Atlantic Geology

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Volume 27, Number 1, March 1991

URI: https://id.erudit.org/iderudit/ageo27_1art05

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Publisher(s)

Atlantic Geoscience Society

ISSN

0843-5561 (print)
1718-7885 (digital)

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Cite this article

Seguin, M. K. & Frydecki, J. (1991). Residual gravity modelling of the Mount Mégantic intrusive complex, Québec, Canada. *Atlantic Geology*, *27*(1), 57–71.

Article abstract

A detailed analysis of the residual gravity anomaly of the Mount Mlgantic area. Province of Quebec, Canada, has led to unconventional modelling of the intrusive masses. A new approach was developed to approximate, as closely as possible, the regional anomaly. Using the relationship between free-air anomaly and elevation it is possible to estimate the Bouguer density at each measurement station. If the variations of the Bouguer field values reflect fluctuations of a body, then the relative error of the calculated density is much smaller than that obtained using Nettleton's method. When the density function is well defined, it is then possible to calculate the depth of the intrusive bodies at each measurement point and to determine the base of the intrusives. The masses with the greatest depth are the syenite on the southeast side of Mount M6gantic and the gabbro underneath the northern half-ring. Deep conical surfaces suggest the occurrence of conduits for the magmatic fluid at the time of intrusion. Therefore, this type of gravity modelling is useful to indicate the mode of emplacement of the intrusive bodies. Two axes, oriented west-northwest and east-southeast, characterise the deepest areas of the granite and syenite. These zones may extend downward to fault planes in the Earth's crust beneath the intrusives. The gravity data suggest successive intrusions from syenite to gabbro to granite. These magmatic upwellings appear to have travelled through a main conduit, which is situated beneath the syenite, and also through other conduits, one of which is located under the northern gabbroic mass and another under the centre of the granitic intrusion.

In this case history, we present a simplified method of gravity data interpretation, which can be effectively applied when overburden thicknesses are minimal at all density calculation points; otherwise densities will be underestimated due to the presence of significant thicknesses of low density surficial sediments. This applies to cases where bedrock geology is well known and where bedrock outcrops are observed at the surface. In addition, the size of geological bodies must be large with respect to the survey station spacing and density calculation points. This paper presents a simplified gravity modelling technique, which may be applied to regions characterized by large altitude variations and outcropping rocks. This method is directly applicable to the Monteregian Hills in southern Quebec and the eastern United States, as well as to geological bodies occurring in other parts of the world where similar conditions are encountered.

Residual gravity modelling of the Mount Mégantic intrusive complex, Québec, Canada

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Date Received January 25, 1990
Date Accepted March 15, 1991

A detailed analysis of the residual gravity anomaly of the Mount Mégantic area, Province of Québec, Canada, has led to unconventional modelling of the intrusive masses. A new approach was developed to approximate, as closely as possible, the regional anomaly. Using the relationship between free-air anomaly and elevation it is possible to estimate the Bouguer density at each measurement station. If the variations of the Bouguer field values reflect fluctuations of a body, then the relative error of the calculated density is much smaller than that obtained using Nettleton's method. When the density function is well defined, it is then possible to calculate the depth of the intrusive bodies at each measurement point and to determine the base of the intrusives. The masses with the greatest depth are the syenite on the southeast side of Mount Mégantic and the gabbro underneath the northern half-ring. Deep conical surfaces suggest the occurrence of conduits for the magmatic fluid at the time of intrusion. Therefore, this type of gravity modelling is useful to indicate the mode of emplacement of the intrusive bodies. Two axes, oriented west-northwest and east-southeast, characterise the deepest areas of the granite and syenite. These zones may extend downward to fault planes in the Earth's crust beneath the intrusives. The gravity data suggest successive intrusions from syenite to gabbro to granite. These magmatic upwellings appear to have travelled through a main conduit, which is situated beneath the syenite, and also through other conduits, one of which is located under the northern gabbroic mass and another under the centre of the granitic intrusion.

In this case history, we present a simplified method of gravity data interpretation, which can be effectively applied when overburden thicknesses are minimal at all density calculation points; otherwise densities will be underestimated due to the presence of significant thicknesses of low density surficial sediments. This applies to cases where bedrock geology is well known and where bedrock outcrops are observed at the surface. In addition, the size of geological bodies must be large with respect to the survey station spacing and density calculation points. This paper presents a simplified gravity modelling technique, which may be applied to regions characterized by large altitude variations and outcropping rocks. This method is directly applicable to the Monteregian Hills in southern Québec and the eastern United States, as well as to geological bodies occurring in other parts of the world where similar conditions are encountered.

Une analyse en détail de l'anomalie gravimétrique résiduelle présente dans la région du Mont Mégantic (Province de Québec, Canada) a conduit à une modélisation peu conventionnelle des masses intrusives. Une nouvelle approche fut développée afin d'approximer le plus possible l'anomalie régionale. Il est possible d'estimer la densité de Bouguer à chaque station de mesure en utilisant la relation entre l'anomalie à l'air libre et l'élévation. Si les variations parmi les valeurs du champ de Bouguer reflètent les fluctuations d'un corps, alors l'erreur relative de la densité qui a été calculée est beaucoup moindre que celle obtenue à l'aide de la méthode de Nettleton. Lorsque la fonction de densité est bien définie, il devient possible de calculer la profondeur des bâtis intrusifs à chaque poste de mesure et de déterminer leurs bases. Les masses situées à la plus grande profondeur sont la syénite sur le flanc sud-est du Mont Mégantic ainsi que le gabbro sous la moitié septentrionale du filon annulaire. Des surfaces coniques en profondeur suggèrent la présence de conduits ayant acheminé le fluide magmatique au moment de l'intrusion. Ce type de modélisation gravimétrique est donc utile pour déterminer le mode de mise en place des bâtis intrusifs. Deux axes, d'orientation ouest: nord-ouest et est: sud-est, caractérisent les zones les plus profondes du granite et de la syénite. Ces zones pourraient être relayées vers le bas par des plans de faille dans la croûte terrestre en-dessous des intrusions. Les données gravimétriques suggèrent une succession d'intrusions allant de la syénite au gabbro puis au granite. Ces bouffées magmatiques semblent être remontées par un conduit principal, qui se situe sous la syénite, ainsi que par d'autres conduits, dont l'un se situe sous la masse gabbroïque septentrionale et l'autre sous le centre de l'intrusion granitique.

Dans cette illustration d'un cas, nous présentons une méthode simplifiée d'interprétation des données gravimétriques, qui donne des résultats satisfaisants là où l'épaisseur du mort-terrain est minime à tous les points de calcul de la densité; autrement, les densités seront sous-estimées par suite de la présence d'épaisseurs significatives de sédiments de surface de faible densité. Ceci s'applique aux cas où la géologie du socle est bien connue et où le socle affleure en surface. De plus, la taille des corps géologiques doit dépasser de beaucoup l'espacement des stations et des sites de calcul de la densité utilisé lors de la traverse. Cet

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article introduit une technique simplifiée de modélisation gravimétrique, que l'on peut utiliser dans les régions caractérisées par de fortes variations d'altitude et où la roche affleure. Cette méthode s'applique directement aux montagnes montérégiennes du Québec méridional et des Etats-Unis orientaux, de même qu'aux corps géologiques situés ailleurs dans le monde, là où des conditions semblables sont rassemblées.

[Traduit par le journal]

INTRODUCTION

Mount Mégantic is one of a group of hills composed of intrusives, which penetrate the Lower Paleozoic sedimentary rocks of the St. Lawrence Lowlands and the western border of the Appalachians of southern Québec (Fig. 1). Adams (1903) has shown that the Monteregian Hills in the province of Québec are genetically related by comparing their petrographic similarities and regional magmatic activity. The age of the Monteregian Hills' intrusives is Cretaceous. Many hypotheses were proposed to explain their origin; some considered them to be volcanic plugs, others labelled them intrusives of various shapes (e.g., stocks, laccoliths, cylindrical or conical conduits). It is clear that one can obtain useful information about the modes of intrusion of the Monteregian Hills if one can define the three-dimensional shapes of these intrusives (Seguin, 1982).

The main objective of this paper is the computation of a geometrical model to interpret the mode of emplacement of the various intrusive phases of Mount Mégantic. We use gravity measurements (residual gravity field map) and the petrophysical data to achieve this objective. The results obtained are integrated with the surface geological (petrographic) data to obtain a coherent interpretation.

REGIONAL GEOLOGY

The Mount Mégantic area is bounded by latitudes 42°22' - 45°30'N and longitudes 71°08' - 71°17'W and reaches a maximum elevation of 1120 m. Recent geological studies were done by Reid (1960, 1976), Chevé (1975, 1977, 1978), Danis (1984), Seguin and St-Hilaire (1985), Roy and Seguin (1986) and Bédard *et al.* (1987). The Mount Mégantic intrusive complex (Fig. 2) cuts the Compton Formation metasedimentary rocks (MS in Fig. 2) of Early Devonian age (Seguin *et al.*, 1982). These metasedimentary rocks are composed of quartzites and slates; they constitute the country rocks around Mount Mégantic except for the southeastern corner of the area. The Compton Formation metasediments are weakly metamorphosed. The metavolcanic rocks (V in Fig. 2) of the Frontenac Group, in the southeastern part of the area, may be synchronous or older than the Compton Formation. The intrusive mass produced a metamorphic aureole in the metasedimentary rocks and transformed them into hornfels (C in Fig. 2).

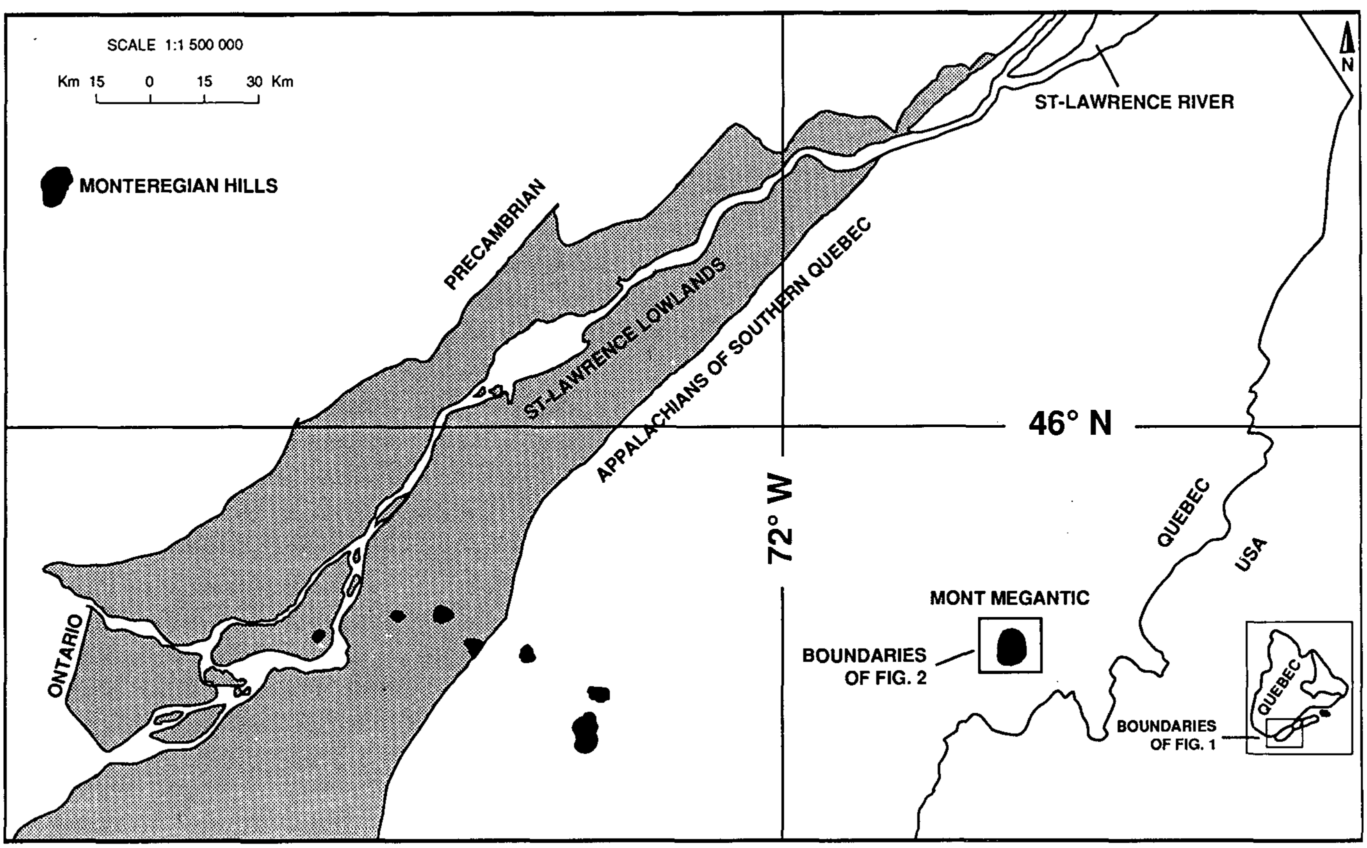

Fig. 1. Location of the Monteregian Hills and boundary between the St. Lawrence Lowlands and the western border of the Appalachians of southern Québec.

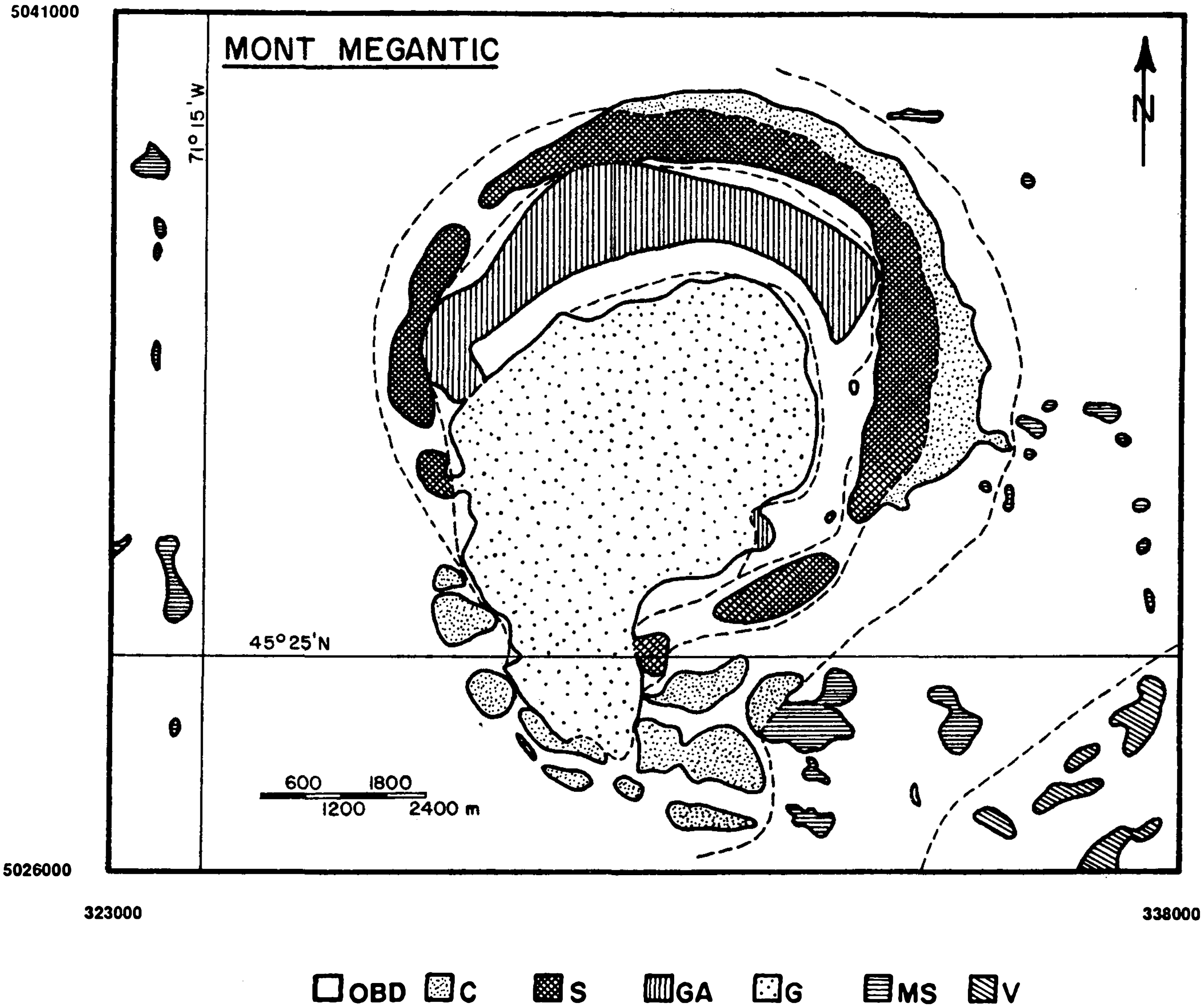

Fig. 2. Simplified geological map of the Mount Mégantic area (modified after Reid, 1976). The UTM grid system is shown for map boundaries. The symbols used for the outcrops of the lithological units are: MS, metasedimentary rocks of the Compton Formation; V, metavolcanics; C, hornfels; S, syenite; G, granite; Ga, gabbro; and OBD, overburden.

Granite (G in Fig. 2) outcrops in a more or less circular pattern in the central sector of the Mount. Its extension to the south suggests that it cuts the gabbro (GA in Fig. 2) and syenite (S in Fig. 2), even though the surface contact is not exposed. The shape of the syenite outcrop is that of a ring, interrupted in the southwestern sector of the Mount by the granite intrusion. It contains many large inclusions of metasedimentary rocks. Similarly, the gabbro outcrop is characterized by a subcircular shape and contains inclusions of metasedimentary rocks. There are less inclusions in the granite compared to the syenite. A paleomagnetic study (Seguin and St-Hilaire, 1985) has confirmed the hypothesis of multiple intrusions during the Jurassic-Late Cretaceous for the Mount Mégantic intrusive complex.

BOUGUER AND REGIONAL GRAVITY ANOMALIES

The gravity survey

Some 350 gravity stations were measured on and around Mount Mégantic. The gravity station distribution is shown in Seguin *et al.* (1989). A LaCoste-Romberg gravimeter was used for this survey with a reading accuracy of 0.005 mGal. Considering the elevation errors, the uncertainty in the gravity values is 0.2 mGal. No gravity measurements have been previously made in this area except for 20 stations outside the area of investigation, which were used to construct a regional anomaly contour map published by Seguin *et al.* (1989). A Bouguer anomaly (BA) contour map with terrain corrections added for the Mount Mégantic area was also published by Seguin *et al.* (1989).

Representativeness of the data

In order to obtain a representative three-dimensional model, the gravity data should be uniformly distributed over each rock type. For statistical reasons, the number of data points covering each lithological unit must be sufficiently representative. A higher ratio of the area covered by the outcrops versus the area occupied by a specific lithological unit increases the degree of representativeness of the data. The distribution of the geophysical information should be uniform, homogeneous and, ideally, conform to Gauss' law (number of observations versus their numerical values). The same conditions must apply to the area occupied by each geological intrusive mass to be modelled. As shown in Seguin *et al.* (1989), the gravity station distribution satisfies these requirements.

Interpretation of the Bouguer gravity measurements

The successful interpretation of the Bouguer gravity data depends on the removal of an estimated regional gravity field to give the residual gravity anomaly used in the modelling process. Many approaches can be used to determine the regional gravity field and each approach should take into consideration the geological setting and style, the tectonic situation and the scale of the problem to be solved, and the dimensions of the object to be modelled. Various approximations for the regional field (A_R) of the Mount Mégantic area were tried, such as the polynomial fit method and the mean within a mobile window (Frydecki *et al.*, 1988). These approaches have shown that an approximation of the regional field by a moving average, with a square window of 20 km x 20 km is the optimum (Seguin *et al.*, 1989). For details of the regional-residual separation, the nature and dimension of the numerical filters and the extent of the surface covered by the regional field, the reader is referred to Seguin *et al.* (1989).

Residual gravity anomaly

Figure 3a shows a detailed contour map of the residual gravity anomalies on and around Mount Mégantic. This contour map results from the subtraction: BA-A_R, where BA is the Bouguer gravity and A_R is the regional gravity. As expected, the largest residual anomalies are located on and in the immediate neighbourhood of Mount Mégantic. The simplified residual gravity anomaly is plotted areally in Figure 3a and as a 3-D plot in Figure 3b. The positive (+ 11 mGal) residual anomaly in the northern sector is oriented ESE-WNW and corresponds to the gabbroic ring. In the southern sector, the negative residual anomaly (- 10 mGal) is oriented NW-SE and coincides partly with the occurrence of granite and partly with syenite. The geological bodies are identified, after modelling, in Figures 8a and 8b.

BOUGUER DENSITY

Nettleton (1954) has shown that it is possible to estimate the mean density of a geological formation with the aid of Bouguer anomaly (BA) data and elevations (H). Bouguer density estimates, obtained by minimizing the relation of this type and using the gravity data from Mount Mégantic, show a large dispersion of the values and, consequently, a large imprecision in density determination (Frydecki *et al.*, 1988). If the BA is considered as a linear transform of the Free-Air anomaly (FA), it is noted that this transform contains at least one additional error due to elevation (H) measurements. An uncertainty in the correlation FA versus H results in a smaller density error than obtained using the correlation BA versus H (Seguin *et al.*, 1989). In order to avoid this difficulty, we use the Free-Air anomaly (FA) values (Seguin and Frydecki, 1989).

Indeed, $BA = FA - 0.04187\,\sigma H$
where σ is the mean formation density.
Assuming that for point number i
$BA^i \simeq A_R{}^i$ where A_R is the regional field value.

If the set of BA^i values is representative of one specific body, then BA^i may be considered as an apparent regional field as long as the area covered by BA^i does not exceed the lateral extent of the body. Consequently, fluctuations of BA^i values reflect shape variations of the body (thickness).

$BA^i = FA^i - 0.04187\,\sigma_a H^i$
where the index a is arbitrary, and
$\sigma_a = \sigma - \Delta\sigma$
With Nettleton's method:
$$\frac{d\,BAa}{dH} = 0.04187\,\Delta\sigma,$$
where the order of the calculated density adjustment is equal to 10^{-3} - 10^{-4} g cm^{-3}.
With our method,
$$\frac{d\,FA}{dH} = 0.04187\,\sigma$$
and the order of the calculated density is then equal to 10^{0} - 10^{-1} g cm^{-3}.
Consequently, $FA^i - A_R{}^i = 0.04187\,\sigma^i H^i$
or else
$FA^i = 0.04187\,\sigma^i H^i + A_R{}^i$

A first approach consists of a statistical correlation (linear model) such as the the least squares method. It yields:
$FA = k_1 H + k_2$

The coefficients k_1 and k_2 are statistically justified and may be identified as:
$k_1 = 0.04187\,\sigma$ and $k_2 = A_R$
Another approach is to use the difference method, which gives:

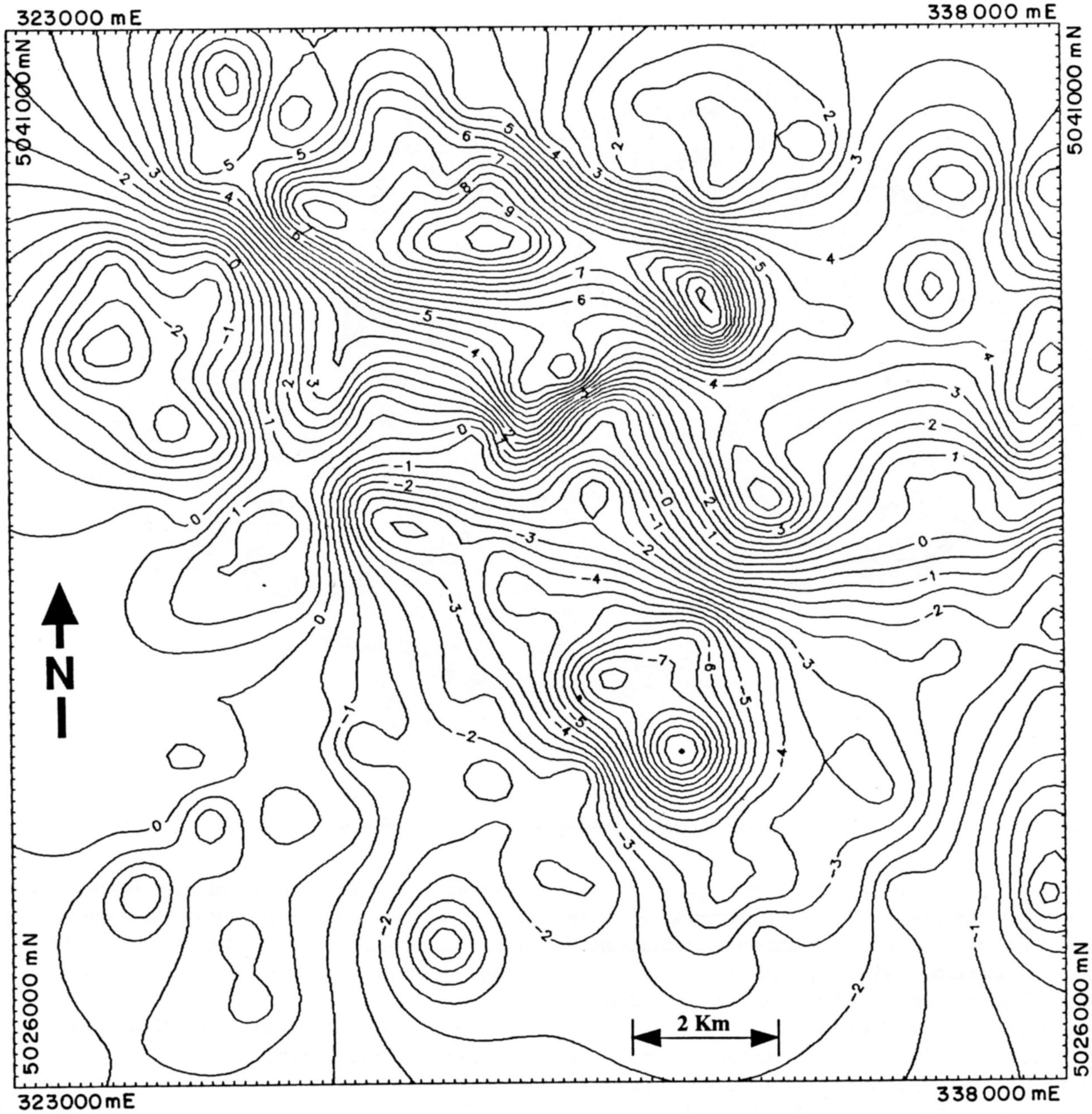

Fig. 3a. Contour map of the residual gravity anomaly. Contour interval: 0.5 mGal. Drape lines represent the coordinates of the UTM grid system.

$FA - A_R \simeq (FA)_r = k_1 H$ and hence

$k_1 = \frac{(FA)_r}{H}$ where $(FA)_r$ is the residual Free-Air anomaly.

Consequently,

$$\sigma = \frac{\Sigma (FA - A_R)}{0.04187 \Sigma H} = \frac{\Sigma (FA)_r}{0.04187 \Sigma H}$$

where σ = mean density.

When carrying out an error analysis reflecting the uncertainty inherited by the above mentioned method, the following statements may be taken into consideration:

First, the errors of BA and FA are of the same order of magnitude but that of BA is larger because the error of H is already included in the calculation of BA. Second, the errors of H are the same for both BA and FA. Third, the calculated value of σ is approximately one thousand times larger than that of $\Delta\sigma$. Thus, the relative error of the method used in this paper is many times smaller than that of Nettleton's method. The other uncertainties inherited by our method are the same as those using Nettleton's method (Nettleton, 1954; Seguin and Frydecki, 1989).

In summary, if the regional anomaly (A_R) is well defined, this is also true for the residual anomaly (A_r) and, consequently, for the density obtained with the relation $(FA)_r$ versus H. For each geological formation investigated, it is possible to estimate the density value (σ^i) at each measurement point "i" of a specific formation and one can follow this procedure for all the formations of the studied area. Geology and topography are not directly

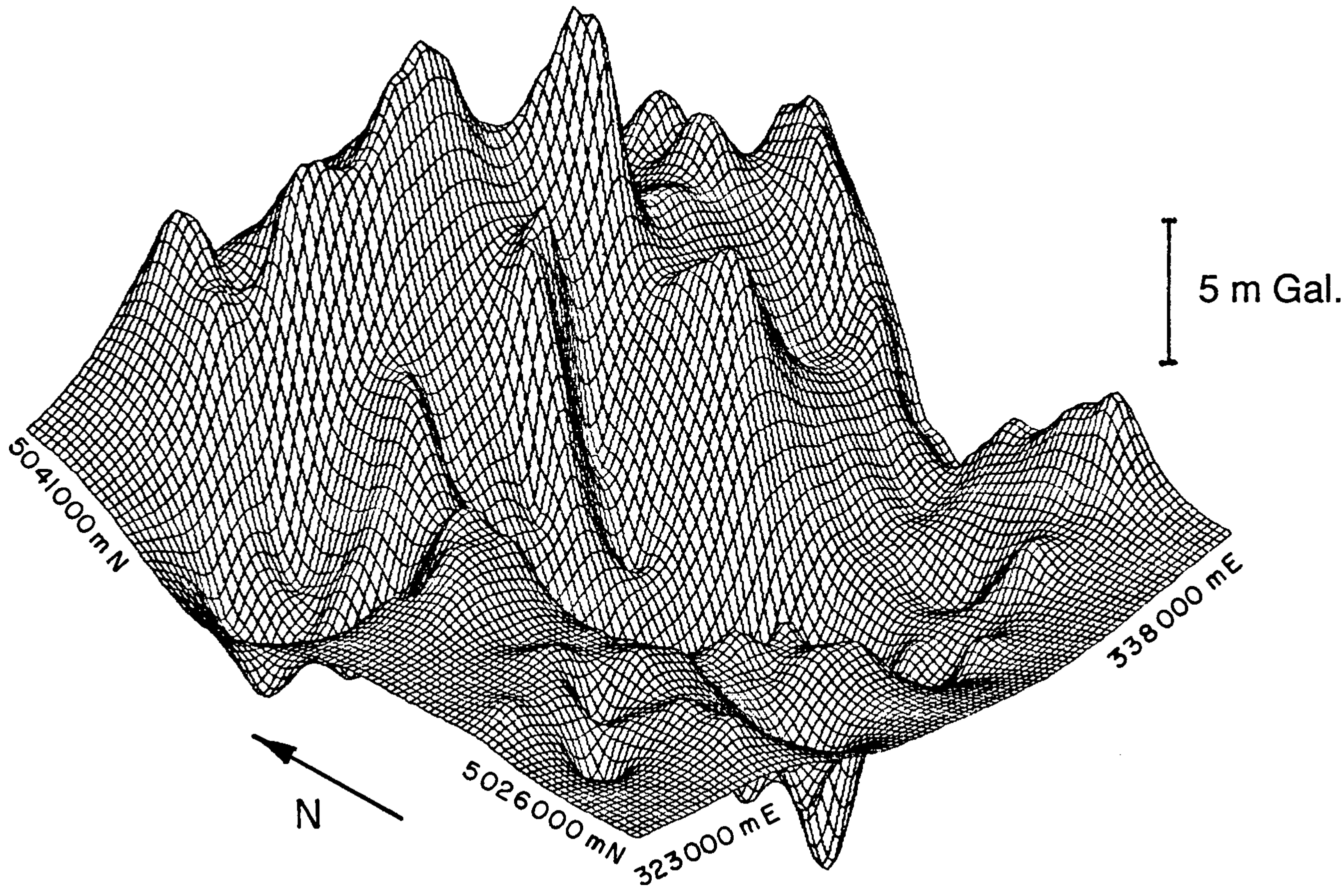

Fig. 3b. 3-D picture of residual anomaly; view from the southwest to the northeast.

correlated since different lithologies (granite, gabbro, syenite and hornfels) make up Mount Mégantic. In this manner, a contour map of the densities, corresponding to the surface formations, is constructed. This methodology was applied to the Mount Mégantic area and Figure 4 shows a contour map of the estimated apparent densities. The term "apparent" is used because the FA^i gravimetric signal at each point is interpreted in terms of density. The density of the anomalous areas for gabbro in the northern part of this figure varies from 2.96 to 3.06 g cm^{-3}. The density of granite in the southern sector ranges from 2.42 to 2.58 g cm^{-3}, that of the hornfels around the intrusive body from 2.74 to 2.90 g cm^{-3} and that of the metasedimentary units, into which the granite and syenite are intruded, from 2.62 to 2.70 g cm^{-3} (Seguin and Frydecki, 1989).

The less dense plutonic crystalline rocks (e.g., granite with perthite texture) have a density of the order of 2.53 g cm^{-3}. For the measured densities from rock specimens, the reader is referred to Seguin and Frydecki (1989). The apparent densities which are less than these values may result from the presence of low density country rock (sedimentary units) included within the intrusive granite, alteration and weathering of the granite and other geological processes. Given the apparent character of the calculated densities and the statistical significance of their estimate, a density map of this nature is useful to discriminate distinct geological units. Figure 4 shows this quite well when compared with the residual gravity anomalies in Figure 3a. Both gravity map and density map depict a continuous function. The distribution of densities and a comparison of various methods to obtain densities, including results of density determination from field sampling, are dealt with in detail in Seguin and Frydecki (1989).

DEPTH CALCULATIONS AND MODELS OF GRANITIC INTRUSION

The granite is characterized by well defined surface boundaries. This explains why the modelling of the granite body is presented separately. Indeed, if the surface boundary of the intrusives (i.e., geological contact between the units) is properly determined, an estimate of depth [i.e., vertical extent with reference to mean sea level (0 m)] will give a 3-D picture of the geometrical shape of the intrusive bodies. A detailed analysis of the outcrop distribution shows that of the four available rock types (gabbro, syenite, granite and hornfels), only the granitic mass has well defined external surface boundaries (Fig. 5). The lateral extent of the three other units is ill defined; consequently, it is difficult to assign a representative density value to measurement points where the location of the unit is either uncertain or unknown. Within the granitic mass it is observed that the northern part is characterized by a positive residual anomaly (Fig. 3a), whereas in the southern part the anomaly is largely negative. The residual anomaly of the low density granite should be entirely negative. This observation suggests that gabbro, and possibly

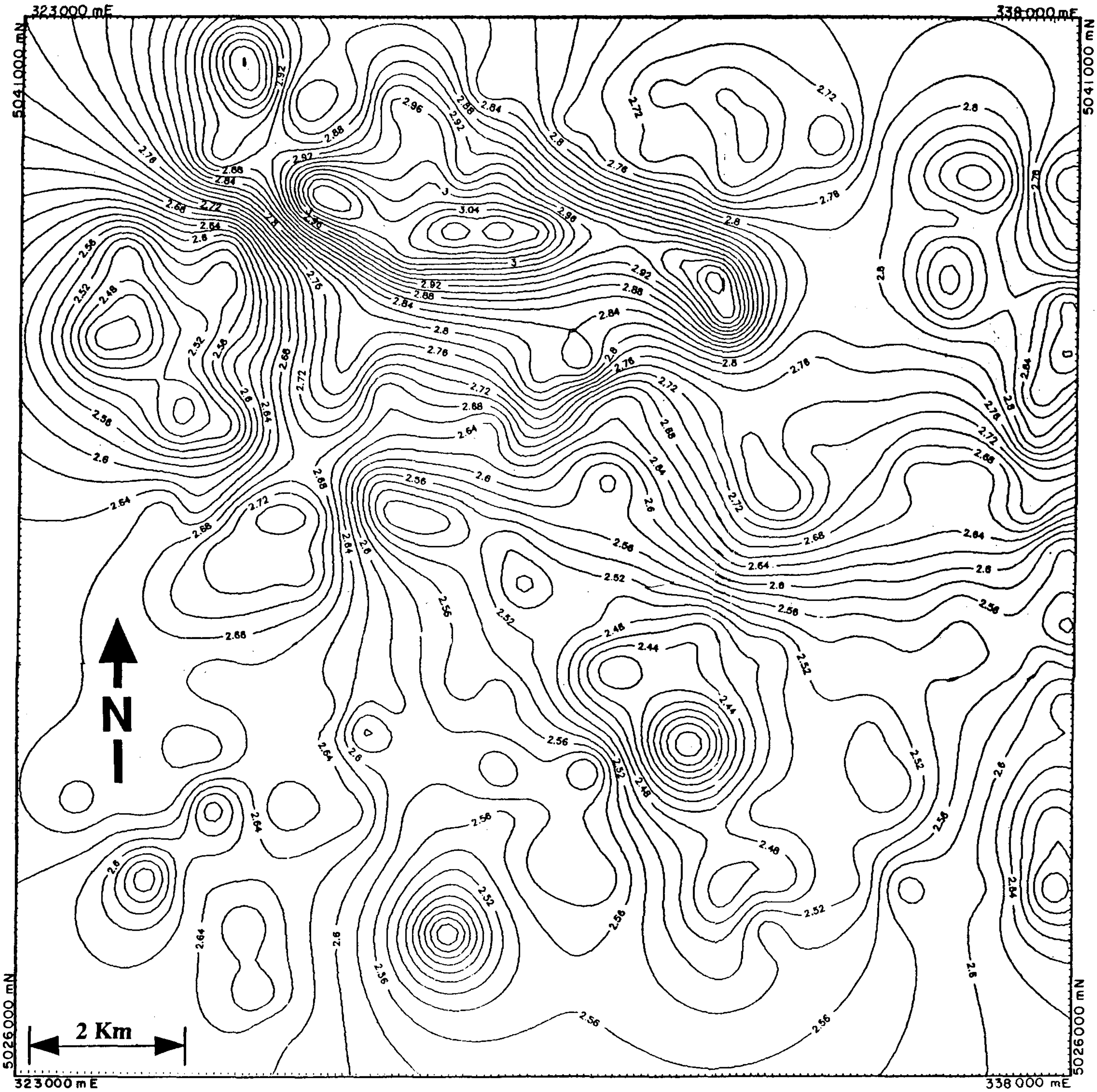

Fig. 4. Contour lines of density variations on and around Mount Mégantic. Contour interval is 0.02 g cm^{-3}.

hornfels, are present beneath granite in the northern sector of the area.

For an independent density determination, the point by point estimate of density was determined. For a specific geological unit, the limits of the range of densities were determined by a combination of the surface geological boundaries and the characteristic density range over this unit. A linear surface density gradient is removed and a mean unit density calculated assuming that the density variations at depth are negligible within a specific unit. The unit thickness is calculated at each point, providing the mean unit density is known, using the residual gravity anomaly, A_r. Using the density distribution above the granitic mass, it is possible to obtain an approximation of the thickness t of the granite with reference to the topographic surface.

As $A_r = 0.04187\, \sigma\, t$, one obtains $t = 23.8834 \times A_r \times \sigma^{-1}$.

Figure 5 shows the contours (in metres) of the granite thickness. The maximum thicknesses are found at four points in the centre of the granitic mass; at these points, the granite is 800-

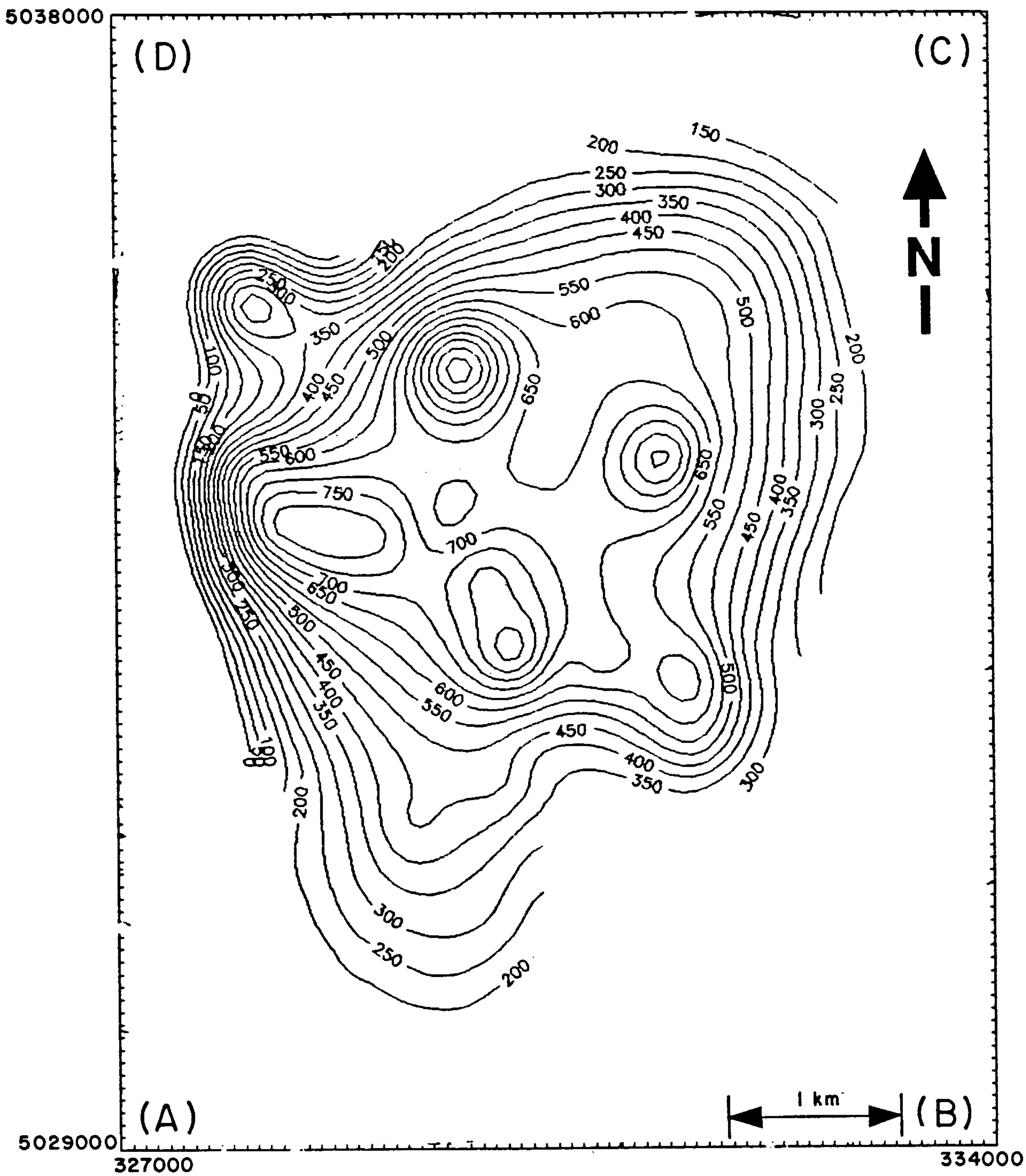

Fig. 5. Contoured estimates of the thickness of the granitic intrusive within surface boundary limits, using each gravity station. Contour interval is 50 m. Thicknesses are calculated relative to the surface elevations at each gravity station.

900 m in vertical extent. Figure 6 shows the depth (i.e., the base) of granite, with respect to mean sea level (zero contour). Figures 7a and 7b are 3-D representations of the surface topography and underground shape of the granite within the Earth's crust. The granitic mass is viewed successively from southeast to northwest and from southwest to northeast (Figures 7a and 7b respectively). The envelope of the granitic body illustrated in this manner shows four important depressions which may be grouped into pairs. Each pair has a general ESE-WNW orientation and is separated by a saddle structure. The highest topographic expression of the granitic intrusion (Figs. 6, 7a, 7b) is located at a short distance to the northwest of these depressions.

MODEL OF VARIOUS BODIES CONSTITUTING THE MOUNT MÉGANTIC INTRUSIVE COMPLEX

It was found necessary to model the thickness and shape of the undifferentiated intrusive masses constituting the whole of

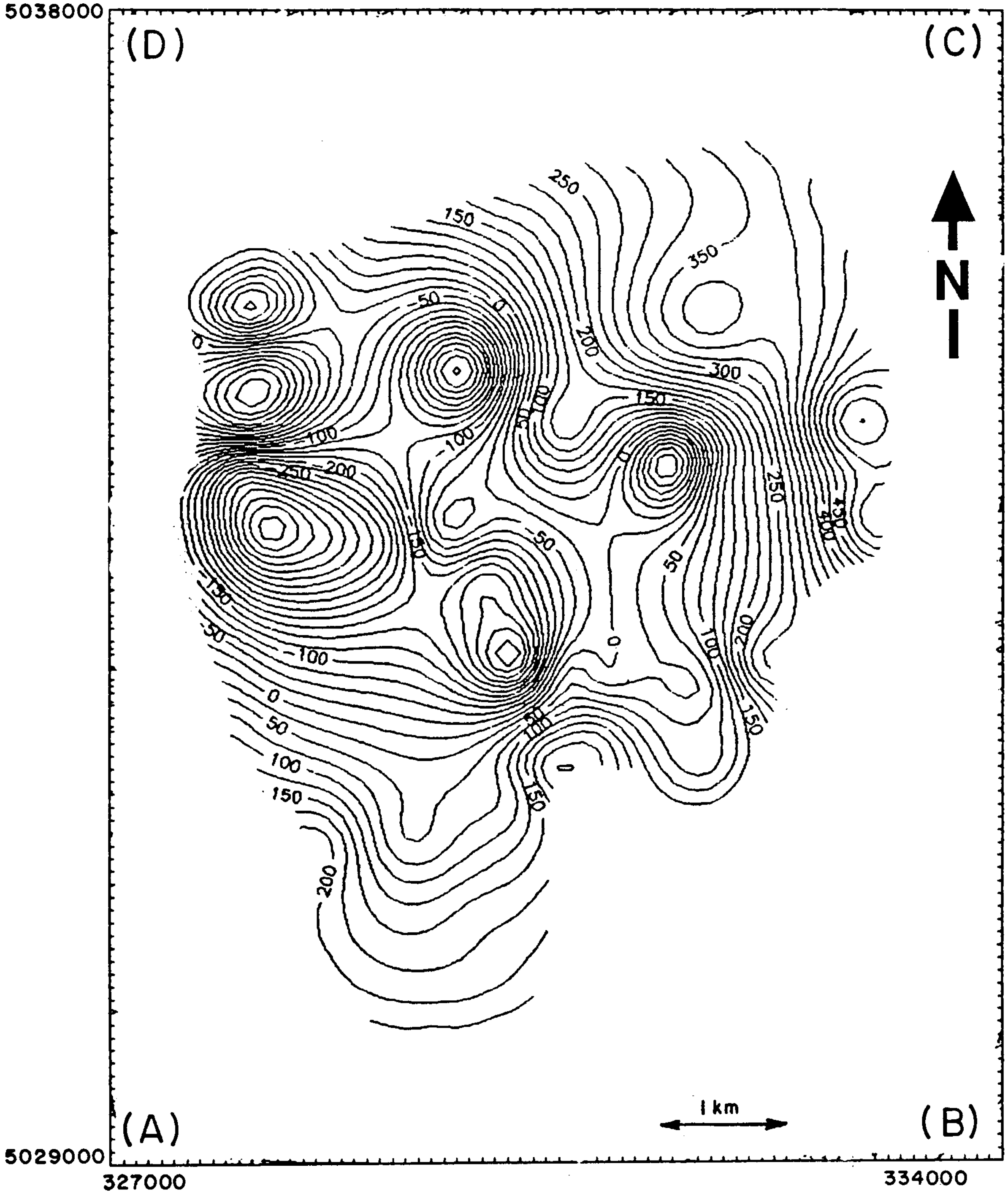

Fig. 6. Granite depth estimates (base of intrusion) within surface boundary limits and with respect to mean sea level (m.s.1.); the positive values (in m) are located above m.s.1. and the negative values below m.s.1. Contour interval is 50 m.

Mount Mégantic. First, we tackled the problem of depth determination for the country rock into which the igneous rocks are intruded, i.e., the depth of metasedimentary rocks underneath the intrusive bodies, including the granitic mass. In the northern sector, under the circular gabbroic outcrop, the depths vary up to 800-900 m. As the elevation of these gabbroic masses above sea level is on the order of 1 km, the total thickness is close to 2 km. In the southern sector of the intrusive complex, a zone of larger depth, extending to 2800 m from zero datum (msl), corresponds to the major part of the southern part of the circular syenite outcrop. The maximum depth of the syenite is about 3.7 km. Elsewhere in the intrusive complex, the mean depth is approximately 250 m. Adding a mean elevation of 700 m, one finds that the thickness of the remainder of the intrusive complex is about 1 km.

In view of its surface topography, the complicated geometry of the masses and the large number of lithological units with varying densities, modelling of the Mount Mégantic massif

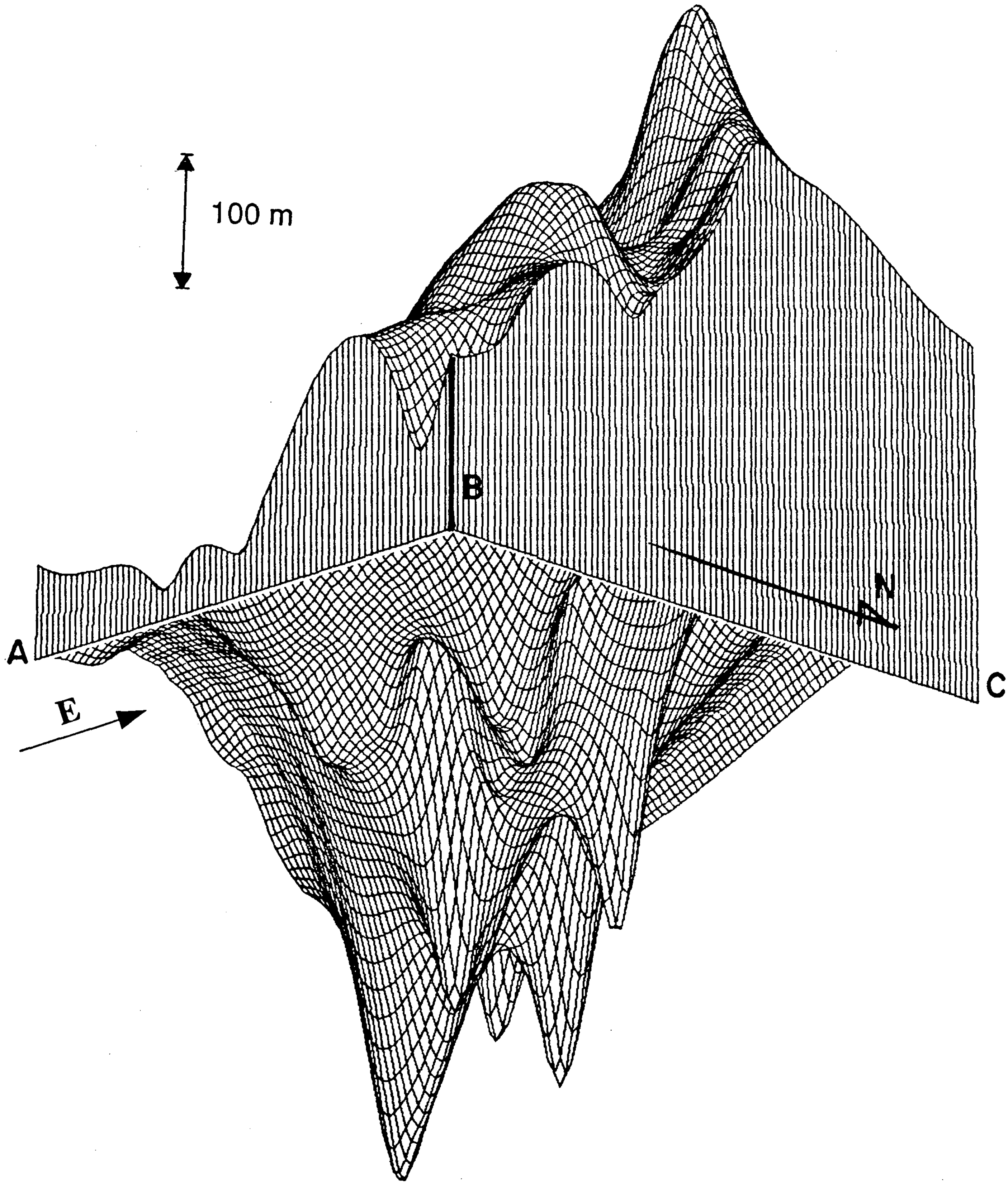

Fig. 7a. 3-D model of the shape of the granitic body. View from the southeast to the northwest. Points A, B and C are located on Figure 6.

represents a complex problem. A conventional 2-D representation, by calculation of gravitational attraction of individual blocks, was found to be inadequate. We finally adopted 3-D models with projections according to various rotation angles to illustrate the complexity of the intrusive complex. Figures 8a and 8b are tilted to the rear at a variable angle (15° to 20°) with respect

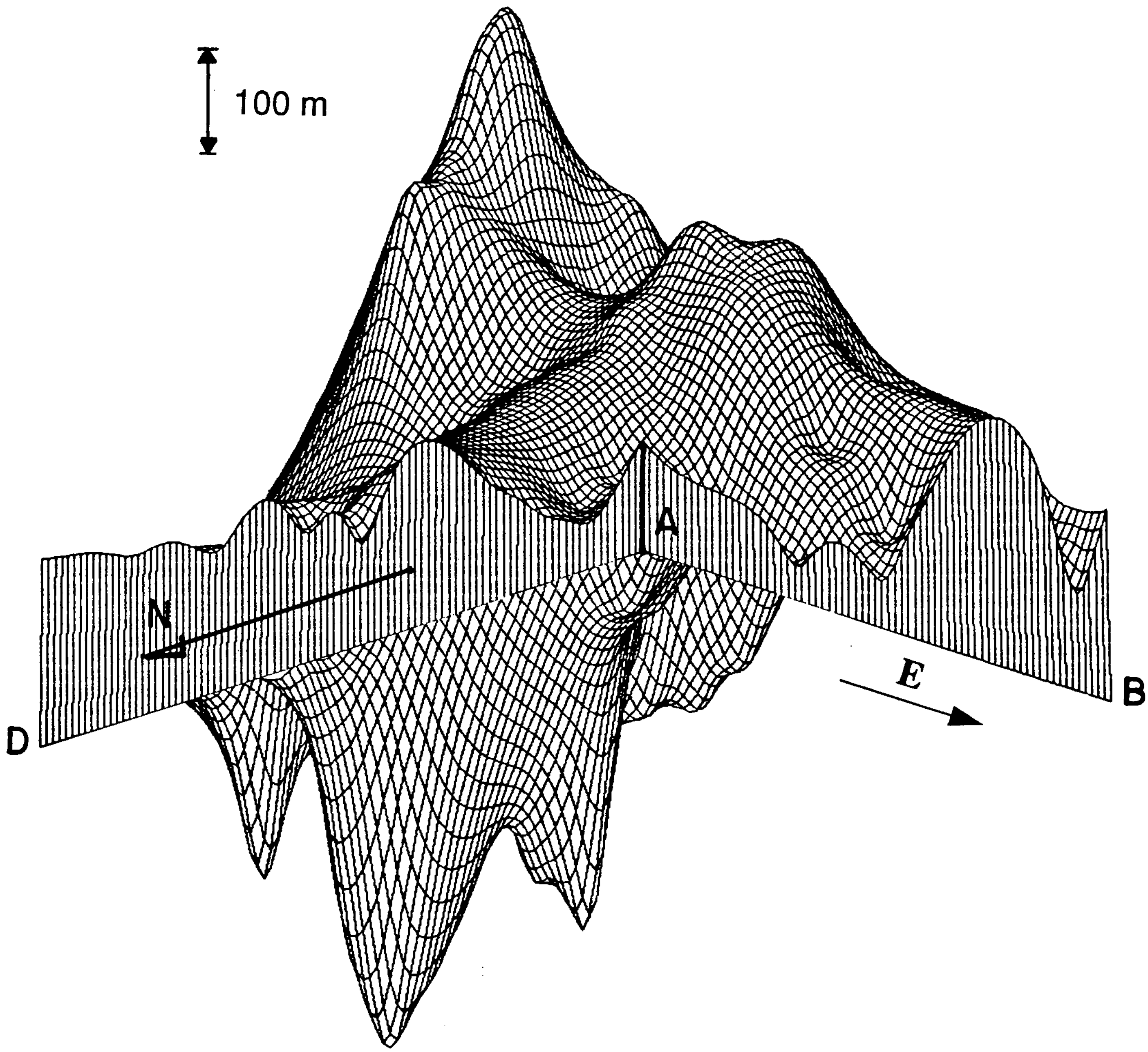

Fig. 7b. 3-D model of the shape of the granitic body. View from the southwest to the northeast. Points A, B and C are located on Figure 6.

to the horizontal. The modelled intrusion is shown from two different angles. Successive rotations of the model around the vertical axis are used (Figs. 8a, 8b).

Figure 8a shows the distribution of the intrusive masses underneath Mount Mégantic. The viewing angle is from southwest to northeast. Beneath the reference plane, two conical surfaces extending to a depth of 3 km or more to the front of the southeastern part of the Mount outline the syenitic masses. In the rear of the diagram to the northeast, the areas at greater depth outline the gabbroic masses in the northern sector of the intrusion. Between the gabbroic and syenitic masses, the area at shallow depth corresponds to the granitic mass. To the west of the conical syenitic surfaces, small peaks show the variations in depth of the granite. Gabbro in the northern sector projects towards the front of the diagram in a southern direction, suggesting an extension under the granitic mass. Above the reference plane, the peak at the rear represents a fragment of the northern gabbroic ring. The two main topographic highs in the centre depict the central zone of the granitic mass, whereas the peak in front of them corresponds to the southern syenitic mass.

On Figure 8b, the viewing angle is from northeast to southwest. Under the reference plane and at the front of the diagram, the conical surface delimits the depth of syenite whereas on the north part of the plot, shallow depths depict the base of the gabbroic massif. The saddle-shaped surface between the two above mentioned masses and the smaller amplitude variations to the rear outline the base of the granitic massif. The gabbroic units extend to a depth of about 1 km beneath sea level and are seen in

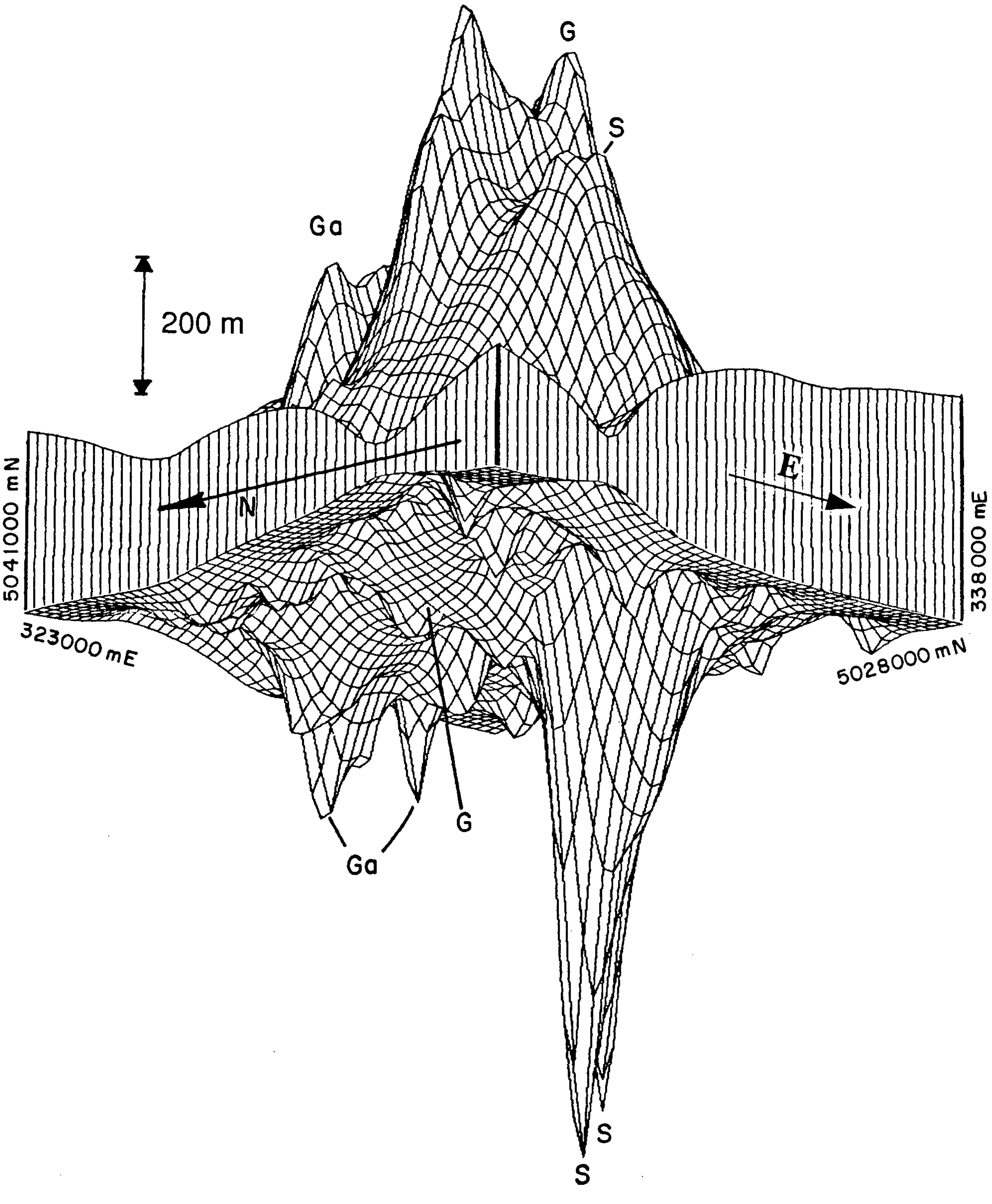

Fig. 8a. 3-D models for the shapes of intrusive bodies composing Mount Mégantic. Symbols G, Ga and S represent granite, gabbro and syenite respectively. View from the southwest to the northeast.

the front to the north. The syenitic mass is in the centre. The granite occurs between gabbro and syenite at the rear and has a shallower depth. Above the reference plane, two granitic peaks are prominent in the centre; the syenite is not easily differentiated from granite. The northern ring of gabbro is isolated to the west in the figure.

Some anomalies were modelled using the conventional 2-D gravity line integral method (Goulet, 1987). The mean depth obtained on ten modelled anomalous blocks is about 2 km. Most of the depths range between 1 and 1.5 km apart; one of them at the syenite-gabbro contact in the southern sector of the intrusion, indicated a depth of 4.5 km. For comparison, it is noted that the

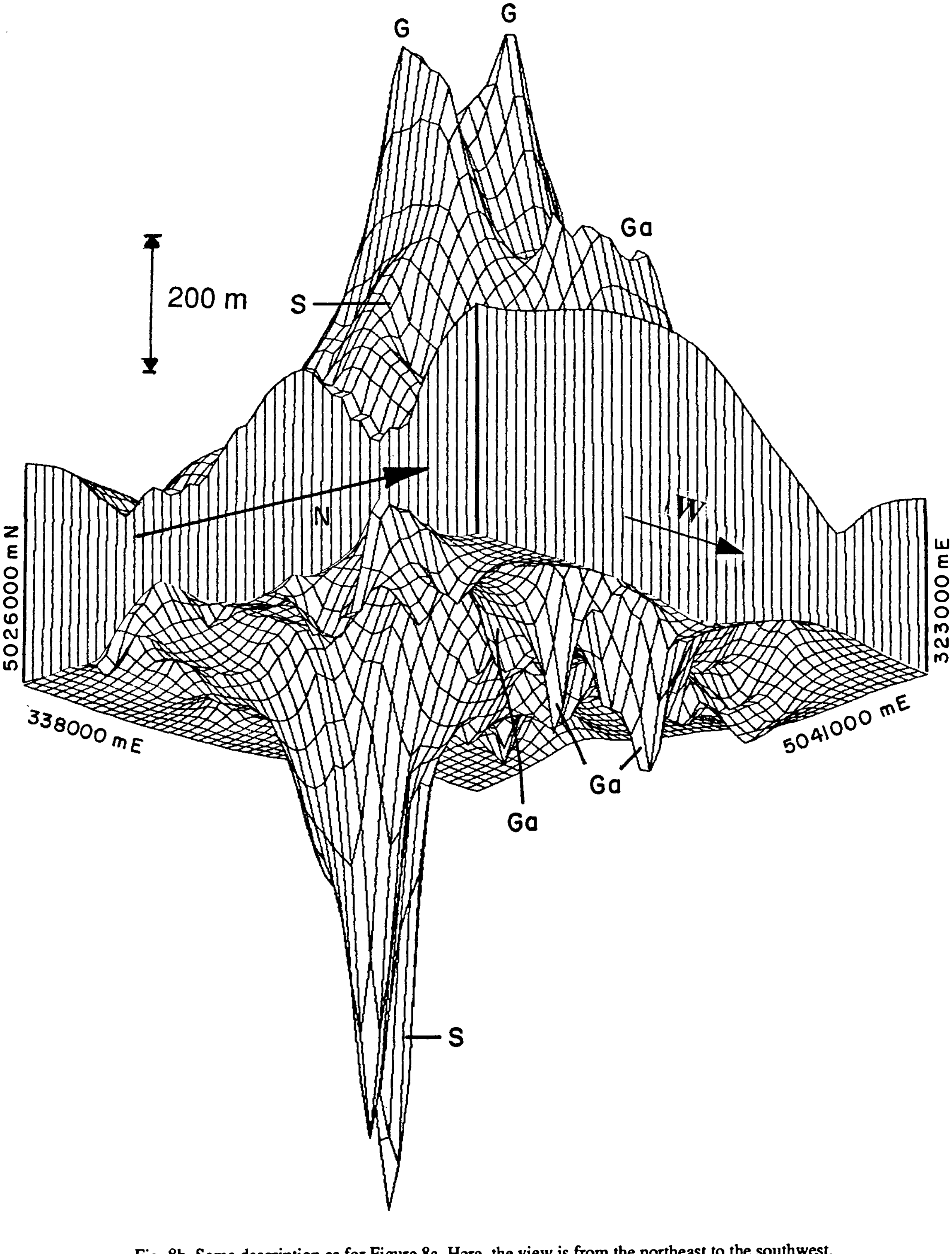

Fig. 8b. Same description as for Figure 8a. Here, the view is from the northeast to the southwest.

mean depth extent determined from geophysical data on six Monteregian Hills is about 1 km (Seguin, 1982).

THE PROPOSED MODE OF EMPLACEMENT

The conical surface outlined beneath the syenitic mass clearly indicates the location of a conduit for the magma at the time of intrusion of Mount Mégantic. Below 3.5 km, the planar or tubular feeding conduits were apparently small in size and linked the intruding mass to the syenitic chamber situated at the base of the Earth's crust in the upper mantle (Pitcher, 1979; Hodge *et al.*, 1982). The average density of the conical mass corresponds to that of syenite. This observation leads to the following three hypotheses: (1) syenite is the residual (final) fluid left in the conical conduit, i.e., syenite is the final intrusive phase, (2) syenite is the magmatic fluid from which the gabbro and granite were fractionated, (3) the conical conduit was first occupied by syenite which crystallized on the sides of the conduit. The central axis of the syenitic cone remained hot and viscous over a period of time, which was sufficiently long that it allowed the successive ascents of gabbroic and granitic magmas.

The first hypothesis is discarded for the following reasons: (a) syenite is the intrusive unit which contains the largest amount of metasedimentary rock inclusions, (b) the syenite is cut by granite, and (c) paleomagnetic data demonstrated that the syenite is the oldest of the three intrusive units. The second hypothesis is not acceptable as: (1) granite definitely cuts gabbro, (2) gabbro contains inclusions of metasedimentary rocks, (3) gabbro is present underneath the granite in the northern portion but is absent in the southern portion of the intrusion, and (4) the paleomagnetic data show that the gabbro has an Early Cretaceous age whereas the granite has a Late Cretaceous age. The third hypothesis is more probable, so that the intrusive units were emplaced successively from a common conduit located underneath the syenite in the southeastern sector of Mount Mégantic, from two adjacent conduits underneath the crescent-shaped gabbro in the northern sector and also from two deep axial zones oriented NW-SE in the granite. The southern zone is linked to the cylindrical conduit underneath the syenite at its southeastern extremity whereas the northern zone is linked to three other conduits. Two of these conduits perforate the underlying gabbro layer and a third one also passes through the gabbro to the west; however, this third conduit does not outcrop. It is also possible that this third conduit is composed of syenite. Geochemical data (Bédard *et al.*, 1987) may provide additional information to determine the nature of this third conduit.

DISCUSSION AND CONCLUSIONS

From the methodological point of view, the modelling approach used in this paper is different from the classical method. The three-dimensional plots of the shape of the intrusive masses are also different from the usual model plots. The calculation of densities, depths and corresponding thicknesses for each gravity station leads to a combined interpretation of the shape of causative bodies. Correlations and comparisons of the surface geology, residual gravity anomaly and geometry of the intrusive bodies are the main criteria used for the interpretation. Applying these criteria to the Mount Mégantic intrusive complex, we conclude that gabbro occurs under the granite in the northern sector of the granitic intrusion. In the southern sector, the intrusive body is composed exclusively of granite. With the exception of some deeper conical conduits, the intrusion has a more or less tabular shape with a thickness of 1 to 1.5 km. The lateral extent and depth distribution of these conduits yield information about the mode of intrusion of the different rock bodies. The depths of these conduits do not exceed 4 km and the deepest conduit is located underneath the syenite. The alignment of the conduits and the axial planes show that emplacement was structurally controlled, possibly by fault planes. The proposed mode of emplacement is that of a sequence of multiple intrusions. From the eldest to the youngest, the intrusive sequence is syenite, gabbro and granite. The magmatic upwells may be affected by one or many conduits. Finally, the 3-D models used facilitate the correlation between topography and surface geology on the one hand and the depth of the intrusive masses on the other hand.

ACKNOWLEDGEMENTS

This research project was partially supported by a NSERC grant (A7070) to M.K.S.

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