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INTERPRETATION OF PUMPING TESTS IN THE ANISOTROPIC BRABANT MASSIF BY MEANS OF A NUMERICAL INVERSE MODEL

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(3 figures and 1 table)

ABSTRACT. – By order of the Belgian Geological Survey the Laboratory of Applied Geology and Hydrogeology of the State University of Ghent has made several pumping tests in the Paleozoic basement of Flanders (Brabant Massif).

A brief study of the observed drawdowns at the first pumping site made it clear that the aquifer was anisotropic in the horizontal plane. In such an aquifer a unique solution can only be obtained if the drawdowns are measured in at least three observation wells located in three different directions with respect to the pumped well. At a few sites, this configuration not being available, two pumping tests were made in order to obtain the data as required.

The drawdowns measured during the pumping tests were interpreted by an inverse model. This model combines a numerical model with a sensitivity analysis and a non-linear regression analysis. The obtained hydraulic characteristics of the aquifer formed by the Paleozoic basement are the effective transmissivity, the anisotropy, the direction of maximum transmissivity and the elastic storage coefficient. A unique solution can be obtained for the pumping tests at the sites Kortemark, Deinze and Deerlijk. This was not the case for the pumping tests at Gijzegem where two possible solutions were found.

The results show that the direction of maximum transmissivity is the same at all pumping sites. A possible explanation for the observed anisotropy in the horizontal plane is the occurence of a system of inclined parallel joints. In this case the direction of maximum transmissivity is equal to the direction of the strike of the joints while the inclination of the joints can be deduced from the anisotropy. The direction of the inclination can not be deduced.

1. INTRODUCTION

By order of the Belgian Geological Survey the Laboratory of Applied Geology and Hydrogeology of the State University of Ghent has made several pumping tests in the Paleozoic basement of Flanders (Brabant Massif).

During the first pumping test we observed that the measured drawdowns in observation wells at nearly the same distance but in different directions towards the pumping well greatly differed. The aquifer reacts in an anisotropic way. In such a case a unique solution can only be obtained if the drawdowns are measured in at least three observation wells which are located in three different directions with respect to the pumped well. Only then one can estimate the values of the effective transmissivity, the direction of maximum transmissivity and the anisotropy with a certain reliability.

At the sites Deinze, Kortemark and Gijzegem only three wells were disponible, all of them equipped with submersible pumps. At these sites, two pumping tests in a different pumped well were made. The measured drawdowns are adjusted for the discharge rate, and supposing the aquifer is anisotropic in a horizontal plane, we obtain the same data as required from three different directions towards a pumped well. These drawdowns were interpreted by an inverse model (L. LEBBE, 1988).

The interpretation method as well as the results are discussed in a concise way. A hypothesis is proposed to explain the anisotropic behaviour of the aquifer.

The results show that the direction of maximum transmissivity is the same at all pumping sites. A possible explanation for the observed anisotropy in the horizontal plane is the occurrence of a system of inclined parallel joints. In this case the direction of

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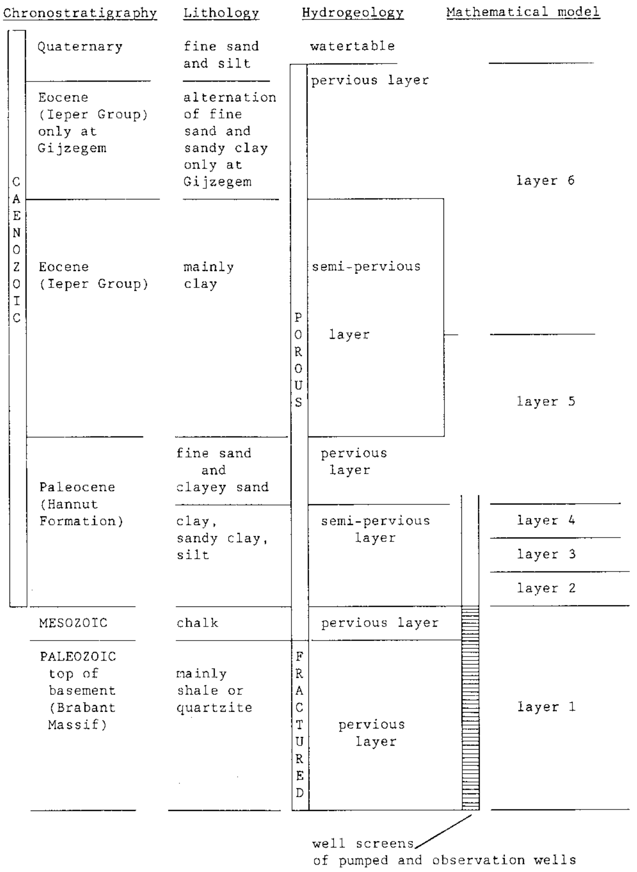


Fig. 1. Schematization of the groundwaterreservoir at the pumping sites of Kortemark, Deinze and Gyzegem

maximum transmissivity is equal to the strike of the joints while the inclination of the joints can be deduced from the anisotropy. The dip direction of the inclination can not be deduced.

2. INTERPRETATION OF THE PUMPING TESTS

At the sites Deinze, Kortemark and Gijzegem the pumped layer consists of the top of the Paleozoic Brabant Massif (mainly shale or quartzite) and a few meters of Cretaceous (chalk) and is covered by a semi-pervious layer of Landenian age. The piezometric head is situated above the top of the pumped layer so the aquifer can be considered as semi-artesian. In these cases the schematization of the groundwater reservoir in the mathematical model is the same (fig. 1). The thickness of the layers is deduced from disponible borelogs.

In the mathematical model, layer 1 is the pumped layer, layers 2, 3 and 4 represent the semi-pervious lower part of the Hannut Formation (Landenian; G. DE GEYTER, 1988) consisting of clay, sandy clay and silt. This rather homogeneous semi-pervious layer is subdivided in the numerical model in three layers. The thickness of these layers increases in the upward direction. This subdivision in the numerical model is necessary because the vertical flow and the storage both change strongly in the vertical direction during the pumping test. Layer 5 represents the pervious upper part of the Hannut formation which consists of fine sands and clayey sands. The semi-pervious layer, formed by the very fine sediments (mainly clay) of the Ieper group, is considered as a horizon between the layers 5 and 6. So in this layer only vertical flow is considered and the storage decrease is ignored in the numerical model. This supposition is well founded because the drawdown caused by the pumping tests is negligible in this semi-pervious layer as can be deduced from the calibrated numerical model.

Finally the upper layer of the mathematical model, which is bounded above by the water table, consists of pervious layers of Tertiary (Ieper Group) and/or Quaternary age.

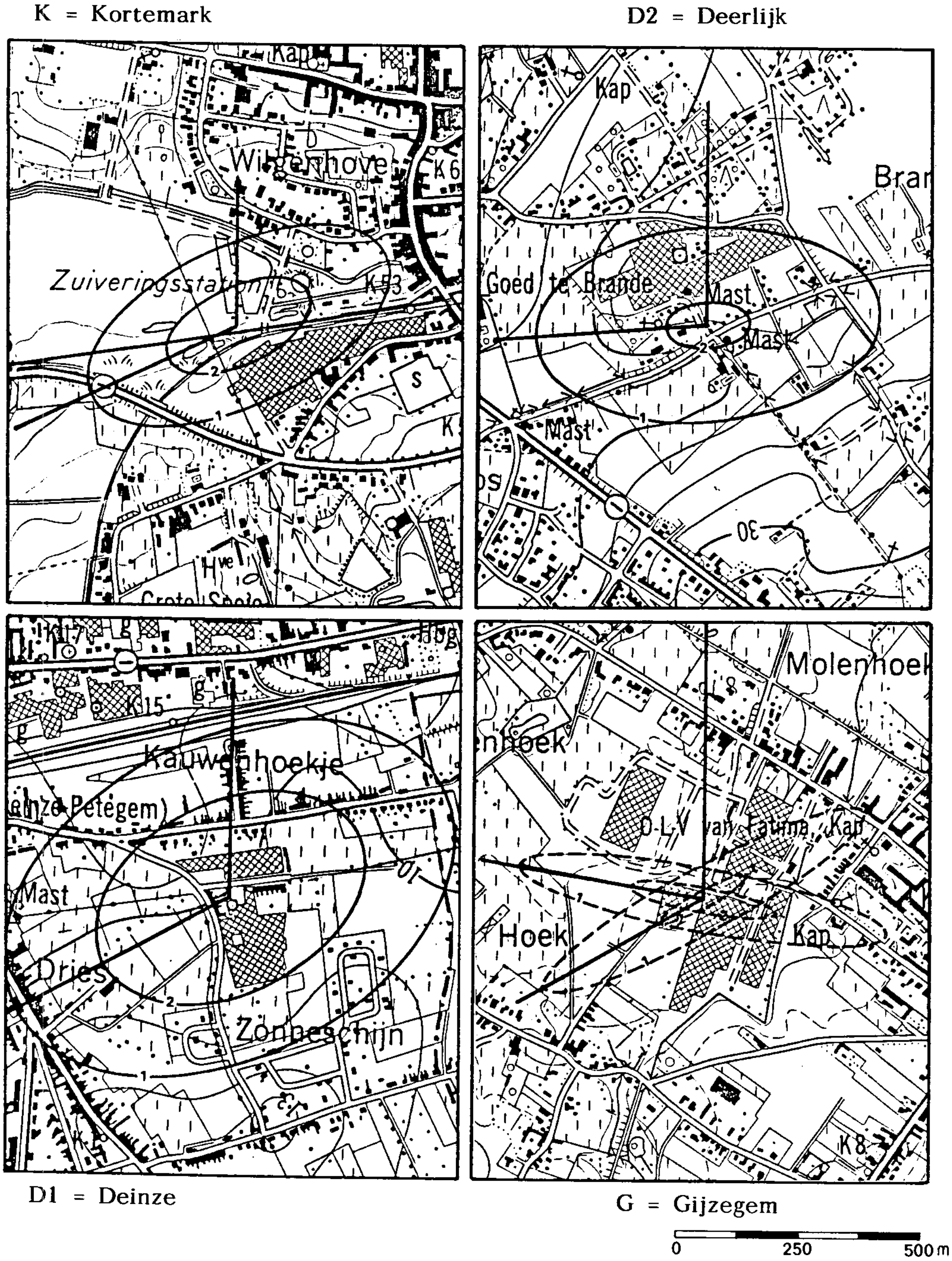
At Deerlijk the piezometric head was situated below the top of the Brabant Massif during the whole pumping test. So the pumped aquifer can here be considered as a phreatic aquifer. In the mathematical model the saturated part of the Brabant Massif, at the beginning of the pumping test, is subdivided in five layers. Layer 1 of the mathematical model is the part of the Brabant Massif which delivers water directly to the pumped well. The flow is mainly horizontal in layer 1. Layers 2 until 5 represent the upper part of the Brabant Massif where the groundwater flow has an important vertical component.

With the axial-symmetric model the drawdowns for the different layers are calculated when layer 1 is pumped. This is done at different times after pumping starts and at different apparent distances to the pumped well. The apparent radial distance, to the pumped well (r_a) is here a function of the real distance of the observation well to the pumped well, r, the anisotropy $\sqrt{m}$ and the angle Θ between the direction pumped well-observation well and the direction of maximum transmissivity (as can be deduced from KRUSEMAN & DE RIDDER, 1970).

$$r_a = r.\sqrt{\cos^2\Theta/\sqrt{m} + \sin^2\Theta.\sqrt{m}} \quad (1)$$

where m is the ratio between the maximum and the minimum transmissivity, respectively kDx and kDy.

During the interpretation of the pumping tests at Deinze, Kortemark and Gijzegem the following hydraulic parameters are determined; the effective transmissivity kDe, the anisotropy $\sqrt{m}$, the angle Θ which defines the direction of maximum transmissivity, the elastic storage coefficient S of the pumped layer, the vertical conductivity k^v and the specific elastic storage S'_A of the covering semi-pervious layer. During the interpretation of the pumping test a Deerlijk kDe, $\sqrt{m}$, Θ and S of the



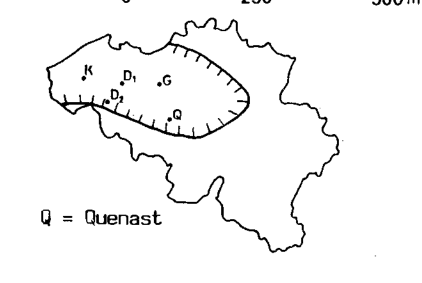


Fig. 2 - Ellipses of equal drawdown (1 and 2 meter) at the four pumping sites for a discharge rate of $0{,}278.10^{-2}\ m^3/s$ ($240\ m^3/d$) after a pumping time of $9{,}6.10^4$ seconds

Table 1. Results of the interpretation of the pumping tests in the Paleozoic basement of Flanders (Brabant Massif)

Pumping site	Thickness of pumped layer (m)	Effective transmissivity KDe in 10^{-4} m²/s	Effective transmissivity KDe in m²/d	Minimum transmissivity KDy in 10^{-4} m²/s	Minimum transmissivity KDy in m²/d	Maximum transmissivity KDx in 10^{-4} m²/s	Maximum transmissivity KDx in m²/d	Anisotropy $\sqrt{m}$ dimensionless	Direction of max. transmissivity	Elastic storage coefficient dimesnionless	Specific elastic storage of Hannut formation (m^{-1})	Vertical conductivity of Hannut formation in 10^{-8} m/s	Vertical conductivity of Hannut formation in m/d	Inclination of joints in degree
Kortemark	66	3,09	26,7	1,49	12,9	6,40	55,3	2,07	N116°W	$0,416.10^{-4}$	$0,16.10^{-4}$	4,6	0,0040	61
Deerlijk	87	5,03	43,5	2,81	24,3	9,02	77,9	1,79	N 94°W	$0,174.10^{-4}$	So=$0,69.10^{-4}$*	$k^{v}pb$** 32	0,028	56
Deinze	56	1,45	12,5	0,958	8,28	2,191	18,9	1,51	N119°W	$0,752.10^{-5}$	$0,34.10^{-5}$	2,3	0,0020	49
Gijzegem solution 1	80	3,68	31,8	0,616	5,32	22,01	190	5,94	N 80°W	$0,125.10^{-3}$	$0,32.10^{-4}$	7,8	0,0067	80
Gijzegem solution 2	80	5,49	47,4	0,926	8,00	32,51	281	5,93	N119°W	$0,217.10^{-3}$	$0,11.10^{-4}$	3,4	0,0029	80

* So is storage coefficient near the watertable in the Paleozic basement (dimensionless)

** $k^{v}pb$ is vertical conductivity of the twenty meter uppermost part of the Paleozoic basement (m/d)

pumped layer are deduced; in addition the vertical conductivity of the Brabant Massif and the storage coefficient near the watertable So are calculated. The results are given in table 1.

Only the interpretation of the pumping test of Gijzegem did not lead to a unique solution. There two possible solution were found. Indeed the sum of the squares of the deviations between the calculated and the observed drawdowns shows two minima. At this site additional data have to be collected to obtain a unique solution. The two possible solutions are shown in table 1. From this table one can deduce for the aquifer of the Brabant Massif that the main direction of maximum transmissivity does not vary considerably. This is also the case for the value of the effective transmissivity.

In figure 2 the ellipses of equal drawdown for all the pumping sites are drawn. They represent the drawdown of 1 and 2 meter for identical pumping conditions, namely a discharge rate of $0,278.10^{-2}$ m³/s (240 m³/d) and a pumping time of $9,6.10^{4}$ seconds. The size of the ellipses is strongly dependent on the effective transmissivity. Large ellipses are due to small transmissivities, small ellipses are due to large transmissivities. The ratio of the main axis of the ellipses is defined by the anisotropy. Large anisotropy results in a large ratio, and vice versa. The direction of the largest axis is the direction of the maximum transmissivity. From figure 2 it is clear that the direction of maximum transmissivity is nearly the same at every pumping site

3. Hypothesis

Then the observation wells and the pumped well intersect a common number of joints a system of parallel horizontal joints results in circles of equal drawdown while a system of parallel inclined joints results in ellipses of equal drawdown (fig. 3).

In a system of parallel inclined joints the direction of the joints is equal to the direction of maximum transmissivity and the inclination α can be deduced from the anisotropy $\sqrt{m}$,

$$\cos \alpha = bs/as = 1/\sqrt{m} \qquad (2)$$

where as and bs are the maximum and the minimum axis of an ellipse of equal drawdown.

From the results of the pumping tests and equation (2) one can deduce the inclination of the joints at the different pumping sites when the above mentioned hypothesis is valid. At Kortemark, Deerlijk and Deinze the inclination of the joints is respectively 61°, 56° and 49°. The inclination deduced from the two solutions of Gijzegem are nearly the same. At Gijzegem the joints are very steep ($\alpha = 80°$). R. LEGRAND (1969) measured vertical layers in the Paleozoic basement at Gijzegem.

The direction of the joints is nearly the same at every pumping test site (table 1) and coincides with the direction of maximum transmissivity. The directions of the joints approximate very closely one of the directions of joints as measured by JEDWAB (1950) at Quenast. JEDWAB found that the joints are distributed in two principal systems which are well characterized with respect to their direction and their inclination.

The direction of one of the systems is parallel to the slaty cleavage and to the contact, it is N 40° W. The direction of the second system is perpendicular to the first (N 130° W). These two systems of joints have generally an inclination to the west; the first system to the SW, the second system to the NW. As a consequence these two systems of joints do not form a system of cross joints. The direction of the joints of the second system, which appears the most

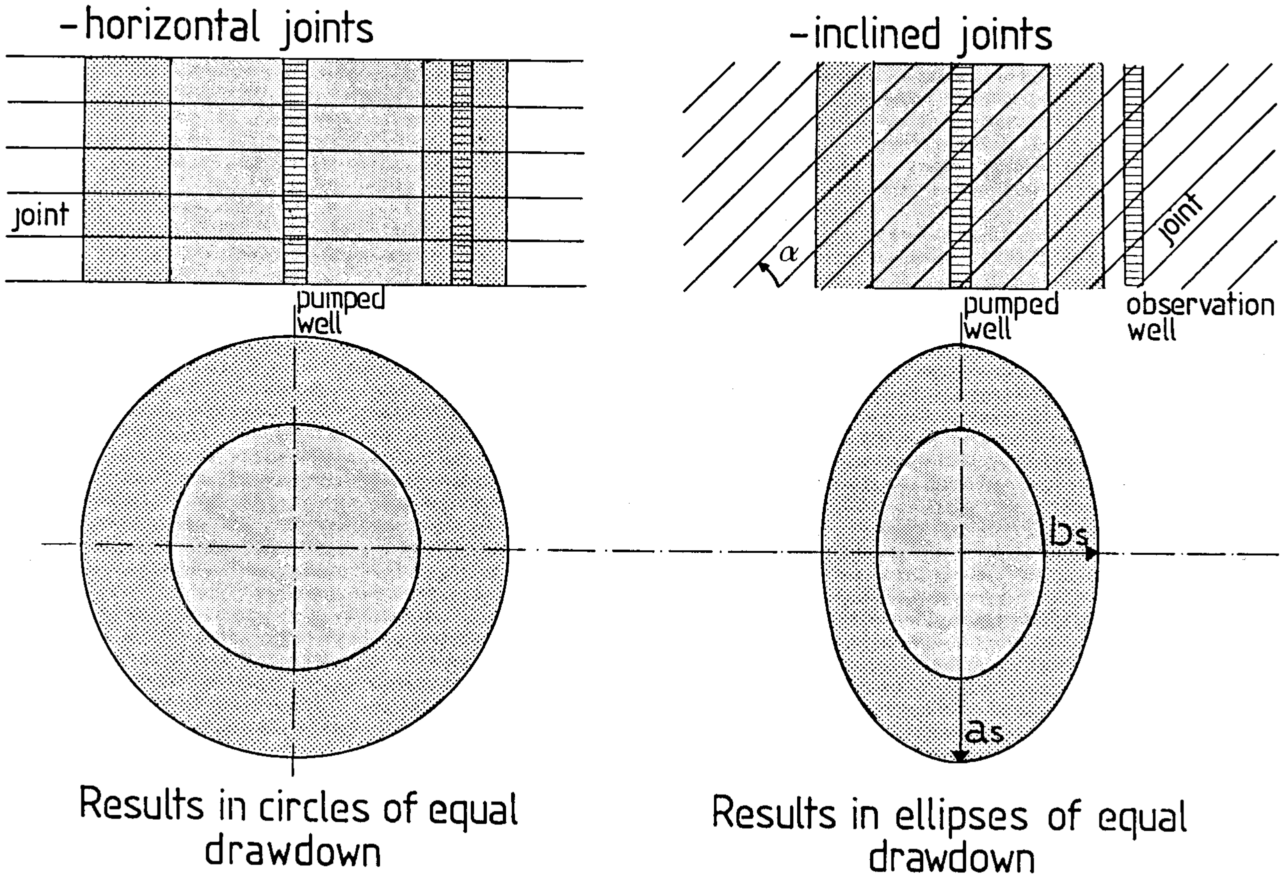


Fig. 3 - Relation between the form of lines of equal drawdown and the inclination of the joints as suggested by the hypothesis

frequently, corresponds with the direction of maximum transmissivity at Kortemark and Deinze and with the direction of one of the solutions found at Gijzegem. The direction of maximum transmissivity found at Deerlijk differs only slightly from the direction of the second system of JEDWAB.

Although the new model of groundwater flow as suggested by the mentioned hypothesis differs slightly from the model which is used for the interpretation, the hydraulic characteristics of the Brabant Massif such as calculated will be close to the real values. The values of the anisotropy, the effective transmissivity and the direction of maximum transmissivity are well estimated. This is probably not the case for the other parameters which influence less the observed drawdowns and have an effect on the calculated drawdown which is strongly dependent on the used model. Therefore the development of a mathematical model of the groundwaterflow to a pumped well in a medium where several systems of parallel joints occur and which is covered with an alternation of semi-pervious and pervious porous layers is advisible. Only with the help of such a model one can obtain a better insight in the differences between the used model and the new model such as suggested by the hypothesis. Because of the loss of any axial symmetry in the new model one has to develop a three-dimensional model which involves a large amount of computer time and memory.

CONCLUSION

From the interpretation of pumping tests at four different sites in the Paleozoic basement of Flanders (Brabant Massif) one can tentatively conclude that the direction of maximum transmissivity is approximately the same at all pumping sites.

Assuming that the observed anisotropy in the horizontal plane is due to a system of inclined parallel joints then the direction of the joints is equal to the direction of maximum transmissivity, and the inclination of the joints can be deduced from the anisotropy. The direction of the joints as deduced from the pumping tests is approximately the same at all sites. The deduced inclination of the joints was the largest at Gijzegem where R. LEGRAND (1969) measured vertical layers in the Paleozoic basement.

To prove or to adjust the proposed hypothesis additional tests and surveys have to be performed. The development of a mathematical model of groundwaterflow towards a pumped well in a medium where several systems of parallel joints occur, and which is covered with a porous medium consisting of an alternation of pervious and semi-pervious layers should be one of the first steps to be taken. This model could also be used for the computation of the regional waterflow in the Brabant Massif and his covering layers under Flanders. The constatation of the anisotropy of the Brabant Massif and its explanation are hydrogeologically both very important.

REFERENCES

DE GEYTER, G. (1988). Landen Groep in Voorstel lithostratigrafische indeling van het Paleogeen, p. 59-81. Nationale commissie voor stratigrafie - Tertiair.

JEDWAB, J. (1950). Introduction à l'étude structurale de la microdiorite de Quenast. Bull. Soc. Belg. Géol. Pal. Hydro, LIX, 225-231.

KRUSEMAN, G.P. and DE RIDDER, N.A. (1970). Analysis and evaluation of pumping test data, 200 p. Bull. ILRI. 11.

LEBBE, L. (1988). Uitvoering van pompproeven en interpretatie door middel van een invers model, 563 p. Rijksuniversiteit Gent : Geologisch Instituut (Aggr. Thesis).

LEGRAND, R. (1969). Le Massif du Brabant, 148 p. Toelicht. Verh. Geol. Kaart en Mijnkaart Belg. 9.