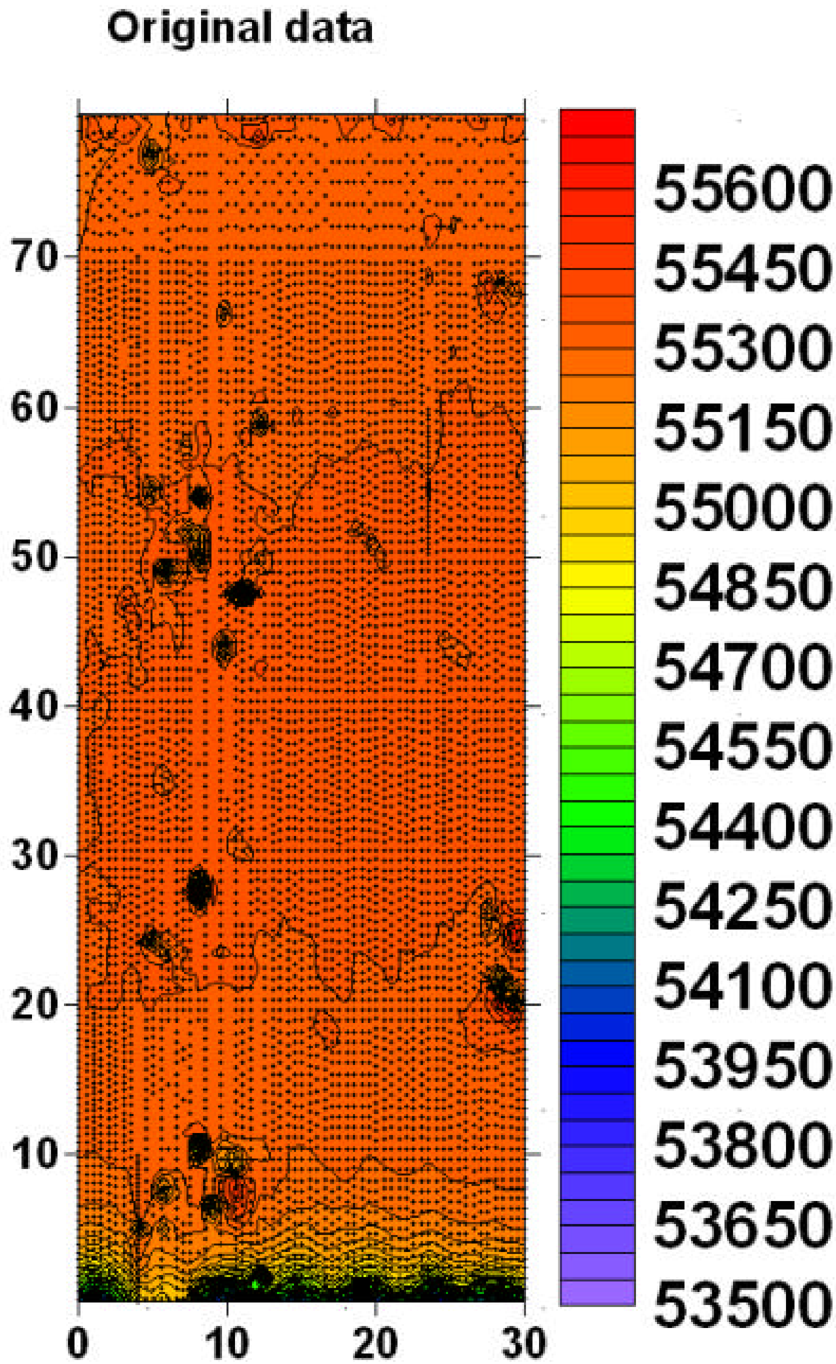
- To find the magnetization from an equivalent source between depths z_1 and z_2, subtract the upward continuation to $2*z_2$ from that of $2*z_1$. That is, simply find the difference between the upward continuations to twice the values of the respective depths. In the wavenumber domain, the optimal filter for that extraction is:

$$B_{slab}(k) = \exp(-2\ k\ z_1) - \exp(-2\ k\ z_2)$$

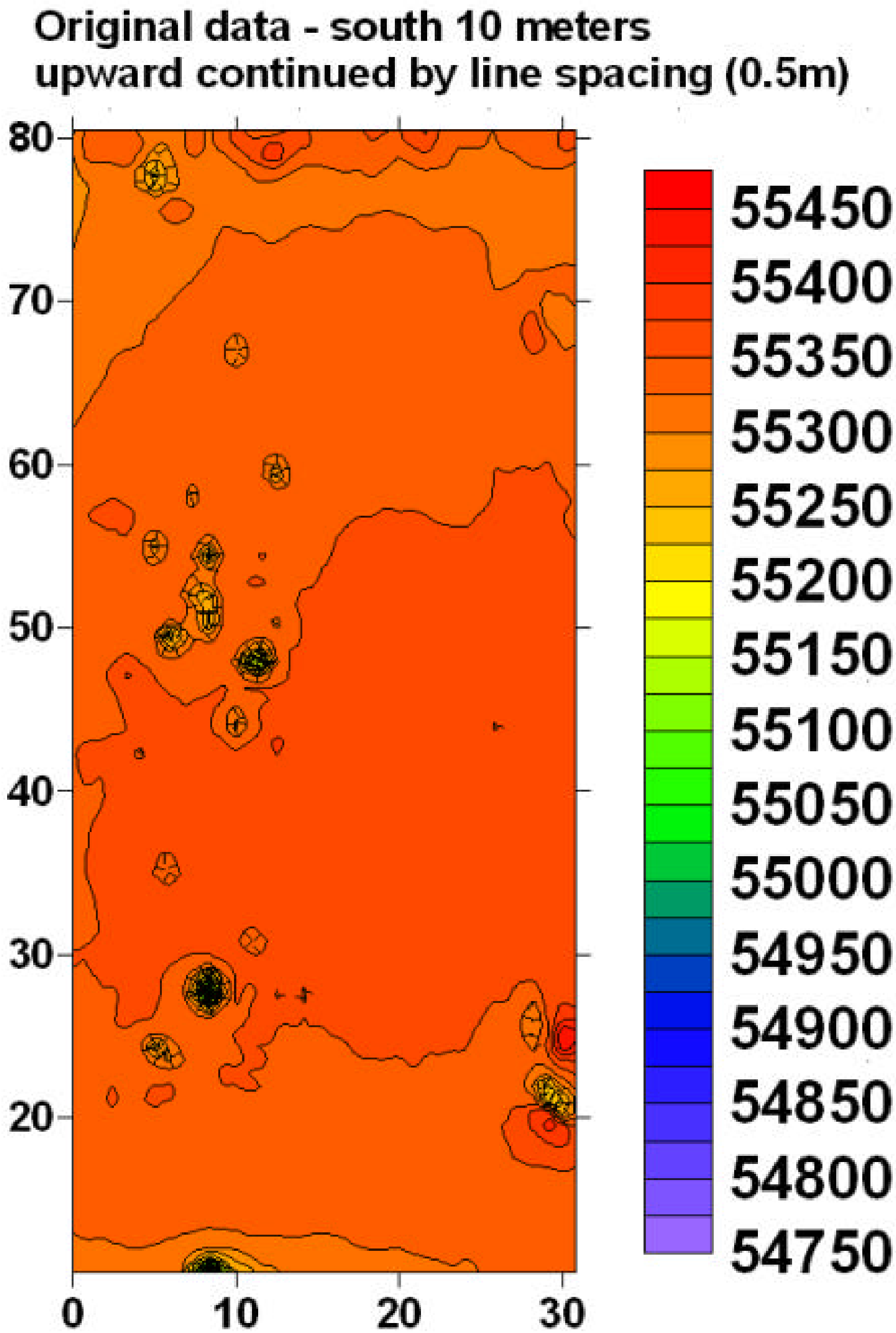
  Anomalies originating inside the equivalent source layer typically stand out much more prominently after the filtering.

Jacobsen, 1987, A case for upward continuation as a standard separation filter for potential-field maps, Geophysics, v. 52. #8, p. 1138 – 1148.

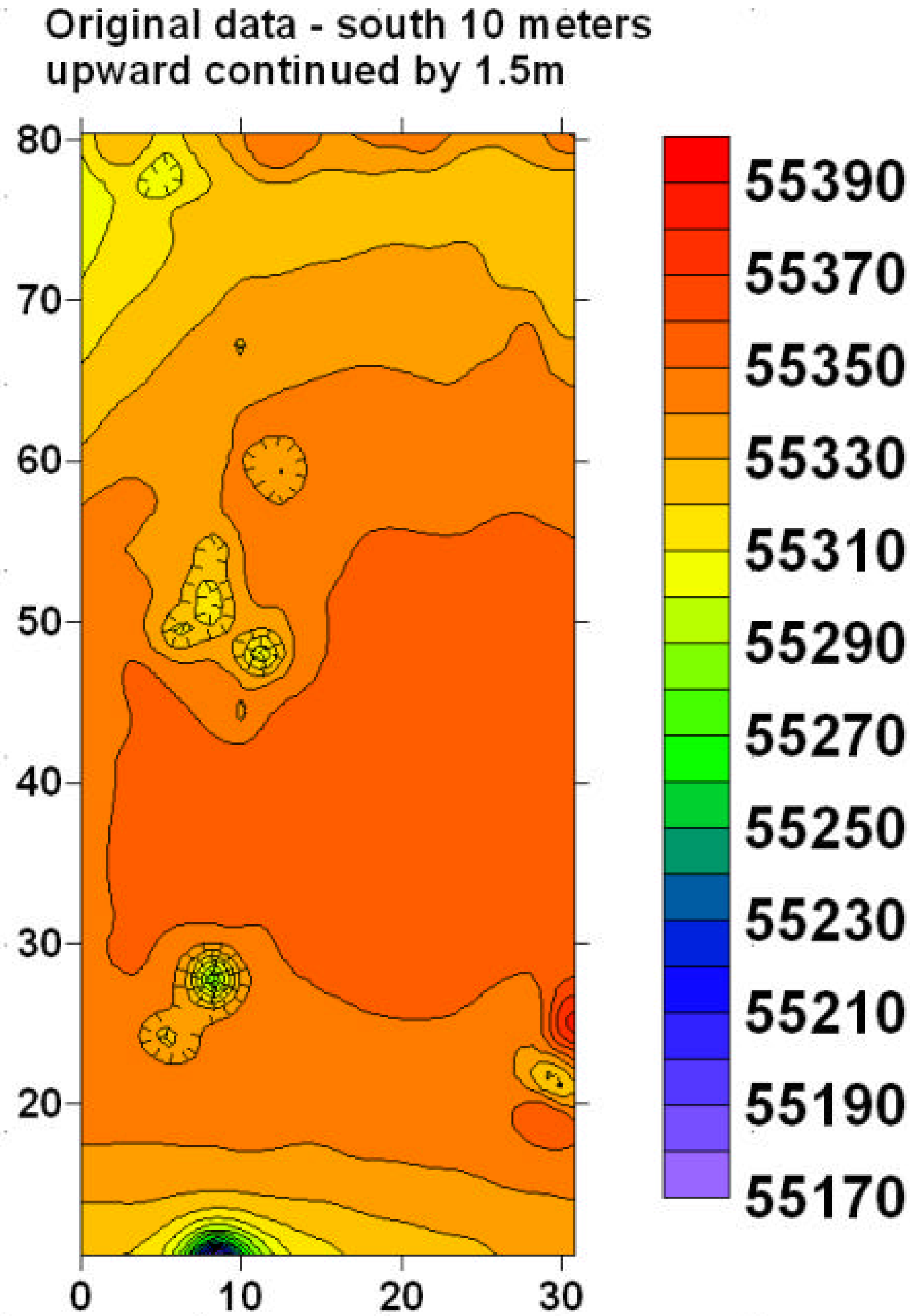
Below, I apply this process as part of a standard processing sequence on some archaeological-scale total field magnetic data collected in Pineview Park, Missoula.



The horizontal scale is meters, the magnetic induction is nanotesla. Black dots show location of field measurements (made with a Cesium vapor magnetometer). Note that we removed (missing points) some observations due to excessive noise. Problematical is that many of the anomalies at the scale of interest (meters) are in the area where there were acquisition problems. The high field gradient at the south end is due to a steel fence. Thus, I removed the southern 10 meters of data for subsequent analysis.

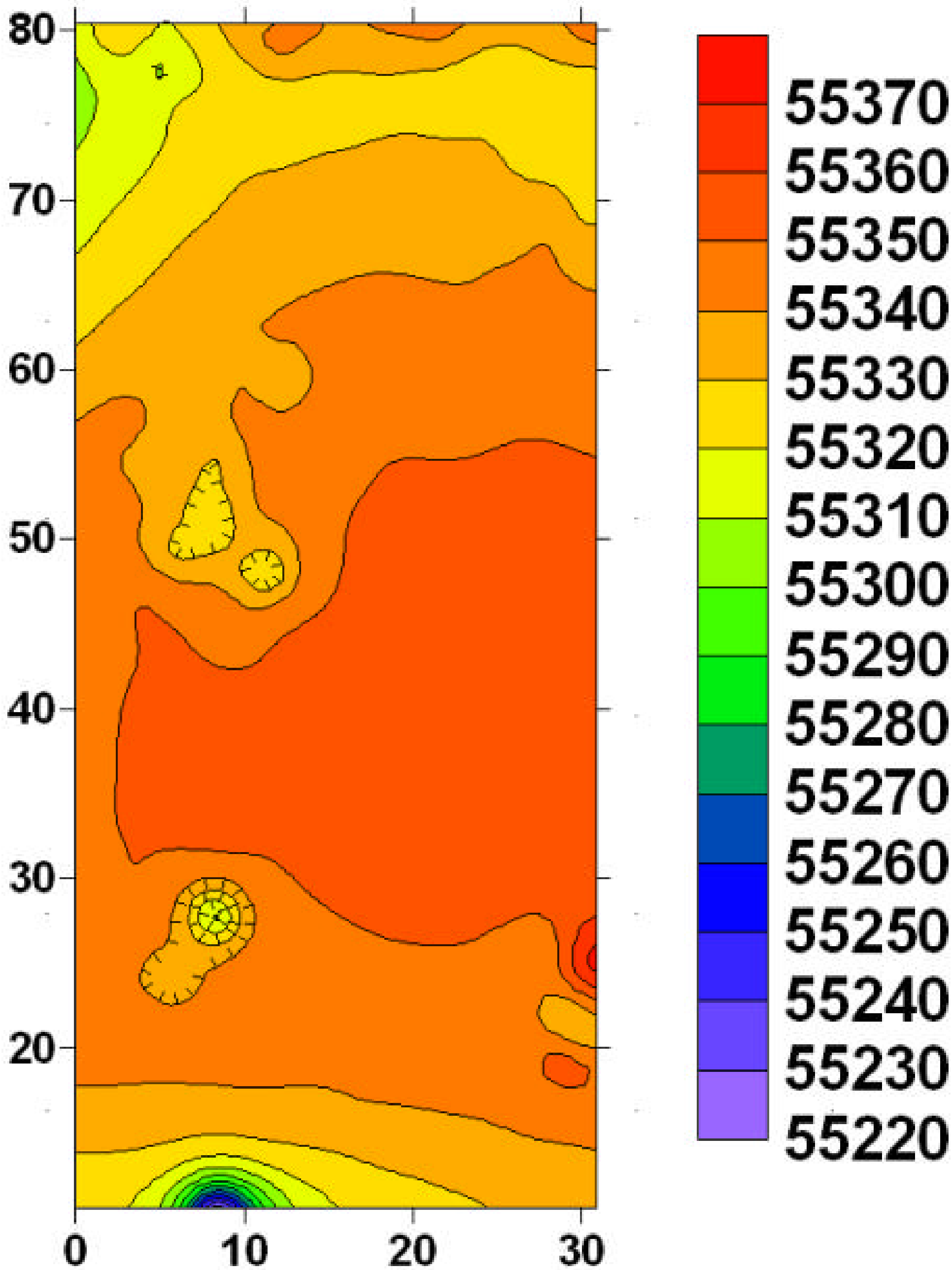


Original total field anomaly upward continued by 0.5 meters to remove short wavelength noise. The contour interval, read off the scale, is 25 nT. Typically, upward continuation by an amount equal to line spacing does not ‘cost’ a lot in terms of resolution and sometimes reduces high frequency (short wavelength) noise considerably.

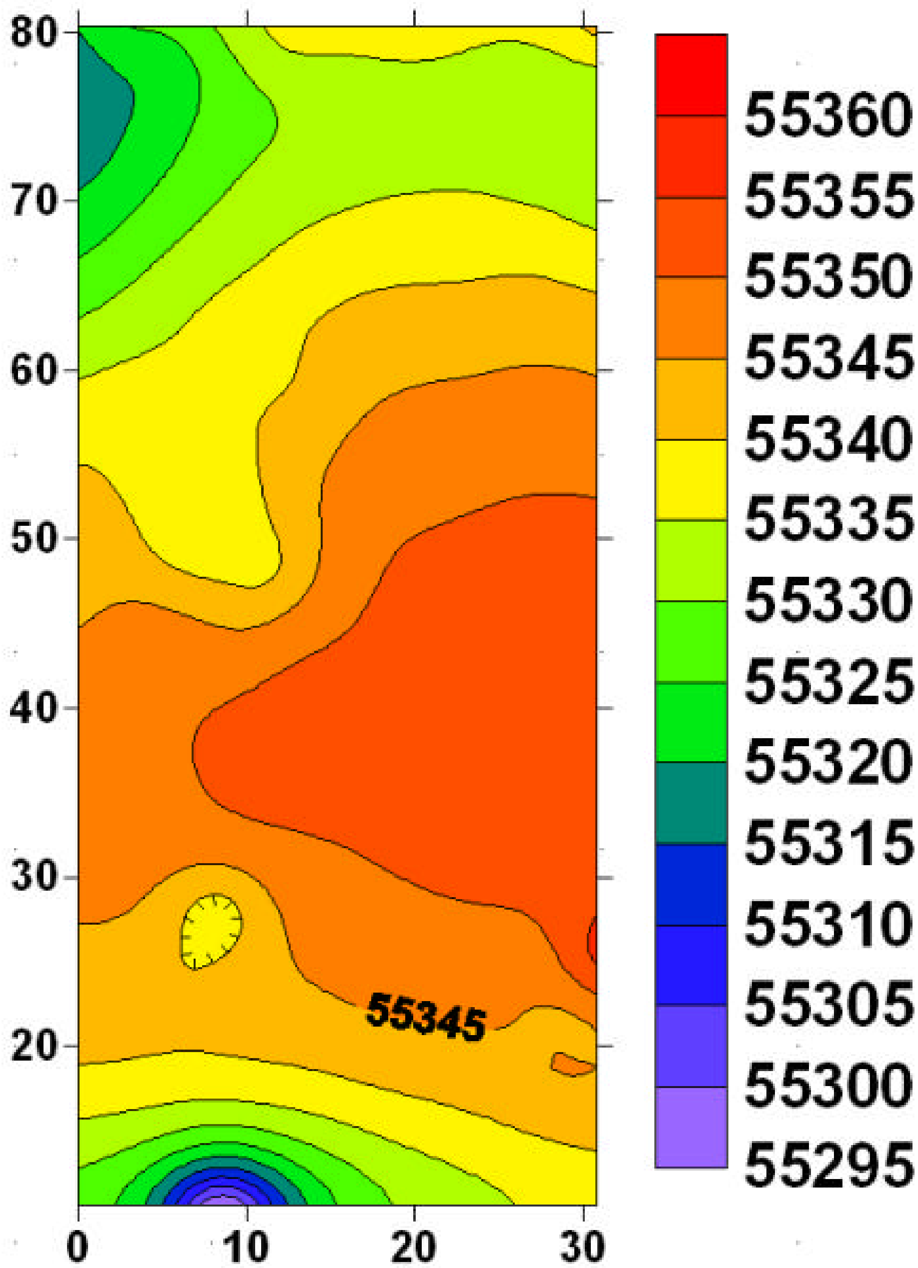


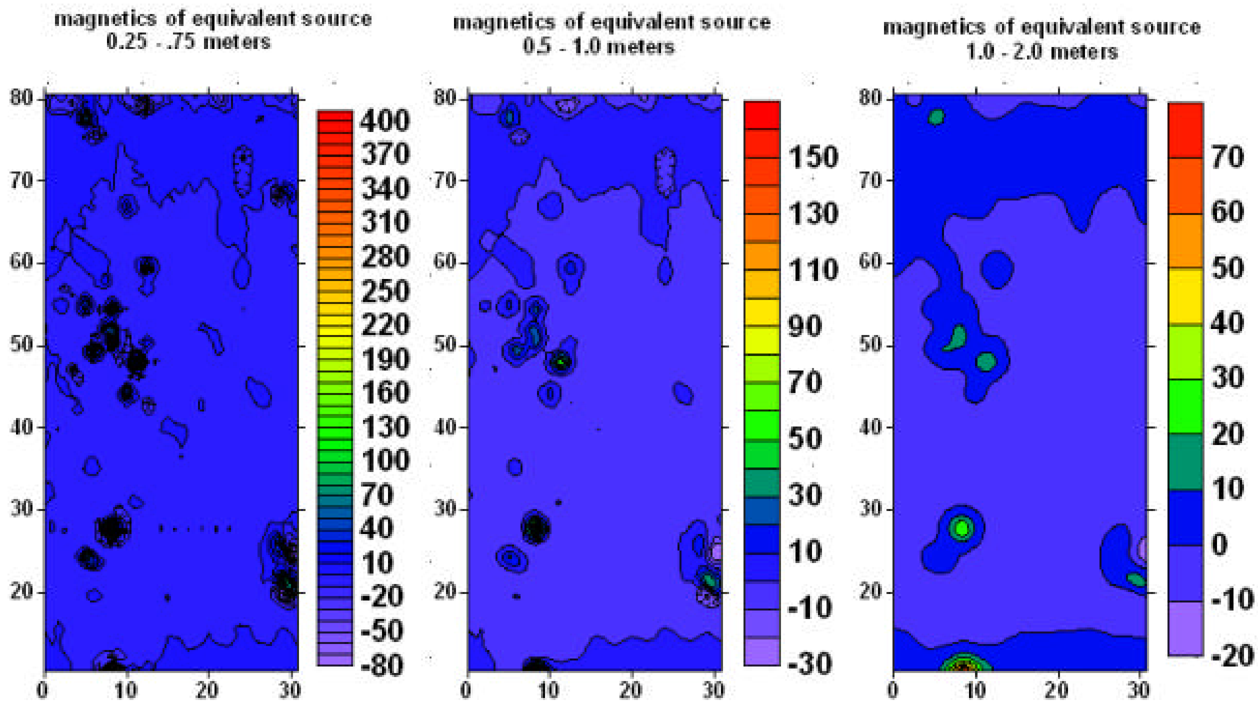
Original data - south 10 meters
upward continued by 1.5m
80
70
60
50
40
30
20
0
10
20
30
55390
55370
55350
55330
55310
55290
55270
55250
55230
55210
55190
55170

Original data - south 10 meters
upward continued by 2 meters

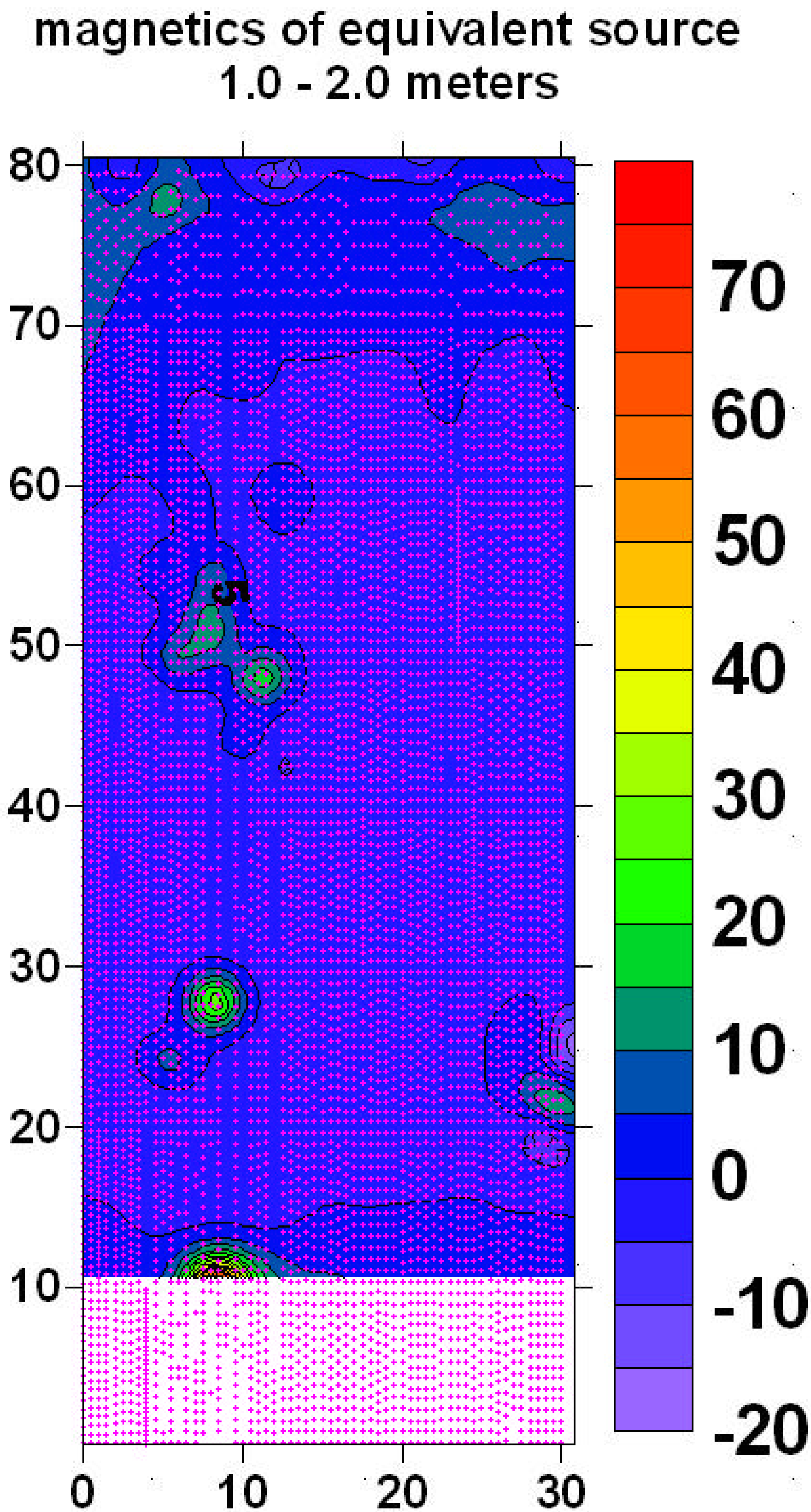


Original data - south 10 meters upward continued by 4 m

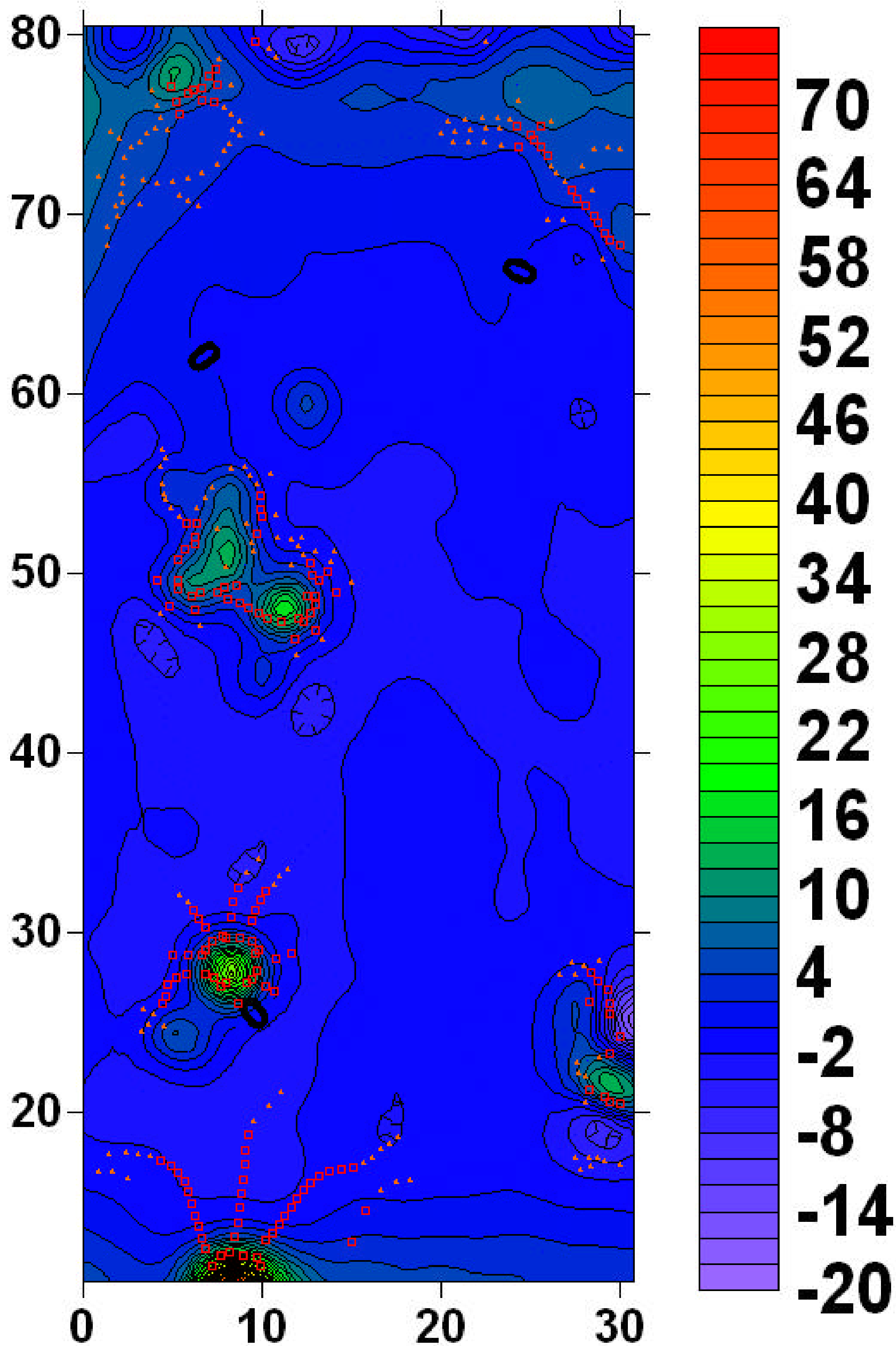




Here, the magnetic anomalies from equivalent source layers have the same contour interval. These maps result from differencing the upward continuations shown in previous figures (0.5m–1.5 m), (1.0m–2.0m), and (2.0m–4.0m), respectively. You can see that these source layers definitely contain correlated solutions. But you also get a sense of which features may have greater depth extent. In the quest for graves, the anomalies centered near: 1) X=8, Y=50, 2) X=8, Y=28, and 3) X=30, Y=22 may be of the most interest. Those three anomalies either contain much magnetic material near-surface, or causative sources at greater depth.



The overlay of acquisition points on the magnetics from the equivalent source layer at 1.0 to 2.0 meters shows that you should have some suspicion regarding the two larger anomalies on the west side of the map. Although there are many observations supporting those anomalies, and they seem to have deep sources, they are also highly correlated with the acquisition lines where we had to omit many noisy points.



The magnetics from the 1-2 meter equivalent source layer contoured at 2 nT. The dots are maxima in the horizontal gradient and are typically reasonable reliable for estimating the edges of causative sources in the subsurface. Note the features at the north edge of the map which are much more apparent with a tighter contour interval and highlighting with the horizontal gradient.