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GEOLOGICAL REASONS FOR CHANGE IN INTENSITY OF
LINEAR MAGNETIC ANOMALIES OF THE KURSK MAGNETIC
ANOMALY

I.A. Zhavoronkin and V.V. Kopayev

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16. Abstract

An examination is made of the geological reasons for fluctuations in the anomalous field intensity along the polar axes. The Kursk magnetic anomaly is used as the basis for the study. A geological-geophysical section was constructed using results of interpreting gravimagnetic anomalies.

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GEOLOGICAL REASONS FOR CHANGE IN INTENSITY OF LINEAR MAGNETIC ANOMALIES OF THE KURSK MAGNETIC ANOMALY

By I. A. Zhavoronkin and V. V. Kopayev

It is common knowledge that linear, highly intensive magnetic   /238*
anomalies of the KMA [Kursk Magnetic Anomaly] are due to steeply
dropping beds of ferruginous quartzites. Laboratory and field meas-
urements have established that the total magnetization vector ($I = I_i + I_r$) is close to the direction of drop of the bed.

Anomalies are heterogeneous along the stripe. Regional, signif-
icant changes are observed in their average intensity over the course
of dozens of kilometers ("steps"). In addition, anomaly bands consist
of alternating local maximums and relative minimums ("contractions").
Field intensity in the "contractions" diminishes several times. The
aforementioned features are used to study the structure and composition
of ferruginous quartzite beds. But it is impossible to state that
their geological dependence has been completely revealed.

Certain authors in the last decade have attempted to provide a
geological interpretation of the noted features of the magnetic field.
In this case they have advanced as the reasons a different degree of
metamorphism and oxidation, postmetamorphic pressures, changes in the
depth of the lower boundary of quartzites and so forth [1, 2, 3, 4, 6,
7]. The "contractions" even now are a search criterion for rich iron
ores of the hypergenic type [5, 11, 13, 14] which indicates the impor-
tance of a more extensive study of the nature of local elements of
magnetic anomalies. This becomes possible because an extensive vol-
ume of factual geological and geophysical material has been accumu-
lated in the form of drilling data, measurements of physical proper-
ties and comprehensive geophysical photographs of increased accuracy.

Fluctuations in the anomalous field intensity along the polar

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*Numbers in margin indicate pagination in original foreign text.

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axes could be due to a change either in magnetization of the ferruginous quartzites, or relative subsidence of the upper pole (the ratio of the depth of occurrence of the upper pole to the horizontal thickness of the bed), or the depth of occurrence of the lower pole.

Below we will examine some of the geological reasons for these factors.

Ferruginous quartzites are divided into two groups according to the nature of their magnetization. The first group includes quartzites with factor $Q<1$, ($Q = \dfrac{I_r}{I_i}$), where I_r is residual magnetization, and I_i is inductive magnetization. Quartzites with a factor $Q>1$ belong to the second group.

Magnetization of the first group of quartzites mainly depends on the magnetite content. It is common knowledge that in the nonoxidized quartzites of KMA, the magnetite content is rarely less than 30%. It has also been established that magnetization of ferruginous quartzites change linearly depending on the magnetite content only to 10 - 15% [1, 10], with magnetite content over 30 - 35% no law is observed [6]. Consequently, under conditions of KMA, change in magnetite content in the nonoxidized quartzites cannot significantly influence the magnitude of the anomaly and is viewed as a secondary factor. As the oxidation process develops to a certain measure, magnetite content in ferruginous quartzites changes in a broad interval (from 5 to 40%) which advances this factor to one of the primary places in studying magnetization of these beds. Oxidation reduces magnetization tens and even hundreds of times. It has been established in this case that the boundary for the oxidation zone is fairly clear.

The second group includes almost nonoxidized, deeply metamorphized ferruginous quartzites. The magnitude of their magnetization is mainly determined by the degree of metamorphism and postmetamorphic

pressures. Laboratory studies and analysis of factual material for KMA [6] have shown that metamorphism influences the grain size of magnetite, while the latter increases inductive magnetization of quartzites, sometimes double. The residual magnetization increases even more strongly under the influence of high temperature metamorphism. Postmetamorphic pressures could reduce residual magnetization more than half [7, 12].

Magnetization of ferruginous quartzites depends to a certain measure on a number of other geological processes (metasomatosis and so forth). However their influence is apparently weak and has not yet been sufficiently studied.
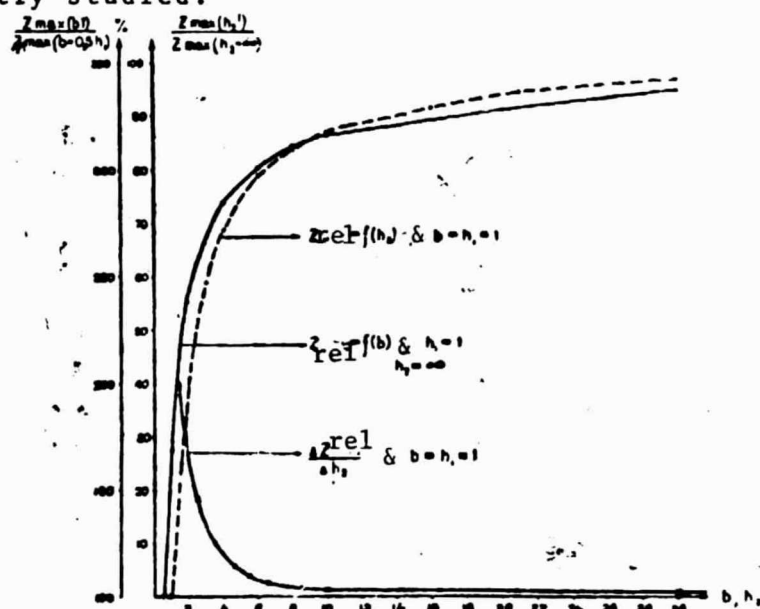

Figure 1. Graphs for Change in Intensity of Anomaly Above a Bed of Ferruginous Quartzites Depending on Relative Thickness (b/h$_1$) and Relative Subsidence of the Lower Boundary (h$_2$/h$_1$)

Change in intensity of the anomalies depending on horizontal thickness of the quartzite bed is shown in Figure 1. With thick beds, change in parameter b (semithickness of the bed) has almost no influence on anomaly intensity. This parameter has the greatest influence when b < 2h$_1$. The ratio b/h$_1$ for the majority of nonoxidized or slightly oxidized ferruginous quartzite beds at the KMA is

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in limits of 0.5 - 3. In this interval, with an increase in bed
thickness 6-fold, intensity of anomaly rises 2.6-fold. The magnitude
of the b/h_1 ratio for the same extended, linearly drawn out nonoxi-
dized bed changes no more than by 20 - 30%. Consequently, the change
in anomaly intensity could not exceed 10 - 15%. When there is a
thick zone of intensive oxidation in the upper part of the quartzite
bed, the b/h_1 ratio diminishes significantly, and in this case anomaly
intensity could change several times (see the left branch of the curve
$Z_{rel} = f(b)$.

Figure 1 also illustrates the graph of the function

$$Z_{rel} = f(h_2) = \frac{Z_{max}(h_2 i)}{Z_{max}(h_2 = \infty)} \text{,}$$

where h_2 is the depth of the lower pole. Calculations were made for
a bed with $b = h = I$.

It is apparent from the graph that on the segment $\infty > h_2 > 10$,
anomaly intensity changes only by 12%. The change in depth of the
lower pole begins to have the most significance at $h_2 < 5h_1$; the latter
is clearly visible from the graph $\frac{\Delta Z_{rel}}{\Delta h_2}$. Consequently, significant
change in the anomaly above the ferruginous quartzite beds can only
be expected if there is sharp undulation in the lower boundary of
folded or fault nature, for example, from depths measured in kilo-
meters to depths measured in hundreds of meters.

Thus, from the reasons examined above which determined field
intensity within one anomaly, one should consider magnetization of
the bed and depth of occurrence of its upper pole to be the primary.

Two types of bed models were constructed to clarify the geolog-
ical reason for anomalous "steps" and "contractions." The model of
the first type consists of two blocks: semi-infinite bed with $h_2 = \infty$ and semi-infinite prism. The model of the second type includes
three blocks: two semi-infinite beds with $h_2 = \infty$, and one finite

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prism. In both cases, the models illustrate the upthrow fault of the ferruginous quartzite beds with different nature of oxidation. Oxidation was modeled by changing the magnitude of manifestation of individual blocks.

A calculator was used to compute the anomalous effects on the long axes of the models with vertical uniform magnetization of different magnitudes [8]. The nature of the field of theoretical models allows us to evaluate the degree of influence of each of the factors on the intensity of the anomaly (Figures 2 and 3). The upthrow fault of half of the bed which is "infinite" along the strike and along the incidence without oxidation of the upthrow fault part is slightly expressed in the magnetic field (see Figure 2, model 1a). The intensity of the anomaly does not drop by more than 20% above the upthrow fault part of the bed, even with $h_2 = 4h_1$. With depths of the lower part of the upthrow fault block $h_2 > 10h_1$, change in anomaly intensity is essentially unnoticeable. If the upthrow fault block is oxidized /241 the entire depth, then drop in anomaly intensity is directly proportional to the degree of oxidation. The presence of an oxidation zone in the upper part of the semibed diminishes very significantly the intensity of the anomaly (see Figure 2, model 1b). Thus, with depth of the lower boundary of the oxidation zone equal to $4h_1$, anomaly intensity drops by 60%. Curves along the extended and deep oxidation zone have the appearance of "steps" and are very similar to the curves above the overthrow fault and part of the bed oxidized to a varying degree.

The overthrow fault of the bed block limited along the stripe creates local minimums "contractions" (see Figure 3, model 2a) slightly pronounced in the absence of oxidation. Complete oxidation of the overthrow fault block proportionately increases the contraction of the anomaly to 90%. The presence of an oxidized zone (model 2b) limited along the stripe and in depth results in similar changes in field intensity. Thus, with extent of the zone 2b = $10h_1$ and vertical thickness $3h_1$ with complete oxidation, anomaly intensity diminishes by 80%.
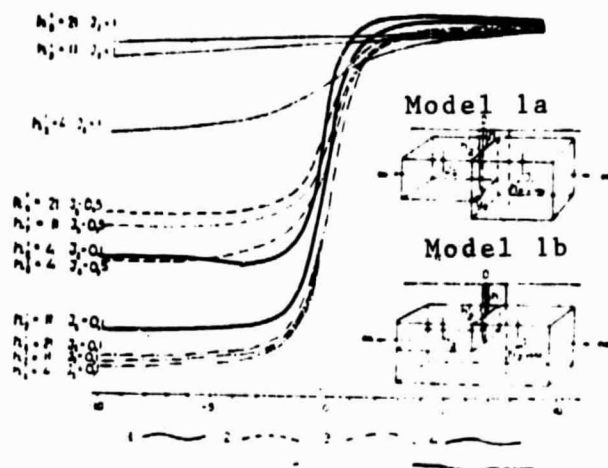
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Figure 2.   Graphs Z_a Along Heterogeneous
Beds of Ferruginous Quartzites:
model 1a (two blocks) overthrow
fault block is not oxidized or
oxidized to the entire depth;
model 1b bed with oxidation zone
in the upper part.

Conventional designations:

1.   Graphs Z_a above overthrow fault (with-
out oxidation)
2.   Graphs Z_a above overthrow fault (over-
throw fault block oxidized by 50%)
3.   Graphs Z_a above overthrow fault (over-
throw fault block oxidized by 90%)
4.   Graphs Z_a above bed with oxidation zone
(upper part of the semibed oxidized by
90%)

Model 1a

$$Z = 2lf \ (h_1; \ h_2; \ X; \ 2Y_0); \ h'_1 = 1; \ h'_2 = 4; \ 11; \ 21; \ h''_2 = \infty;$$
$$2Y_0 = 2; \ 2I_1 = 1; \ 2I_2 = 1; \ 0,5; \ 0,1$$

Model 1b

$$Z = 2lf \ (h_1; \ X; \ 2Y_0); \ h_1 = 1; \ h'_2 = 4; \ 11; \ h''_2 = \infty;$$
$$2Y_0 = 2; \ 2I_1 = 1 \ 2I_2 = 0,1$$

It follows from what has been said that thick zones of oxidation of ferruginous quartzites appear most distinctly in the magnetic field. Other factors create local elements which are close in intensity. In order to distinguish their influence, it is necessary to study the spatial distribution of the field. Characteristic changes of the field linked to the effect of each of the factors creating the contractions of the anomaly and the steps are presented in the table.
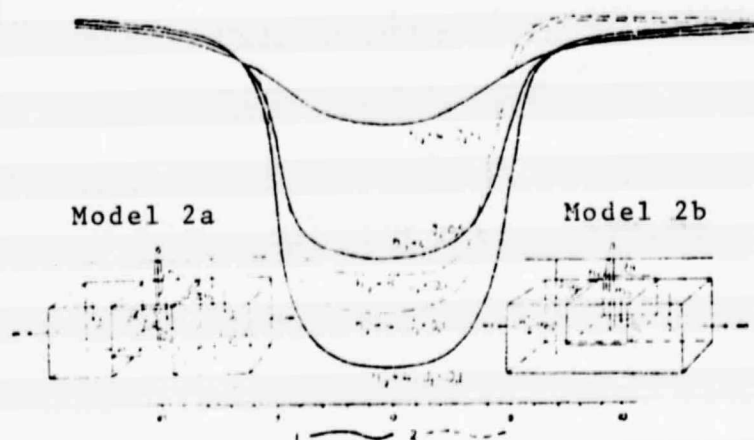
Figure 3. Graphs Z_a Along Heterogeneous
Beds of Ferruginous Quartzites:
model 2a (three blocks) overthrow
fault block not oxidized or oxi-
dized to entire depth; model 2b
bed with limited oxidation zone
Conventional designations:
1. Graphs Z_a above model 2a
2. Graphs Z_a above model 2b
Model 2a

$$Z = 2If\ (h_1;\ h'_2;\ 2Y_0;\ 2b);\ 2Y_0 = 2;\ 2b = 10;\ h_1 = 1;\ h'_2 = 4;$$
$$h''_2 = \infty;\ 2l_1 = 1;\ 2l_2 = 1;\ 0.5;\ 0.1$$

Model 2b

$$Z = 2If(2Y_0;\ 2b;\ h_1;\ h'_2);\ 2Y_0 = 2;\ 2b = 10;\ h_1 = 1;\ h'_2 = 4;\ 6;$$
$$h''_2 = \infty;\ 2l_1 = 1;\ 2l_2 = 0.1$$

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The reasons for the formation of "steps" on the magnetic anomaly axis are mainly changes in metamorphism, mineralogical composition of the nonoxidized quartzites, complete and partial oxidation of the bed over a long area, decrease in bed thickness, and overthrow fault of the extended block bed. Oxidation of the upper part of the bed on a limited course, postmetamorphic pressures and overthrow fault of a short part of the bed govern the "contractions" of the anomalies.

With careful examination of the table presented, one can note that each factor is characterized by only one inherent combination of changes in the magnetic field. Analyzing the changes in the magnetic field along and cross to the course of the anomalies, one can obtain rich additional information about the geological structure of the ferruginous quartzite beds, their composition and certain geological processes. However solution to these problems in practical geophysical work is very complicated for a number of reasons. The fact is that such processes as postmetamorphic pressures, tectonic dislocations and movements, as well as subsequent oxidations are in close interrelationship. Therefore simultaneous influence of several factors changing the intensity and shape of the anomalies always occurs.

In addition, there are a number of factors which complicate the anomalies from the ferruginous quartzites that are not examined in this article (heterogeneity of magnetization, complications in the form of occurrence in the beds, lateral influences). They distort the shape and intensity of the minimums accompanying the positive anomaly, and impair their use. Relative intensity of the accompanying minimums rarely reach 5%, therefore even insignificant outside influ- /244 ences noticeably complicate them. Quantitative calculations on complex minimums or their use as qualitative criteria could result in serious errors.

In order to reduce the ambiguity in the geological interpretation of local developments of the magnetic field, one should use data of other geophysical methods for this purpose. We will examine below

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TABLE. FACTORS GOVERNING CHANGES IN ANOMALIES FROM FERRUGINOUS QUARTZITES

| Physical Factors	Geological Nature of Physical Factor	Nature of Field Change
Change in effective magnetization of bed of ferruginous quartzites	Degree of metamorphism	Change in intensity of anomalies and relative intensity of accompanying minimums Z_{min}/Z_{max}
	Decrease in magnetite content, increase in quantity of nonmagnetic interlayers Postmetamorphic pressures	
	Oxidation of bed entire depth on great course (kilometers, first dozen kilometers)	Decrease in anomaly intensity two-fold; shape in anomaly preserved or somewhat constricted with unaltered relative intensity of minimums Decrease in intensity of anomalies 10 and more times with preservation of form
Change in relative subsidence of upper poles	Fault; oxidation of upper part of bed	Decrease in intensity by 10 - 70% with expansion of anomaly. Increase in relative intensity of minimums with simultaneous removal from the anomaly axis
Decrease in horizontal thickness of the bed	Features of lithogenesis of tectonics	Decrease in intensity of anomaly by 10 - 80%, considerable decrease in width of anomaly (to maximum dimensions with line of poles)
Change in depth of occurrence of the lower pole	Overthrow fault	Decrease in intensity of anomaly by 20 - 25%, decrease in width of anomaly, increase in relative intensity of minimums
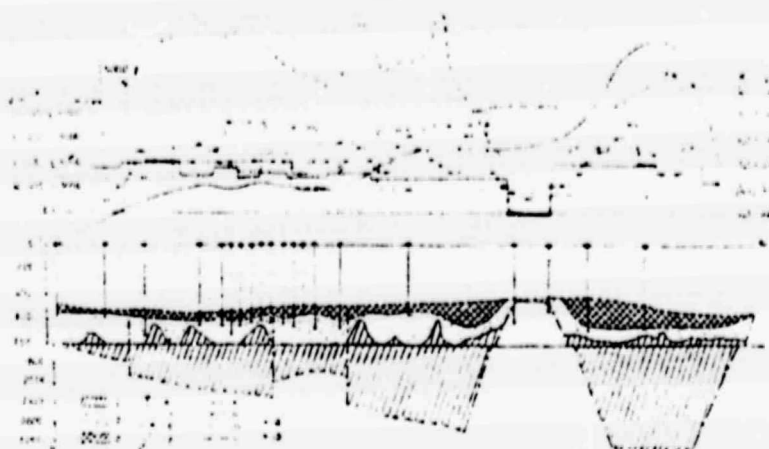
Figure 4. Geological-Geophysical Section Along One
           of the Poles of Ferruginous Quartzites of
           KMA

Conventional designations:
1. ferruginous quartzites
2. hypothetical zone of ferruginous quartzite
   oxidation
3. ore formation
4. well

Position of lower boundary of ferruginous quartzites:
5. schematic
6. from interpretation data
7. hypothetical lines of tectonic dislocations

Graphs of physical parameters:
8. density from laboratory analyses g/cm^3
9. surplus density from data of curve interpre-
   tation Vx$\dot{z}$
10. magnetic susceptibility from laboratory measure-
    ments in CGSM units
11. boundary velocity, m/sec

Points at which physical parameters were defined:
12. from samples
13. from interpretation data

examples of geological interpretation of "contractions" of magnetic anomalies together with the gravimetric data. Figure 4 shows the curve Z_a along one of the ferruginous quartzite bands of KMA. It also presents graphs for density, magnetic susceptibility and boundary velocities from the data of laboratory measurements and interpretation results.

Curve Z_a has a complicated nature. Narrow local complications of both signs are observed on the background of three large-sized maximums. Regional maximums essentially coincide with their position with the gravitational force maximums, which indicates the close linkage of their causes.

Examination of the presented material with regard for the main conclusions formulated n the table allows us to provide the following geological interpretation of the magnetic field features.

The deep "regional" minimum is mainly governed by the approach of the lower pole to the surface of the Precambrian. One can essentially consider that at a certain interval, there is no ferruginous quartzite band. The less intensive "regional" minimum is governed by two reasons: decrease in the depth of occurrence of the lower edge of the bed and presence of a thick oxidation zone. The minimum /245 gravitational force indicates the decrease in the vertical thickness of the ferruginous quartzites.

Local complications in the Z_a curve are characterized by considerable gradients, which indicate their link to heterogeneities in the upper part of the bed. To a varying degree they are oxidized sections of ferruginous quartzites. In this case the minimums correspond to sections with thicker oxidation zone, and the maximum to ridge-like projections of nonoxidized ferruginous quartzites.

The conclusions drawn are confirmed to a considerable degree by the results of measuring physical properties of quartzite. In a
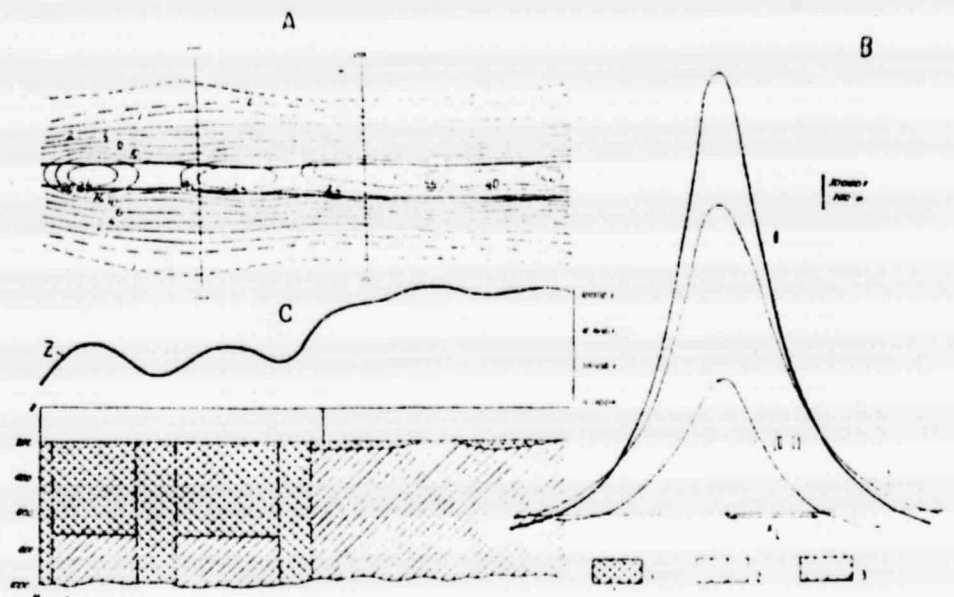
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Figure 5. Nature of Magnetic Field Above Ferruginous
Quartzite Bed with Oxidation Zone
Conventional designations:
A. map for vertical component of magnetic field
B. graphs Z_a along calculated profiles
C. geological-geophysical section of the upper part
of the ferruginous quartzites
1. hypothetical oxidation zone
2. line of tectonic dislocations
3. ferruginous quartzites

number of places, the zones of local maximums, magnetic susceptibility
of quartzites is much higher than in the zones of minimums. Unfortu-
nately, there are few tested wells, and therefore it is impossible
to make this comparison for the entire graph.

A geological-geophysical section (see Figure 4) was constructed
on the basis of results of interpreting gravimagnetic anomalies. It
reflects the entire complexity of the structural-tectonic structure
of the iron ore mass (presence of blocks, fault dislocations, thick
oxidation zones and so forth).

Figure 5 presents yet another example of the geological inter-
pretation of changes in anomaly intensity along the stripe. There
is a sharp drop in anomaly intensity along the bed, simultaneously
with a certain expansion in the zone of the first profile. Relative
intensity of the minimum in this case increases strongly. Based on
the factors formulated in the table, the reason for the decrease in /246
intensity is oxidation of the upper part of the bed, which was shown
on the longitudinal section of the iron ore mass. Constriction of
the anomaly in the left part of the figure apparently occurs because
of decrease in horizontal thickness of the ferruginous quartzites.

These examples show the possibility of deepening the interpre-
tation by analyzing local field elements which indicates the signif-
icance of the questions touched upon in this article. A number of
them require further development and verification on models, which
the authors are setting as their next task.

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