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Geonics Limited Technical Note TN-34

# Application of Geophysical Surveys Measuring Soil Magnetic Susceptibility to Locate the Site of the Eighteenth-Century Parish Church of Saint-Charles-des-Mines

at

Grand Pré National Historic Site

J. Duncan McNeill

November, 2012

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# Application of Geophysical Surveys Measuring Soil Magnetic Susceptibility to Locate the Site of the Eighteenth-Century Parish Church of Saint-Charles-des-Mines at Grand Pré National Historic Site.

J. Duncan McNeill
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Updated version of a talk presented at the Canadian Archaeological Association Annual Meeting, Halifax, NS, May 18-22, 2011

This talk will describe geophysical surveys (measuring terrain magnetic susceptibility with the Geonics Limited EM38B) to search for the site of the Parish Church of Saint-Charles-des-Mines (in which 418 males were incarcerated prior to the expulsion of the entire Acadian population of Grand Pré in 1755).

Our survey area lies in the historic Annapolis Valley in Nova Scotia.

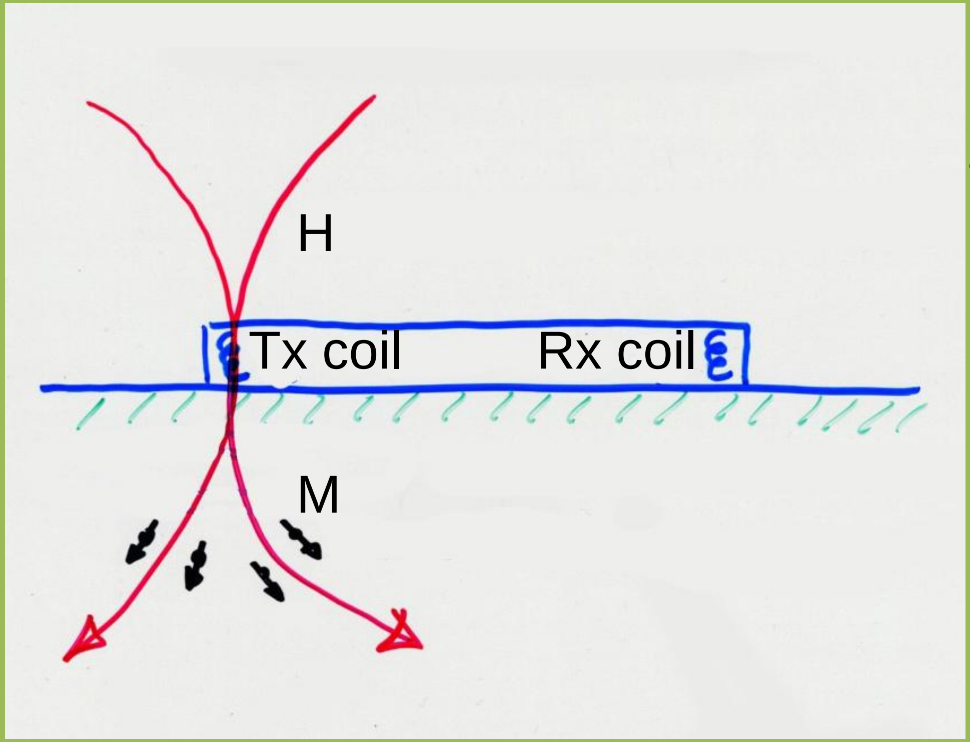
Over the years the entire area surrounding the modern Grand Pré Memorial Church (shown in the next slide) has been surveyed by combining a number of smaller survey blocks.

The outline of the Memorial Church will be shown on many of the rest of the slides to facilitate orientation of the smaller survey blocks with respect to the Church and the entire survey area.


N
Grand Pré National Historic Site
Modern Memorial Church
South Field

But first, what is the soil magnetic susceptibility and how do we measure it?

It is a measure of how easily the soil can be polarized by a magnetic field. We measure it with small transmitter and receiver coils mounted in a rigid, non-magnetic, non-conducting frame, such as the Geonics Limited EM38B.




The transmitter coil generates a primary, alternating magnetic field in the soil, of strength (H).

The result is that any magnetic mineralization in the soil becomes magnetized, with strength (M), causing a secondary magnetic field. Both primary and secondary magnetic fields are measured by the receiver coil.

We define the magnetic susceptibility as κ (kappa), where

$$\kappa = \text{soil magnetic susceptibility} = M/H$$

On what does the magnetic susceptibility of the ground depend?

We will see that, at Grand Pré, the magnetic susceptibility, κ, depends (1) on the iron-rich (mafic) mineralization of the soil, (2) on the mineralization present in any boulders included in the soil, and (3) very likely, on whether the soil has been physically burned in the past.

The susceptibility of the boulders at Grand Pré arises from the fact that many of them are volcanic in origin. They are not indigenous to Grand Pré , having been eroded from the south edge of the North Mountain volcanic (basaltic) lava sheet twenty kilometres to the north, and subsequently transported from North Mountain to the Annapolis Valley ten thousand years ago by the last glaciation,.

Their size, shape, and hardness makes them ideal for building purposes, and they have apparently been used as such ever since Europeans settled in the area.

They also make ideal geophysical targets!

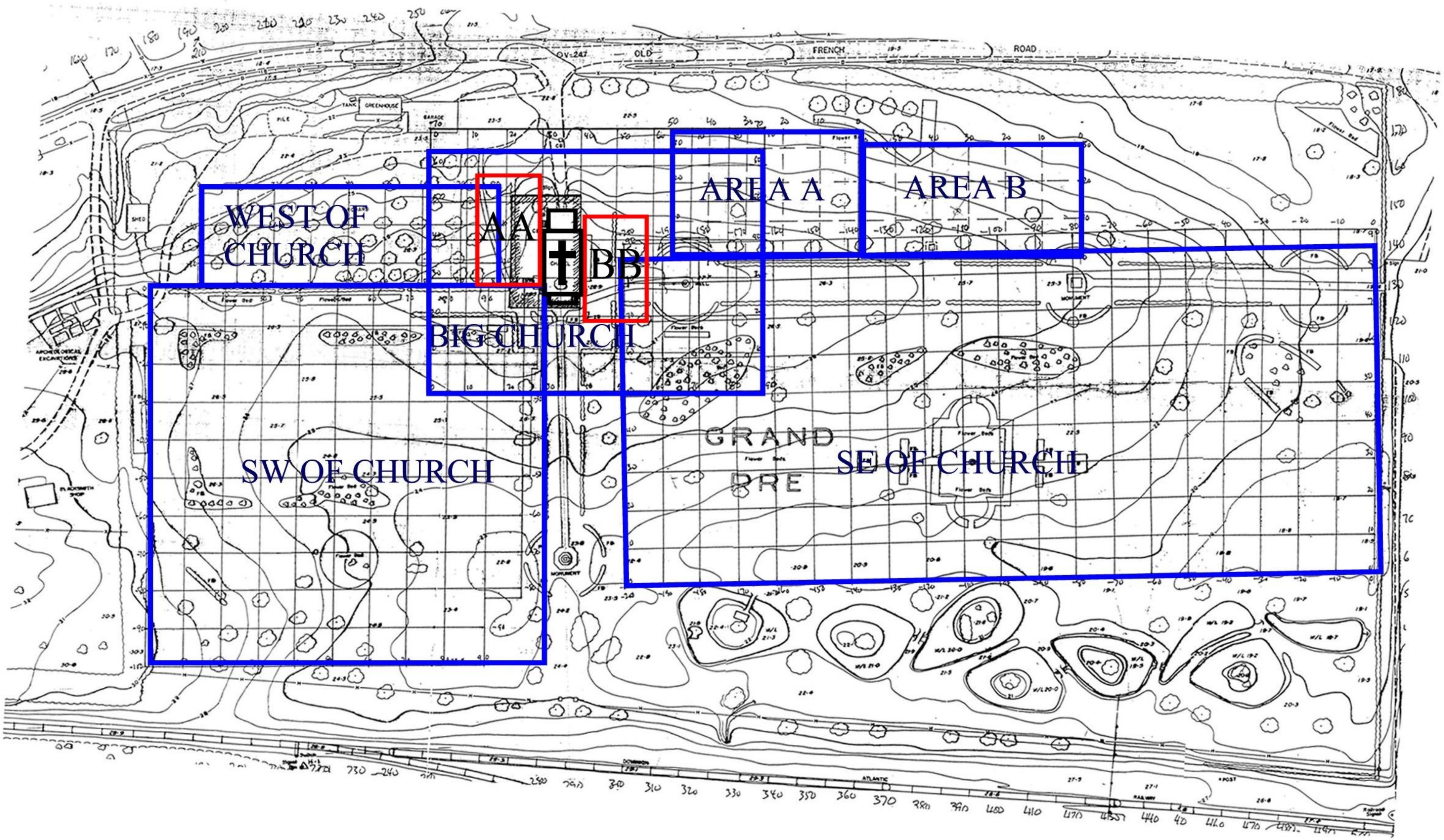
The following slide (7) outlines the smaller survey areas that will be discussed in the talk (note the location of the Church in each slide).

The next two slides (8,9) show contours of magnetic susceptibility data, first for the area south-west of the Church, and then for the area west of the Church.

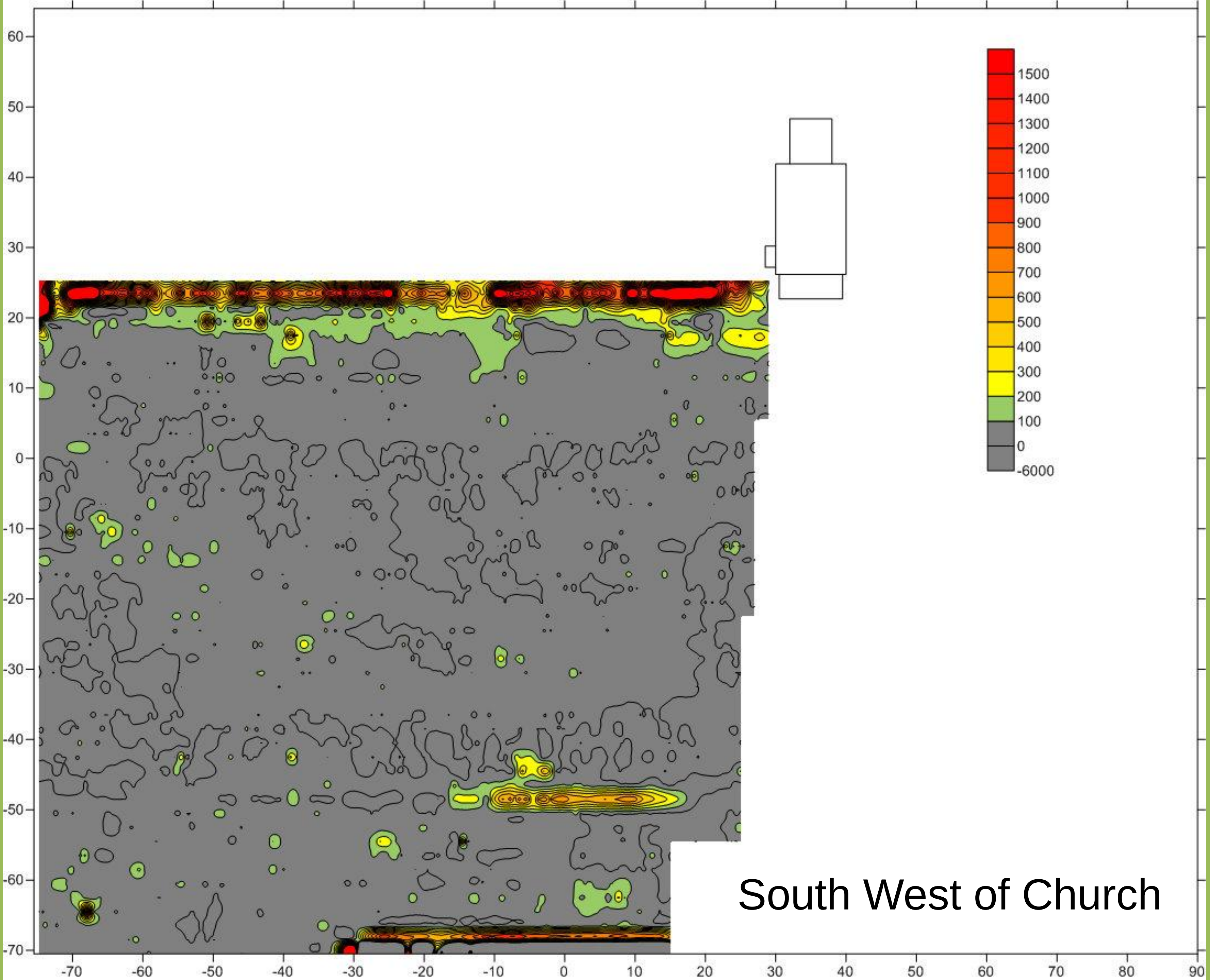
The susceptibility will be in units of parts per million (ppm), or occasionally in parts per thousand (ppt) of the primary magnetic field strength. Colour bars will show the range of contour colours as a function of susceptibility, running from a lows of grey to highs of red.

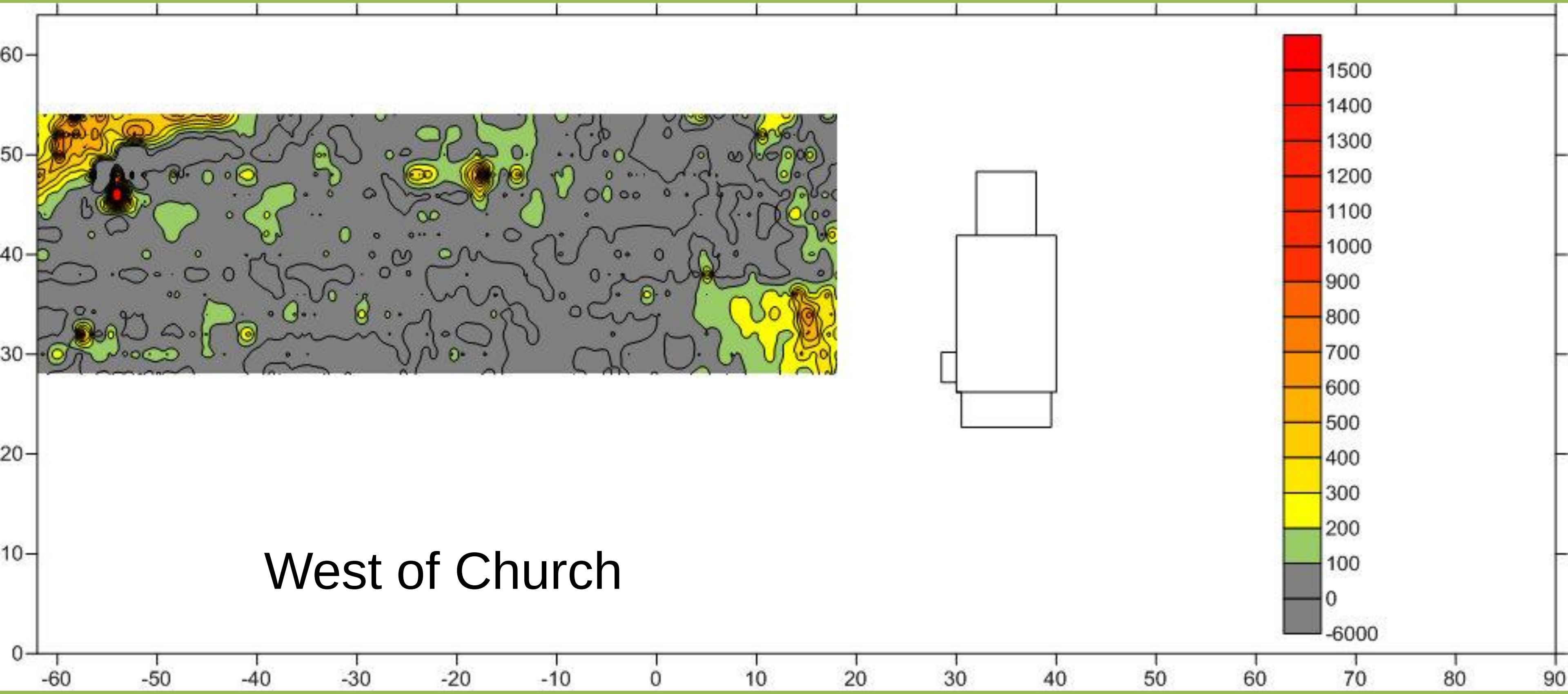
These two slides will suggest that, in the majority of the entire survey area, the susceptibility values are quite low, often less than 100 ppm, and this is indeed the case.

Where there are high susceptibility anomalies, they will often be linear in shape and caused by the many metallic irrigation pipes that run in various directions across the entire area.



WEST OF CHURCH
AA
BB
AREA A
AREA B
BIG CHURCH
SW OF CHURCH
SE OF CHURCH
GRAND PRE
OLD FRENCH ROAD


1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
-6000
South West of Church

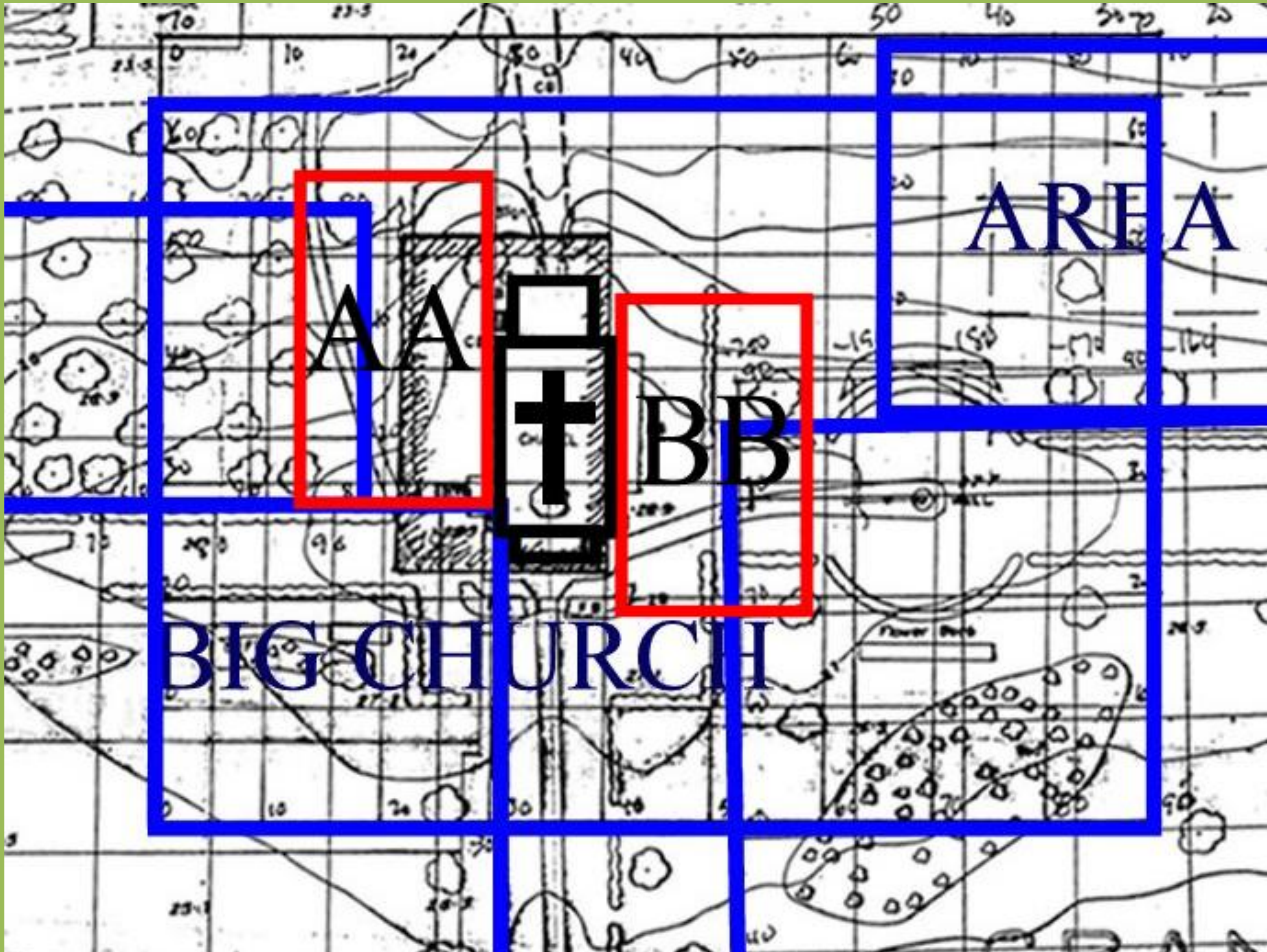


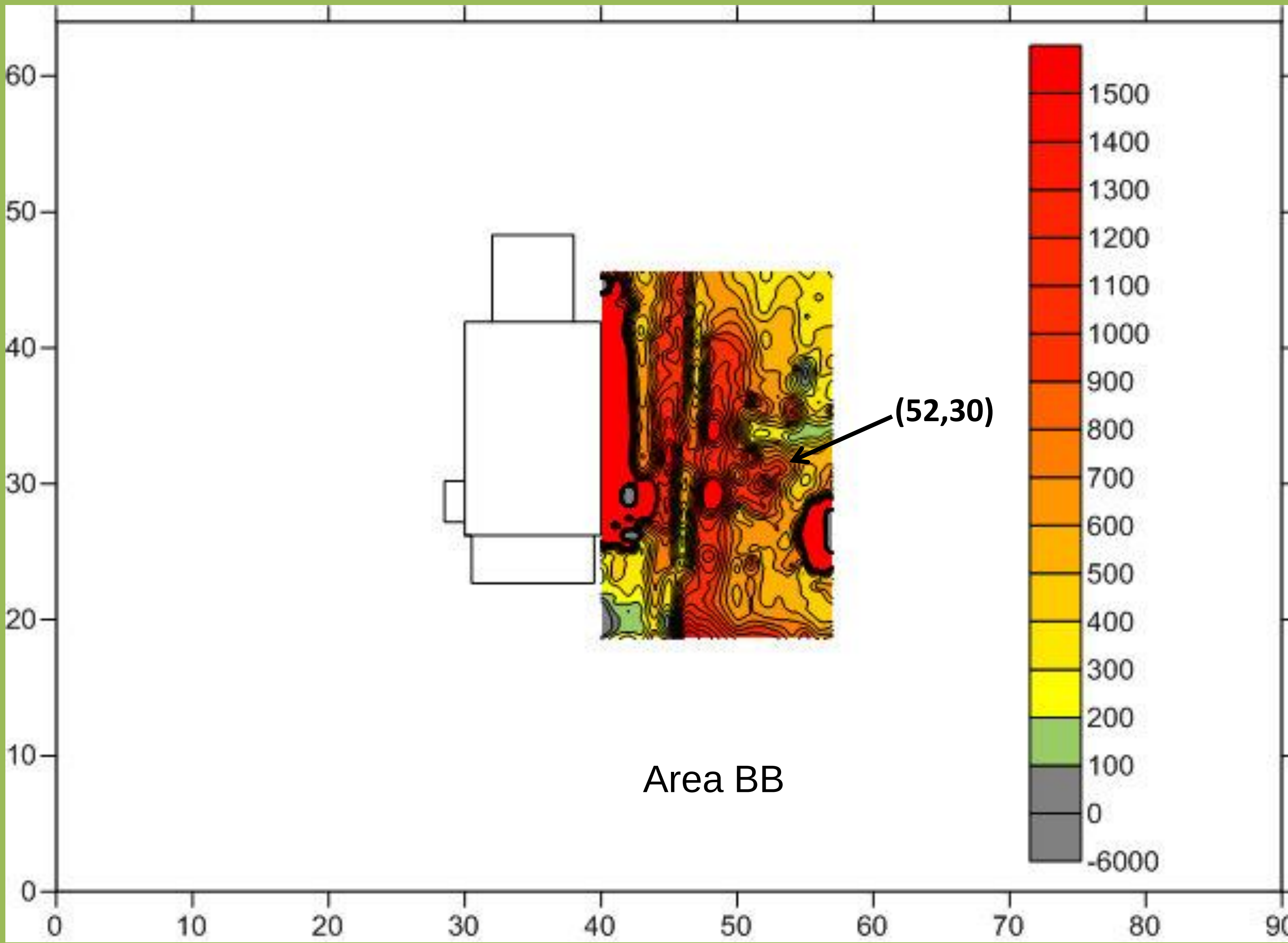
West of Church
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
-6000
-60
-50
-40
-30
-20
-10
0
10
20
30
40
50
60
70
80
90

We should always keep in mind that it is both the morphological shape and the maximum values of susceptibility anomalies that are important in interpreting surveys and deciding where interesting targets might be located.

The next four slides (11-14) show successively…
(11) The location of  Area BB, one of the smaller survey areas.
(12) Contours of susceptibility.  Note particularly the anomaly at (52,30).
(13, 14), Photos of excavations at that anomaly, showing the foundations of an early building. This building has been ascribed to Acadian occupation and moreover shows evidence of having been burnt.

Examination of the boulders shows that many of them are basalt and therefore contribute at least in part to the susceptibility anomaly.  It may also be possible that the act of burning itself has converted some non-magnetic iron oxides in the surrounding soil to magnetically active magnetite or maghemite, which would also contribute to the anomaly.


AREA A
AA
BB
BIG CHURCH


60
50
40
30
20
10
0
0
10
20
30
40
50
60
70
80
90
(52,30)
Area BB
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
-6000

13

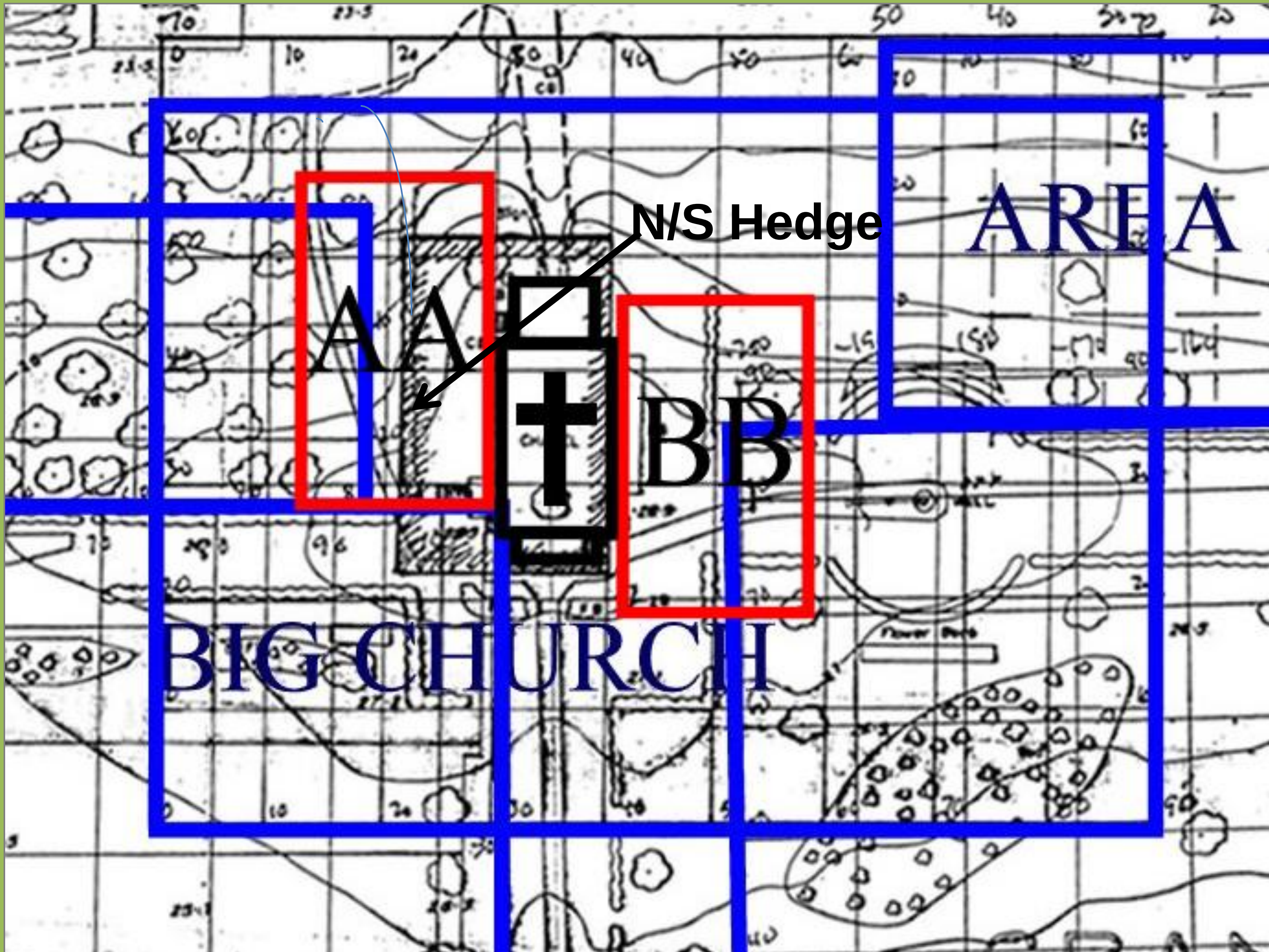
In slide (16) we go next to Area AA, just to the west of the Church.

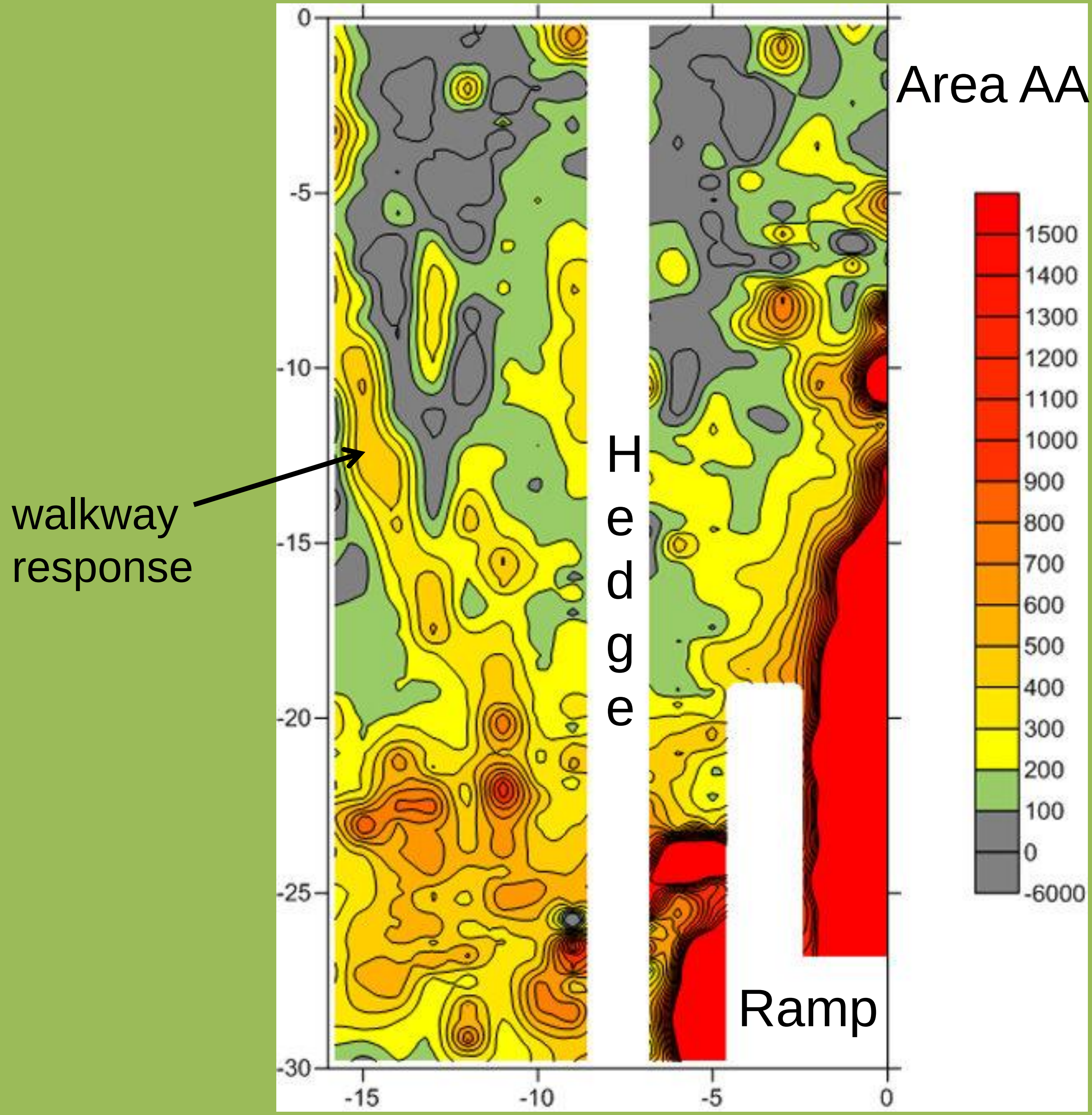
Note the curved pathway (lying under the letter A, it is rather hard to see) which tends to the NNW, and also the labeled N/S hedge that lies just to the east of this pathway.

The following slide (17) shows contours of the susceptibility, which is responding to, amongst other features, the gravel material that was used to make the path.

The following two slides (18,19) show the results of excavations in Area AA. Note again the pathway and hedge. We see, on the closest side of the wall, other stone features that are not directly associated with the wall.

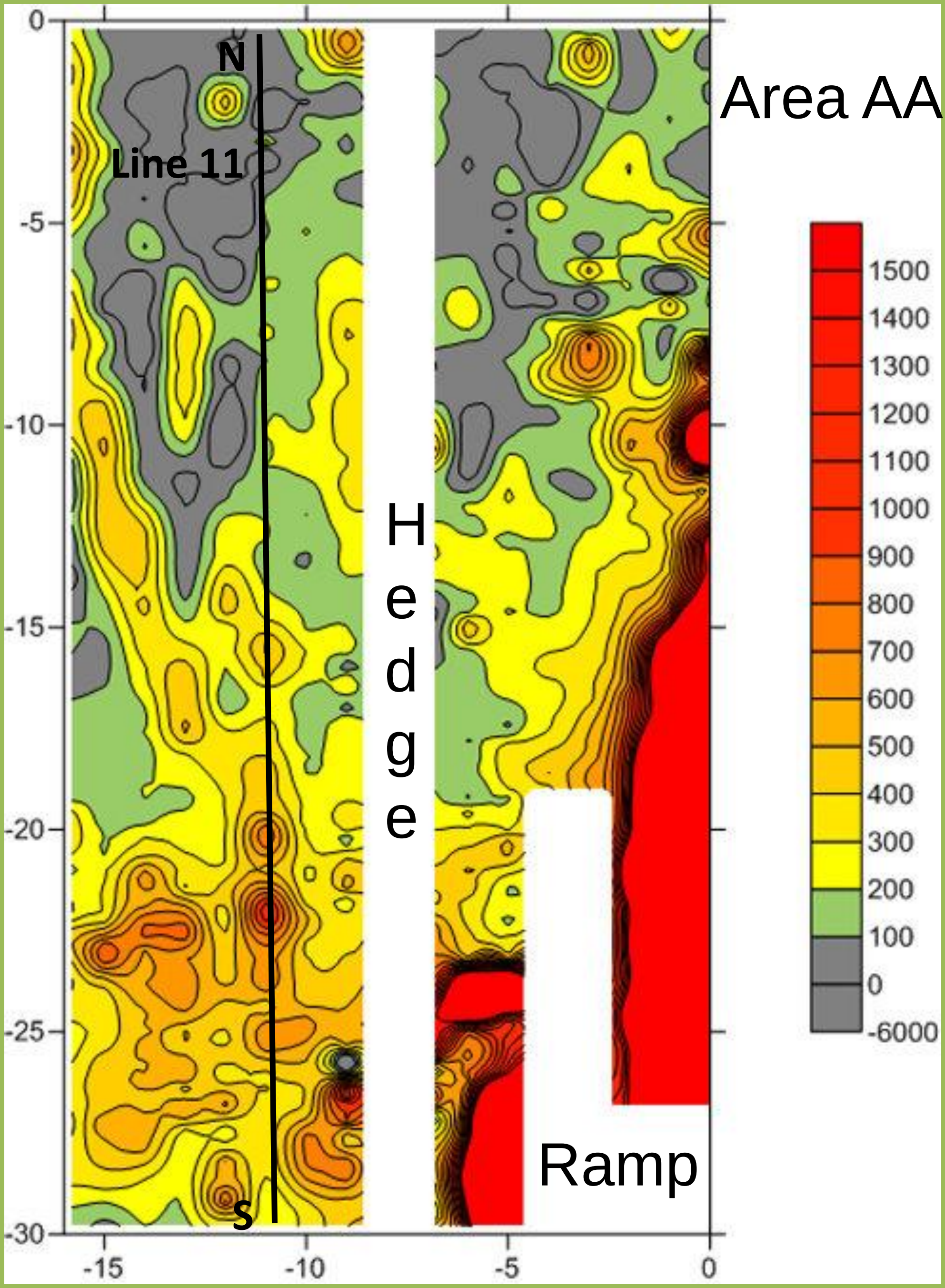
It would be nice to be able to say that the buried rock wall was a geophysical discovery but it was in fact discovered during excavations for the installation for a new water pipe. However it is definitely a geophysical success.


N/S Hedge
AREA
AA
BB
BIG CHURCH

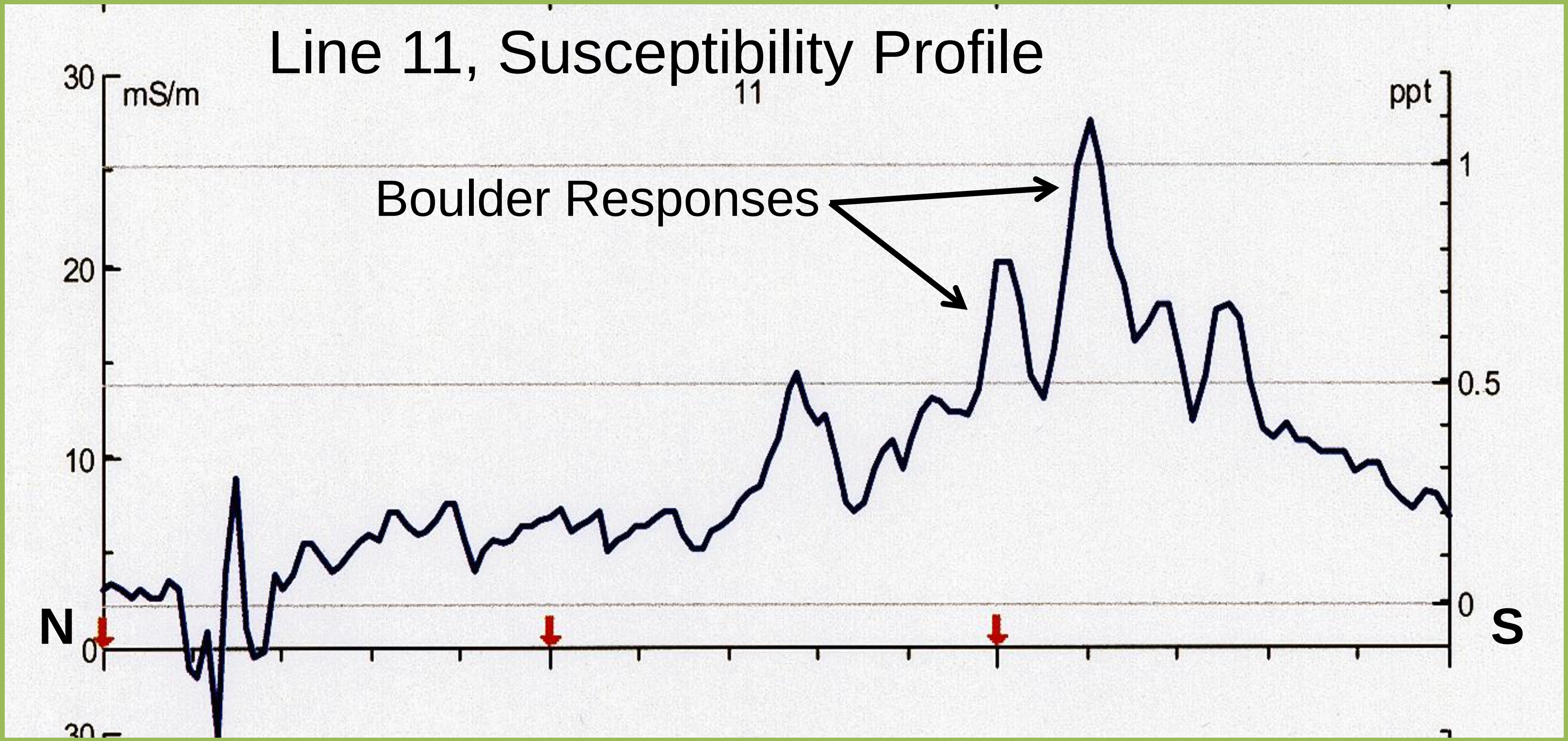

Area AA
Hedge
Ramp
walkway response
0
-5
-10
-15
-20
-25
-30
-15
-10
-5
0
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
-6000

The next three slides (21-23) successively show…
(21) The same contours of the susceptibility of Area AA, but now with the location of survey line 11N added to the plot.
(22) The actual survey profile of the susceptibility from south to north.  We note that there are two components to the response.
(23) The first is a spatially slowly varying component.  Superimposed on this component is the spike-like response from isolated basalt boulders.

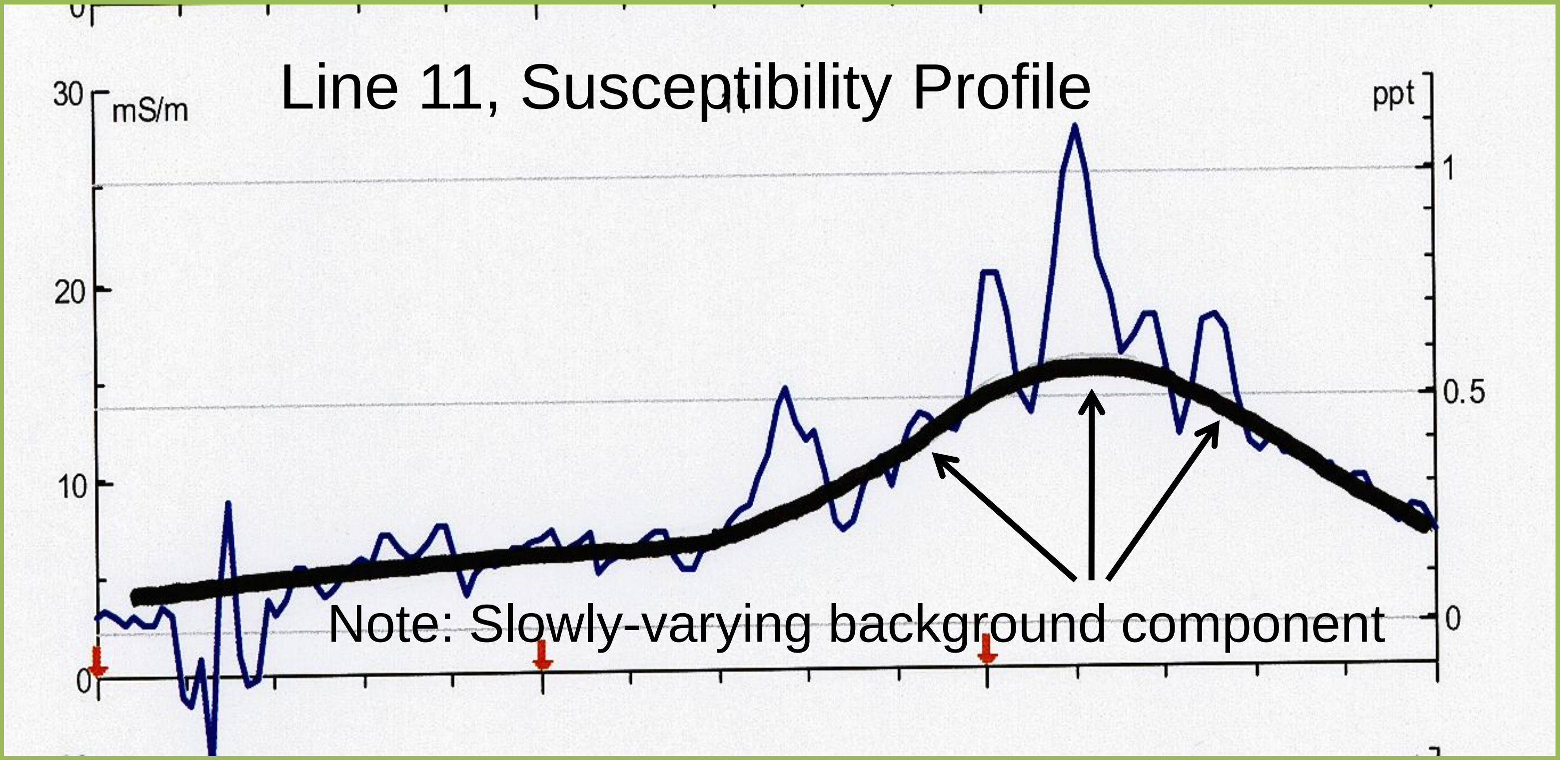
Our interest lies in the slowly varying component.  We shall see more of this type of feature again later.



N
Line 11
S
Area AA
Hedge
Ramp
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
-6000
0
-5
-10
-15
-20
-25
-30
-15
-10
-5
0



Line 11, Susceptibility Profile
mS/m
11
ppt
Boulder Responses
30
20
10
0
1
0.5
0
N
S



Line 11, Susceptibility Profile
30
mS/m
20
10
0
ppt
1
0.5
0
Note: Slowly-varying background component

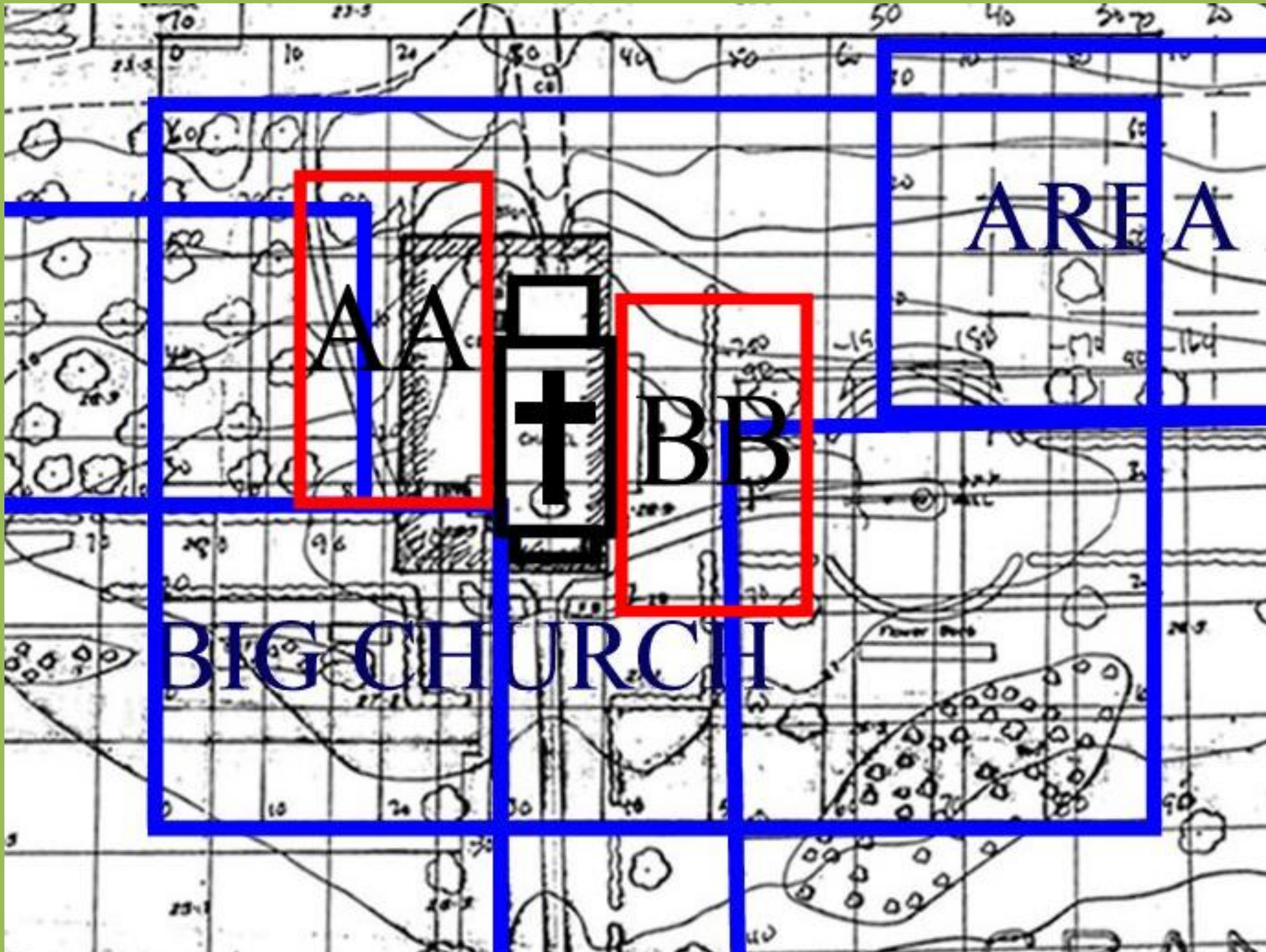
The next slide (25) shows the outlines of the larger area known as the Big Church, which encompasses the smaller areas with which we have been dealing to date.

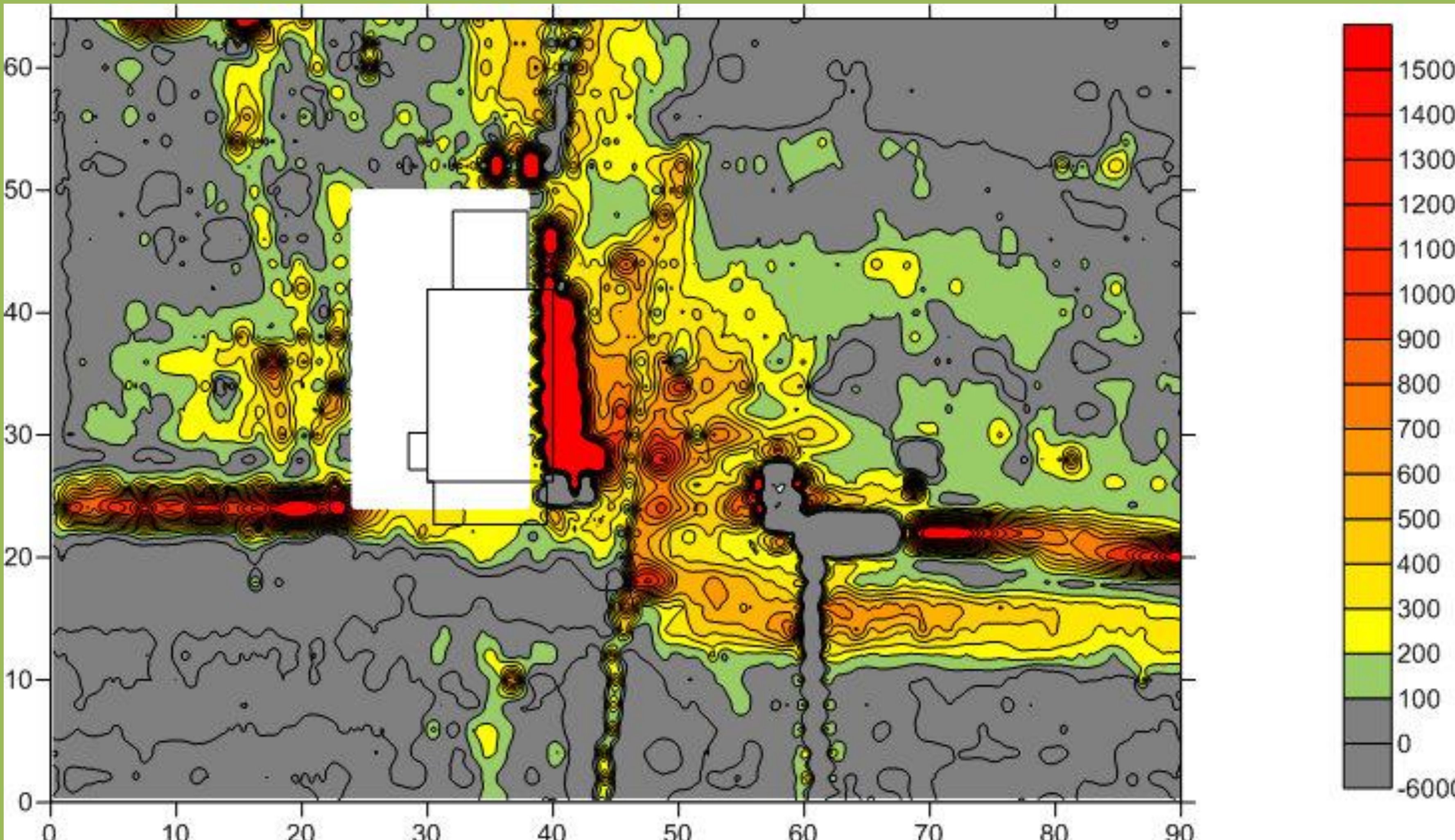
The following slide (26) shows the susceptibility contours for this new area. Some might describe it as a ‘dog’s breakfast’ but we find it interesting.

The main problem with interpretation is that the area near the Church is studded with underground metallic pipes and/or cables (all linear features, trending in both E/W and N/S directions).

This survey was done with E/W lines at 2 meter interline spacing so they do not show the E/W anomaly particularly well. The E/W pipes do not help!

Our interest lies in the large, broad, roughly E/W anomalous area outlined by the yellow contours at a level equal to or greater than 200 ppm. The major part of this anomaly lies to the east of the Church, but a smaller portion lies to the west of the Church as well.


AREA A
AA
BB
BIG CHURCH



60
50
40
30
20
10
0
0
10
20
30
40
50
60
70
80
90
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
-6000


Big Church

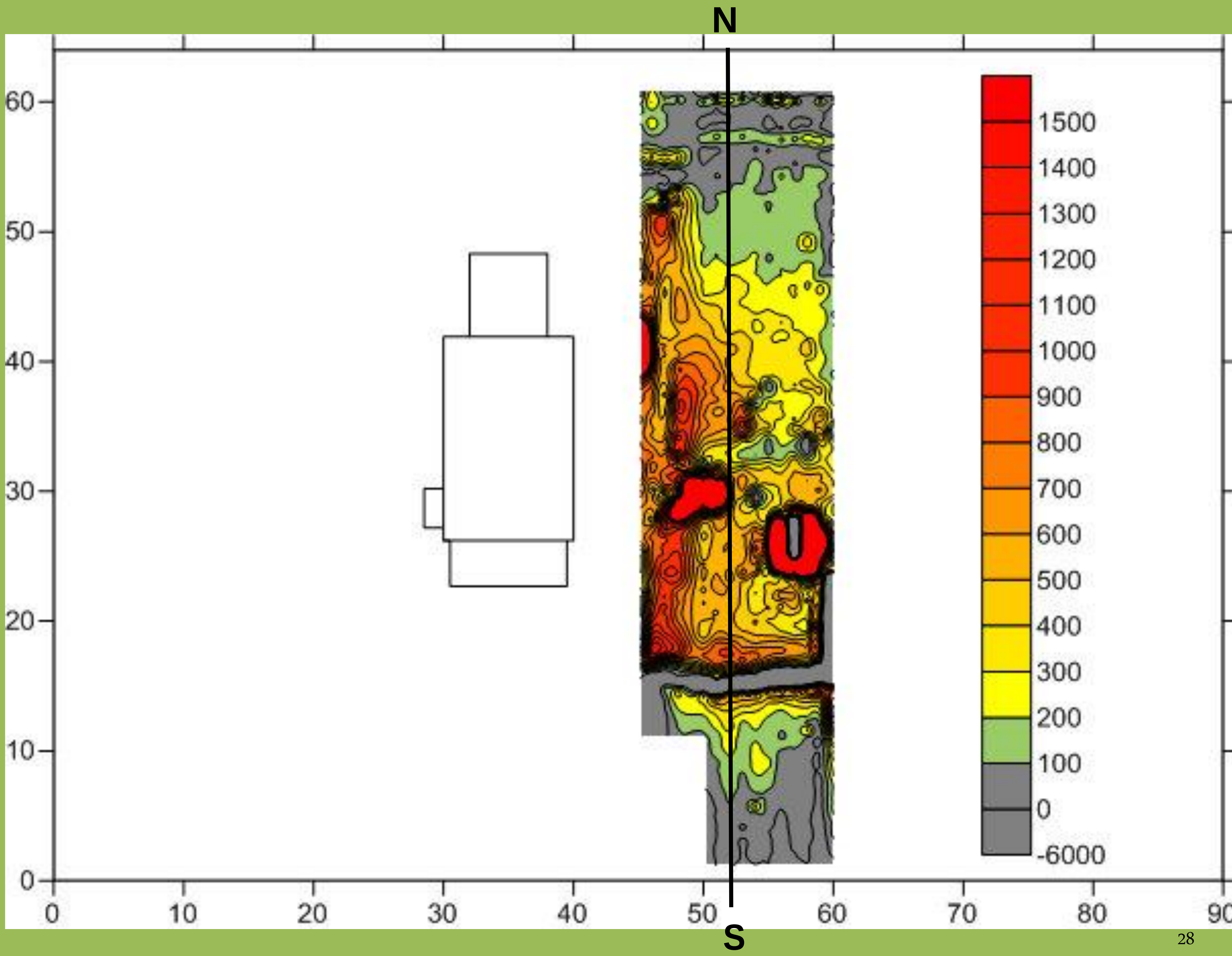
A later survey, just east of the Memorial Church, was carried out using N/S survey lines spaced at one meter to help understand the large, broad E/W trending anomaly referred to above.

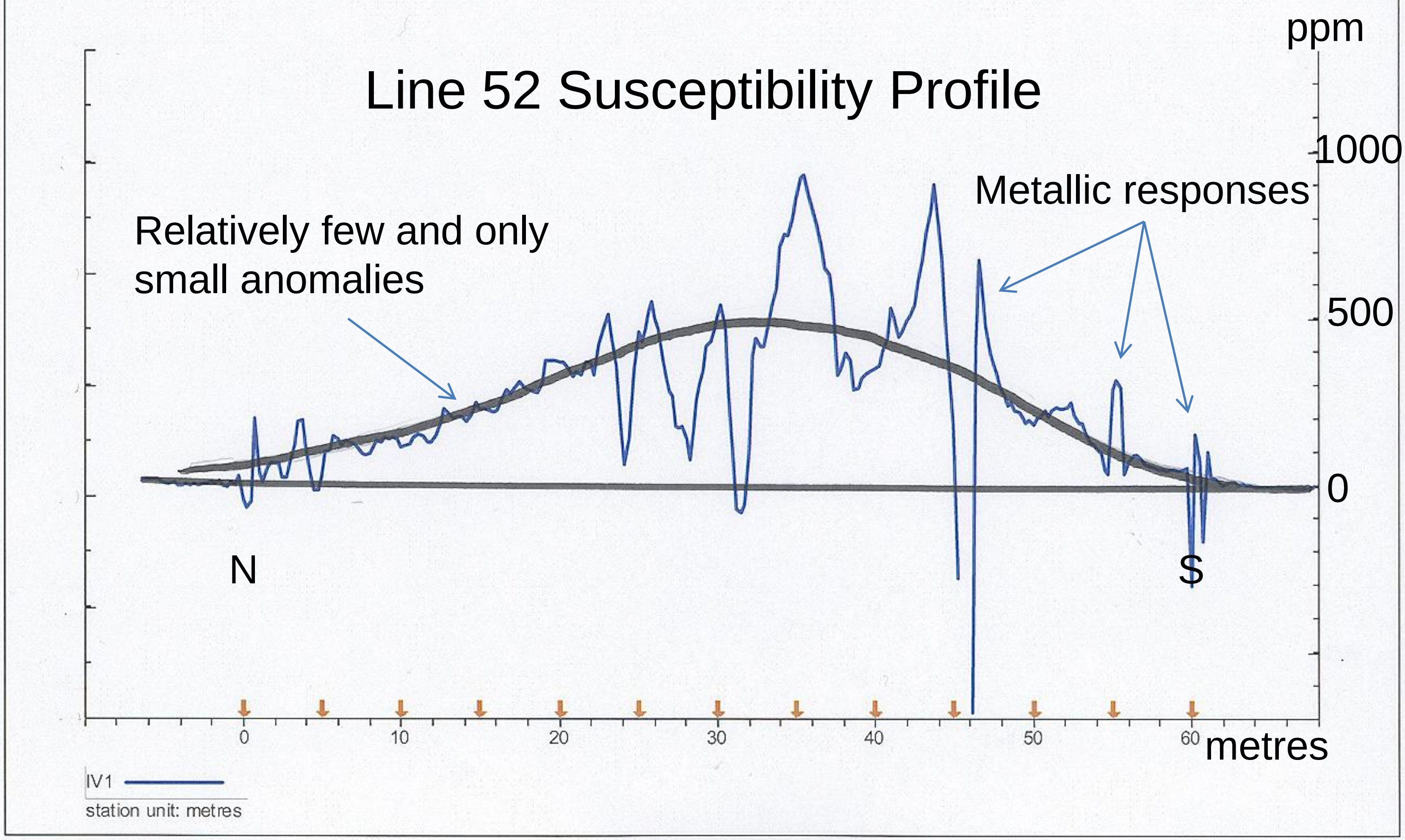
Contours (and the location) for this survey are shown in the next slide (28).

The anomalous area is somewhat better defined by the N/S lines.

The N/S profile along line 52 from this survey, shown on the next slide (29), shows this anomaly more clearly. Also sketched in on the profile is another slowly varying component, quite similar to that seen earlier on the west side of the Memorial Church.

As before, also seen are responses from basaltic materials, and, in this case, the metal pipes.


N
S
0
10
20
30
40
50
60
70
80
90
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
-6000


Line 52 Susceptibility Profile
ppm
1000
500
0
Relatively few and only
small anomalies
Metallic responses
N
S
0
10
20
30
40
50
60
metres
IV1
station unit: metres

In the next slide (31) we show three susceptibility profiles from this survey. But now, in addition to the susceptibility (inphase) response, the slide also shows for each profile a simultaneously occuring quadrature phase response (which response normally responds only to the electrical conductivity of the ground).

We often note that, where there are susceptibility anomalies, the quadrature phase profile is a mirror image of the inphase response, and of roughly comparable amplitude. The two responses are clearly related.

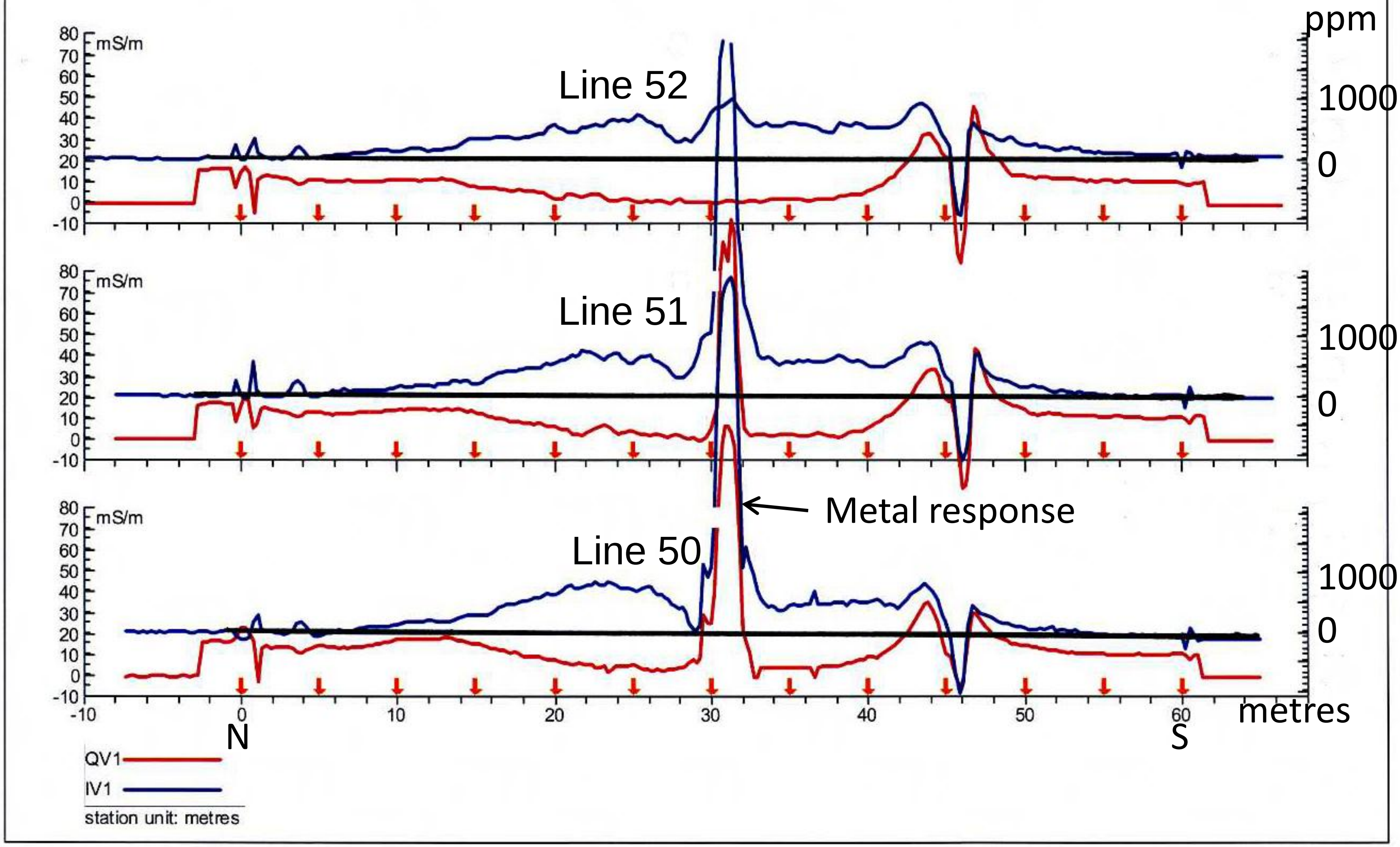
This behaviour occurs when the iron oxide mineralization causing the susceptibility response is derived from extremely small mineral particles.

Under these conditions the susceptibility response takes longer than normal to respond to the inducing primary magnetic field and lags behind it. We say that there is a ‘relaxation effect’ influencing the response.

It is also known that soil burning greatly enhances the soil susceptibility.

# Lines 50 to 52 (Susceptibility:blue, Conductivity:red)

Note that the conductivity accurately reflects the susceptibility.



These slowly-varying inphase susceptibility responses and anomalous quadrature phase susceptibility responses are seen (1) throughout the ‘Big Church’ anomaly, (2) in the north-west corner of the Park, and (3) at other surveyed areas near the Park. We suggest that one of the causes of the soil magnetic susceptibility enhancement is soil burning.

Such burning is known to convert low-susceptibility iron oxides (such as hematite) to strongly magnetic oxides (such as magnetite and maghemite) which are readily detected by the EM38B.

We also suggest that the relaxation effect is due to fine mineral particles generated by soil and building burning (which was widely prevalent during the expulsion of the Acadians from their Nova Scotia homeland).

Throughout the Grand Pré survey area localized susceptibility anomalies are caused by the presence of mafic boulders. But there are also broader regions that appear to have been subjected to burning.

And finally, there is much buried metal, mainly in the form of pipes.

## Conclusions

That *if* the Parish Church was situated within the current Park area, then the geophysical evidence tells us that, since there are no other large, high susceptibility anomalies characteristic of basalt rocks and/or soil-burning in the Park, it is very likely that the anomalies just east and west of the Memorial Church are indeed directly related to the Parish Church.

Geophysics will suggest where to look, but excavation will have to tell the whole story!

Acknowledgements

I would like to thank Rob Ferguson, recently retired archaeologist with Parks Canada, for introducing me to the delights of archaeology combined with geophysics, and for his continuing use of geophysics for archaeology in the Maritimes over the past two decades, Jonathan Fowler, Assistant Professor of Archaeology at St. Mary’s University, for his enthusiasm, advice and ongoing support for the geophysical survey work at Grand Pré over the past decade, and last but not least my wife and partner-in-crime, Sylvia, who has assisted me in carrying out all of the many surveys, and who has also put up with much, much more while I poured over the data.