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COALIFICATION MAPS FOR THE WESTPHALIAN OF THE CAMPINE COAL BASIN

by

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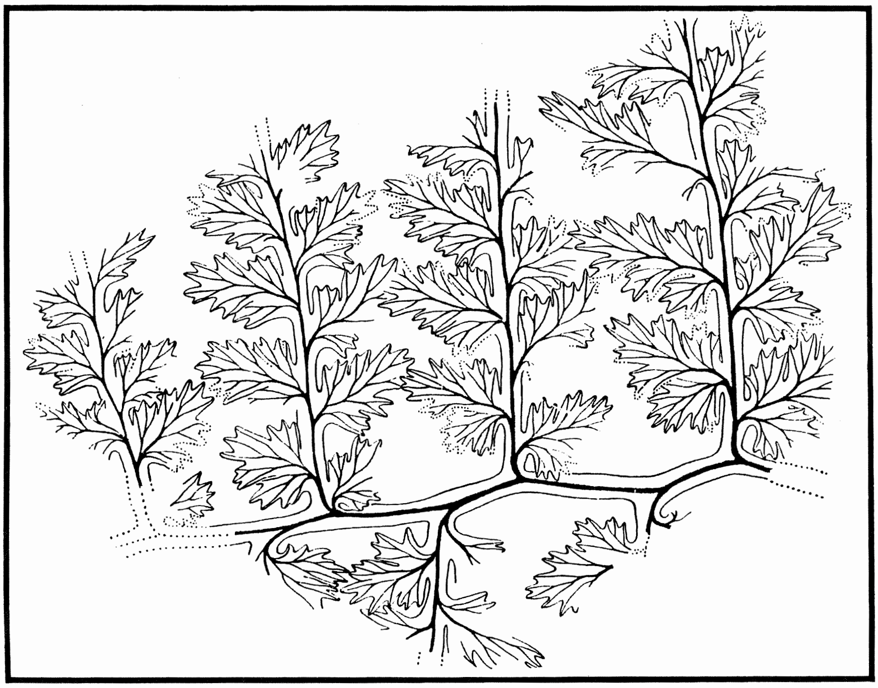

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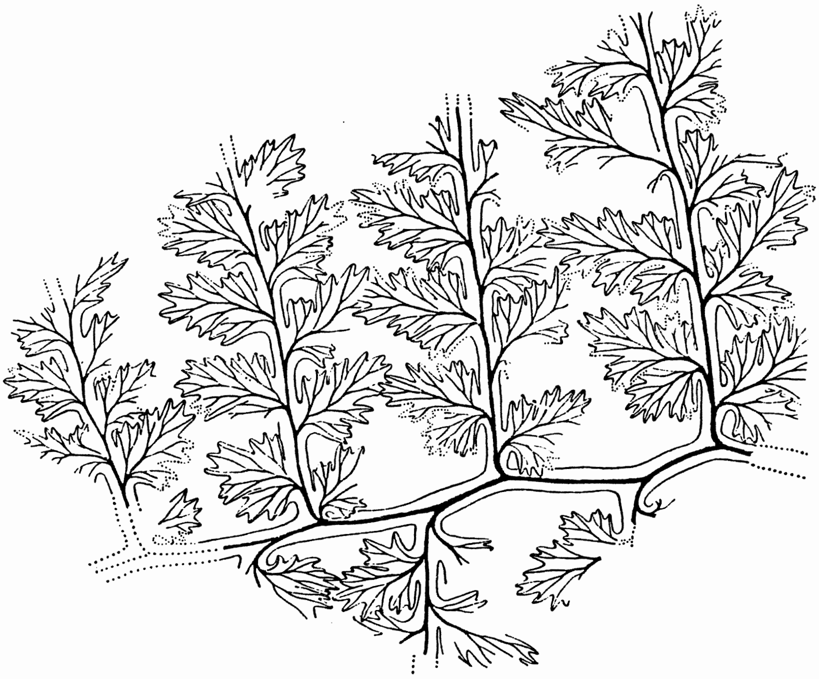

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ABSTRACT

More than 6000 coalification data from the Westphalian in the Campine Basin were analysed. The organic maturity in VRm% was calculated for 11 different stratigraphical levels in the Westphalian based on a statistical treatment of the borehole data. Coalification maps were constructed for the Sarnsbank, Finefrau Nebenbank, Wasserfall, Tonstein Karl, Quaregnon, Wijshagen (Leaia), Eisden, Lanklaar, Maurage, Tonstein Nibelung horizons and the base of the Neeroeteren Sandstone. These maps show a large difference in coalification between the eastern and western part of the Campine coal basin as well as a clear South-North increase in coalification.

KEY WORDS

Campine Basin, Westphalian, Coalification

I. INTRODUCTION.

The subcropping Paleozoic of the Campine Basin has been explored by deep wells for more than 90 years now. The almost 200 boreholes reaching the Devono-Carboniferous in the Campine have yielded a vast amount of geological data (Fig.1.a.). One of the most interesting parts of this knowledge base deals with the maturity of the organic material in the basin of which especially the Westphalian coal seams were intensively sampled and studied.

No general synthesis of the coalification data was presented until the present. A limited study of the Westphalian, based on 140 vitrinite reflectance measurements, was incorporated in a doctoral study (Pillement, 1982). Muchez et al (1987) reviewed the scarce data on the Lower Carboniferous, focussing on the western and southernmost parts of the Campine Basin. The present study incorporates more than 200 vitrinite reflectance measurements as well as some 6000 volatile matter analyses from 157 wells throughout the Campine. The large majority of these data originate from the mining area and the coal exploration zone to the north of the collieries, in the eastern part of the Campine Basin. The results presented here are restricted to this area (Fig.1.b.).

II. THE COALIFICATION DATA.

Volatile matter analyses on coals have been carried out since the beginning of coal exploration in the Campine Basin. The main purpose of this was to assess the coal rank of the drilled seams. In most cases these data were published together with the lithological descriptions in the Annales des Mines de Belgique. A complete list of the references for wells with coalification data used for the coalification maps is given at the end of the paper.

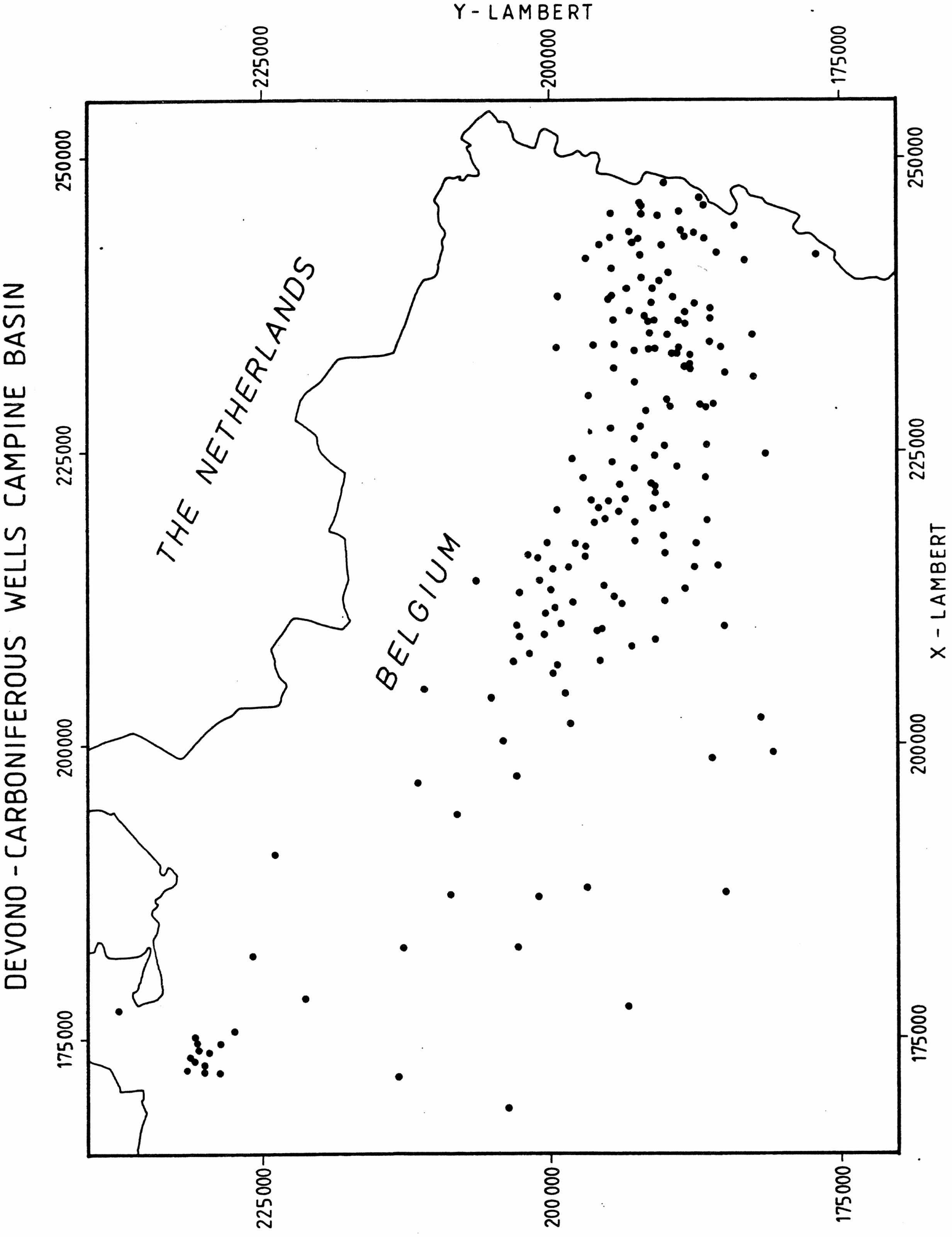


Fig.1. a: Location of the wells reaching the Paleozoic in the Campine Basin.

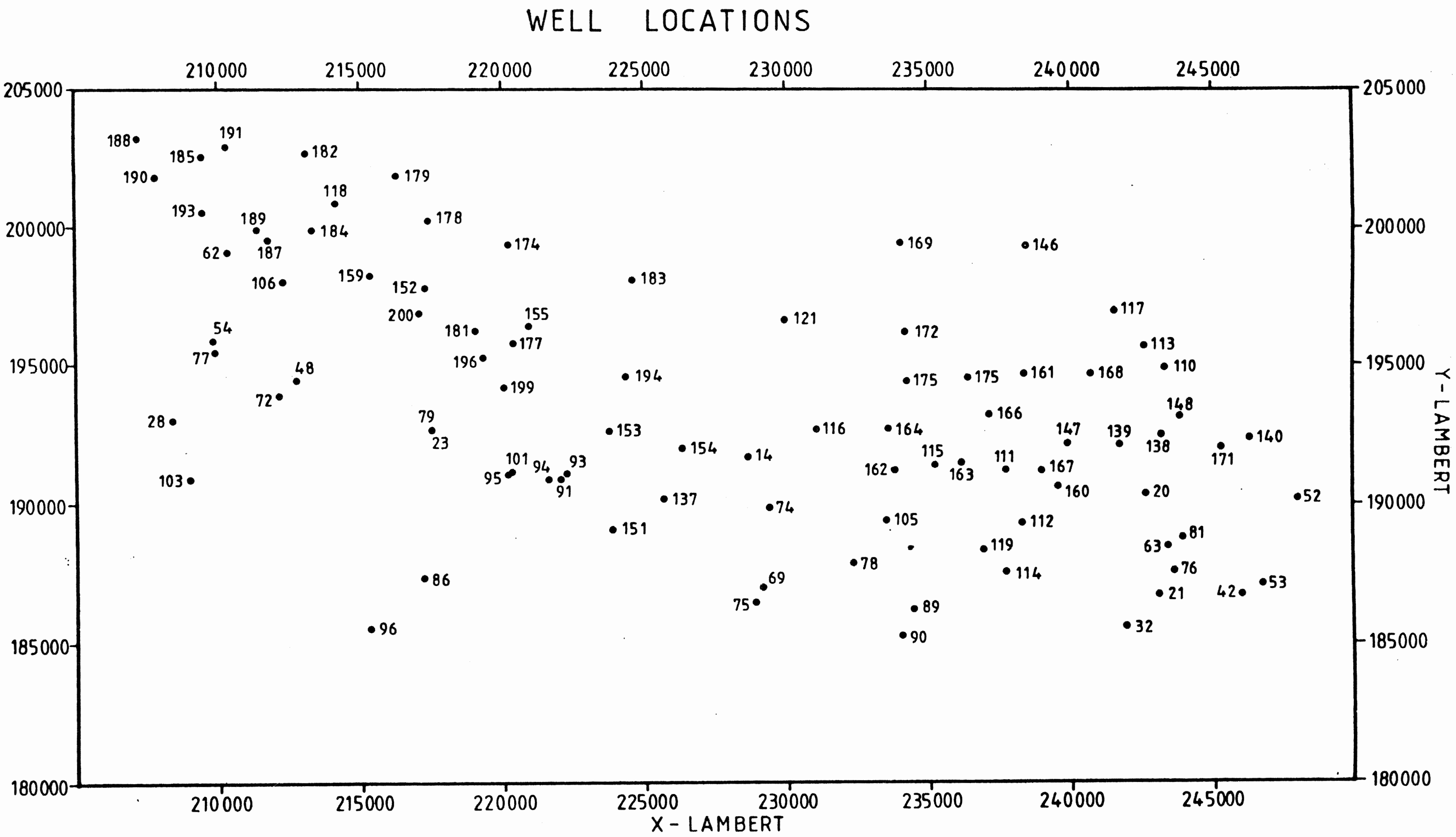


Fig 1. b: Wells incorporated in the present coalification review for the eastern part of the Campine Basin.

Compilations for these borehole data from the first half of the century are Lohest et al (1903) and Delmer (1963). The second coal exploration campaign in the Campine, starting in 1979, again yielded a large amount of volatile matter data together with some vitrinite reflectance measurements in wells of the Belgian Geological Survey. The descriptions for five of these wells were published by Dusar and co-workers (see references list). For the remaining wells of the BGS and the more than 40 wells of the Kempense Steenkolenmijnen, the coalification data were kindly provided to the author for which many thanks are indebted.

The collected volatile matter data were in most cases ashfree although for the older wells these values frequently had to be calculated using the non-ashfree volatile matter percentage and the ash content. Although the ashfree volatile matter parameter is since long used by coal geologists to measure the coalification, it is clearly not as universally known and used as the mean vitrinite reflectance. Therefore all the volatile matter data were recalculated into mean vitrinite reflectance (VRm%) using the relation between both parameters presented in Teichmüller et al (1979; their table 2).

For 7 wells drilled for the Belgian Geological Survey, both parameters were measured in a number of coal seams. A comparison between the calculated and the measured VRm% was made for these wells. Table 1 shows that the calculated values are always on average higher than the measured VRm%. For 5 of the 7 wells the difference is below 0.05 VRm% which falls within the standard deviation of an average VRm% value. For well KB183 the difference is 0.078 VRm% however and for KB174 VRm% even 0.116. The reason for these differences is not clear. An additional set of VRm% values was calculated from Rock-Eval Tmax values assuming that all the analysed organic material was type III kerogen and using a graph from Tissot et al (1987) for the relationship between VRm% and Tmax. This third set of VRm% values plotted between the measured values and those calculated from the volatile matter. Since there is no explanation for the differences between the sets of VRm% in this well, the best thing to do was to use all the values of the first two sets (measured VRm% and calculated VRm% from volatile matter) and treat these as if they were just one data set as was done in the other wells. The relationship between VRm% and volatile matter from the wells of table 1 is shown on figure 2. The VRm% against depth data for 6 of these wells of the Belgian Geological Survey are shown on figure 3.

After recalculating all the data into VRm%, diagrams of VRm% against depth were plotted for all the wells with data. A first selection of the wells to be used in the further calculation was carried out on the basis of these diagrams. Only wells with a sufficient amount of data and a recognizable increase of VRm% with depth were chosen for the next step in the analysis (Fig.4).

Tab.1: Average difference between measured and calculated mean vitrinite reflectance in 7 recent wells of the Belgian Geological Survey.

Well	Number of data	Average difference in Vrm% ($VRm\%_{calc}$ - $VRm\%_{meas}$)
KB146	16	+ 0.027
KB161	22	+ 0.045
KB168	26	+ 0.041
KB169	19	+ 0.026
KB172	29	+ 0.046
KB174	27	+ 0.116
KB183	18	+ 0.078

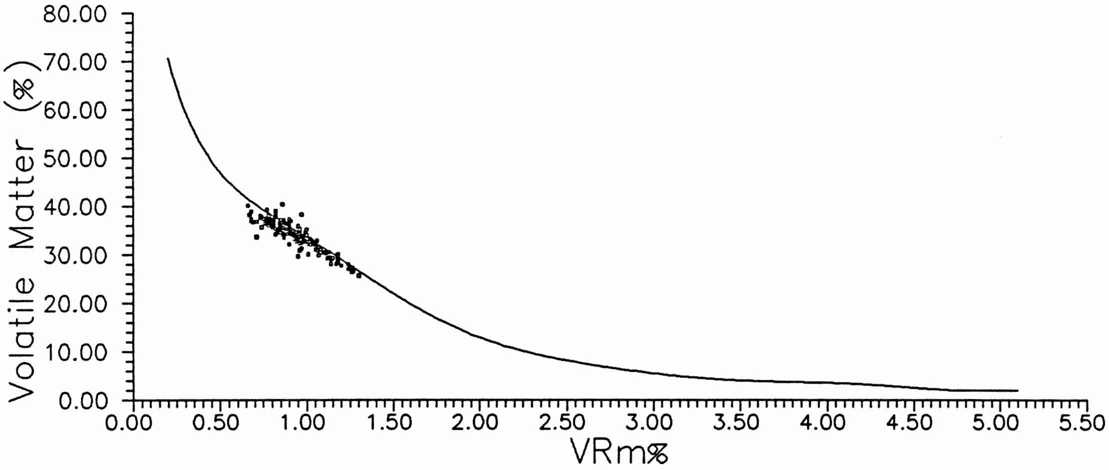


Fig.2. Relationship between mean vitrinite reflectance and volatile matter content. The data pairs from 7 Belgian Geological Survey wells (table 1) are plotted.

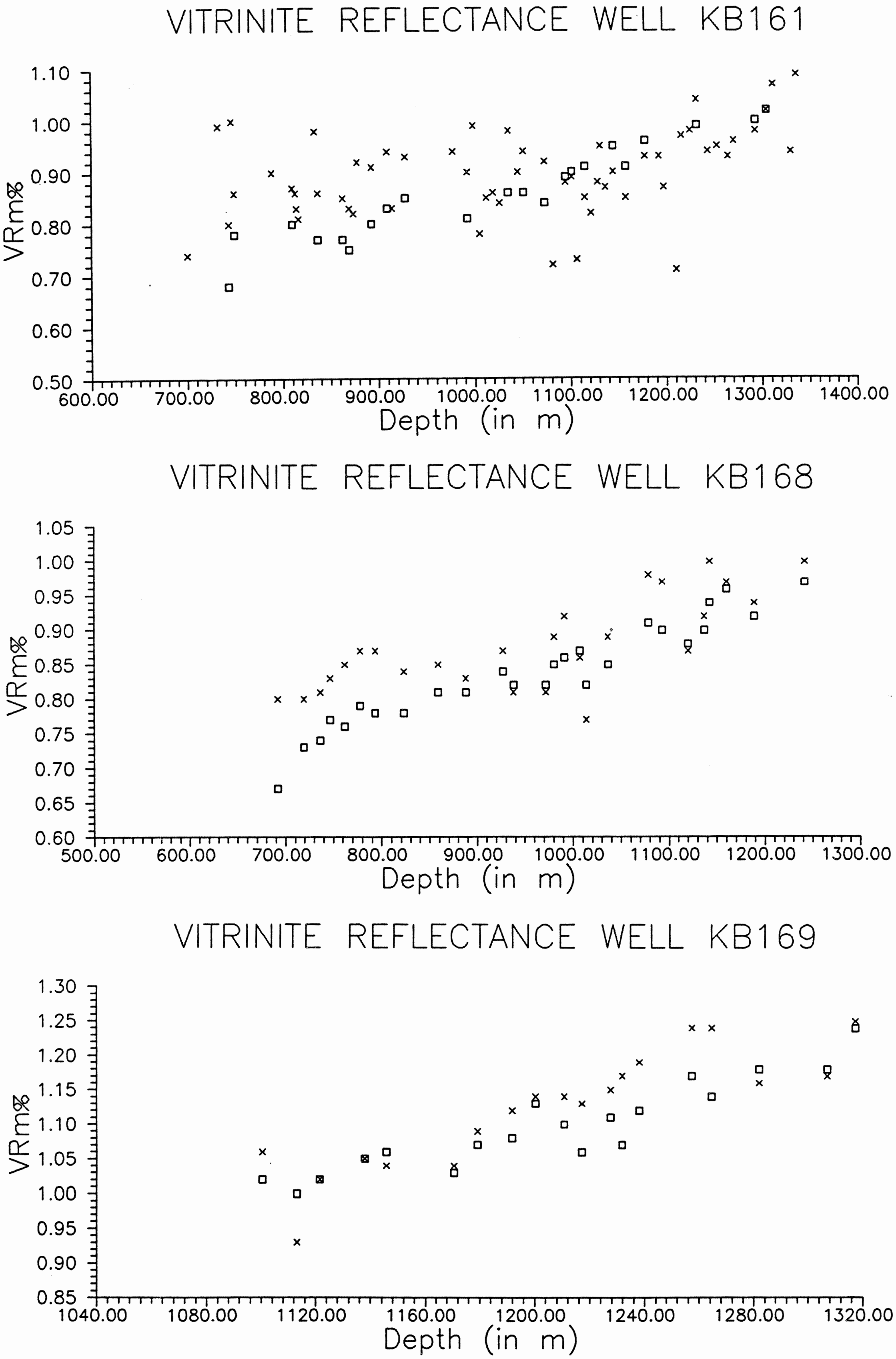
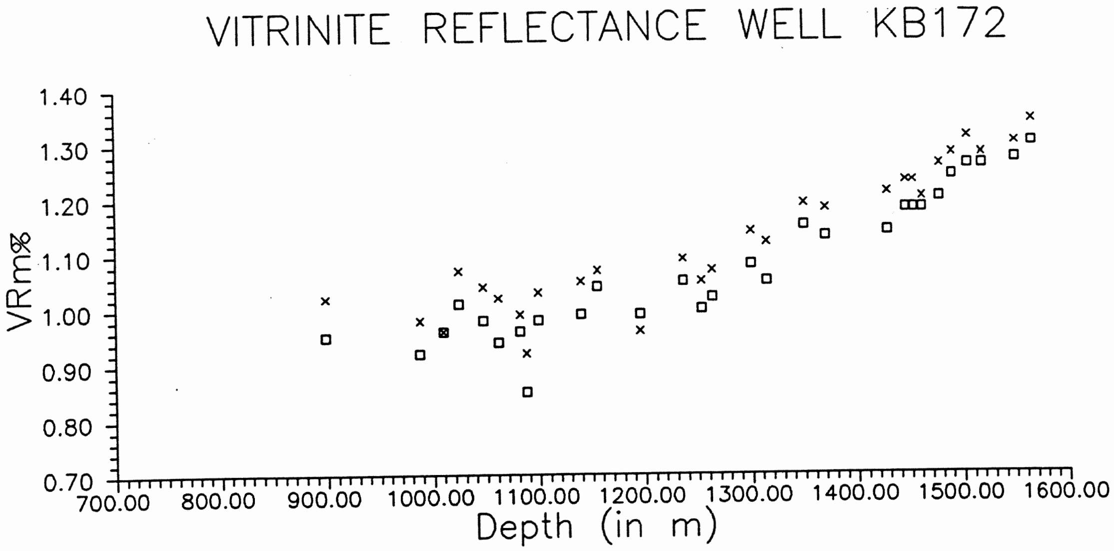
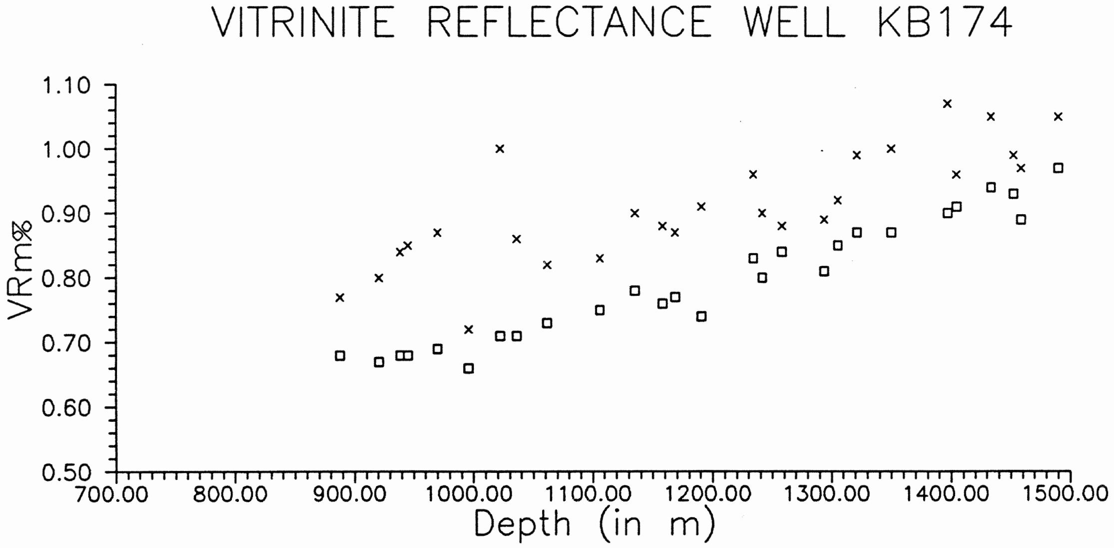


Fig.3. Vitrinite reflectance data in 6 recent wells of the Belgian Geological Survey. The squares indicate measured VRm% while the crosses are VRm% calculated from the volatile matter content.





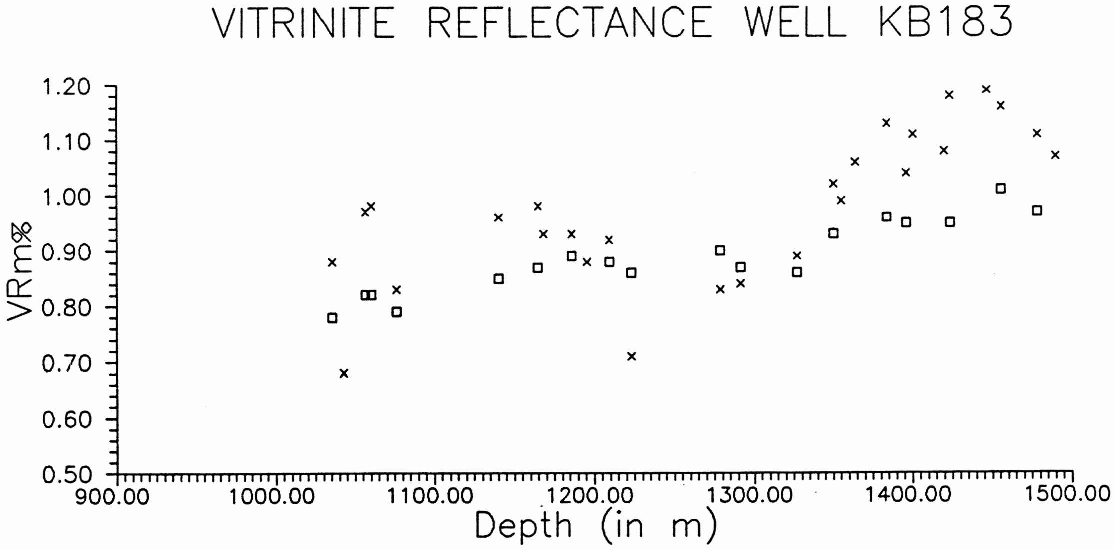
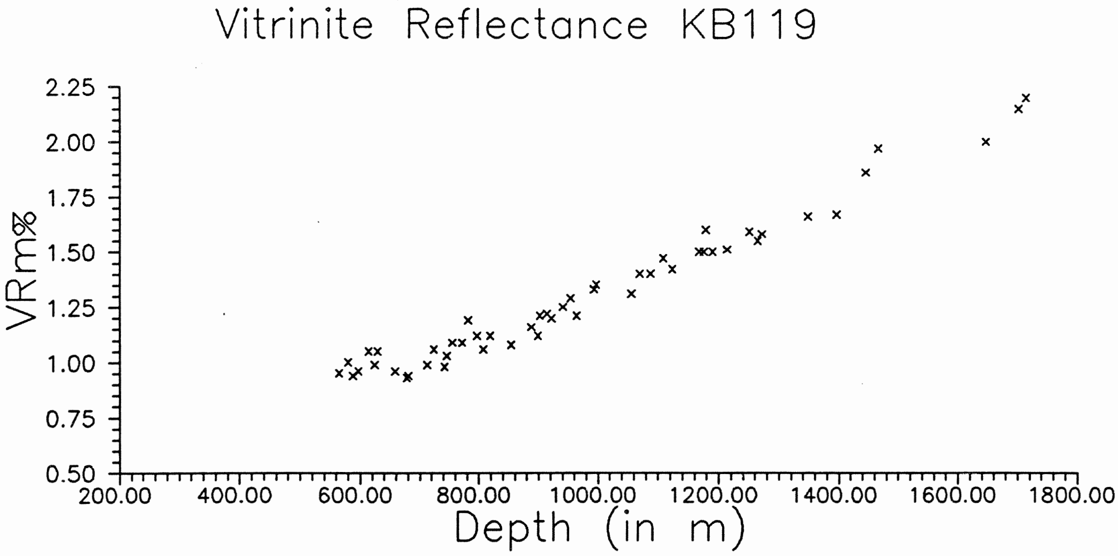


Fig.3. (continued).



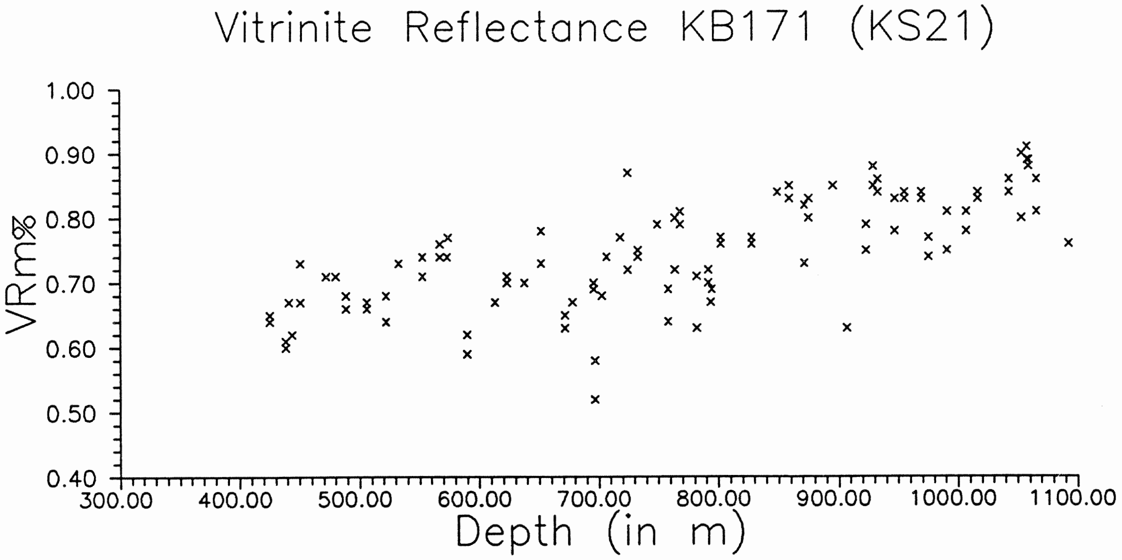
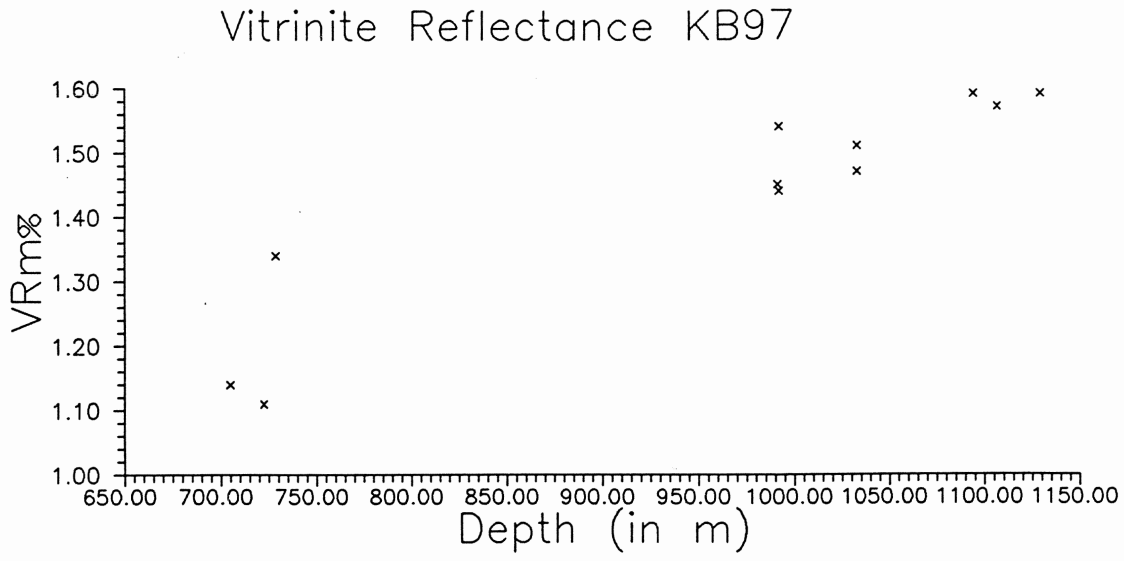


Fig.4. Examples from calculated VRm% in 4 wells. Wells KB119 and KB171 were used in the study because of the clear trend in the data and the good (KB119) to fair (KB171) spread of data points around this trend. Well KB97 shows a trend but the number of data points in insufficient. Well KB173 has sufficient data but exhibits no trend. The latter 2 wells were not used in the study.



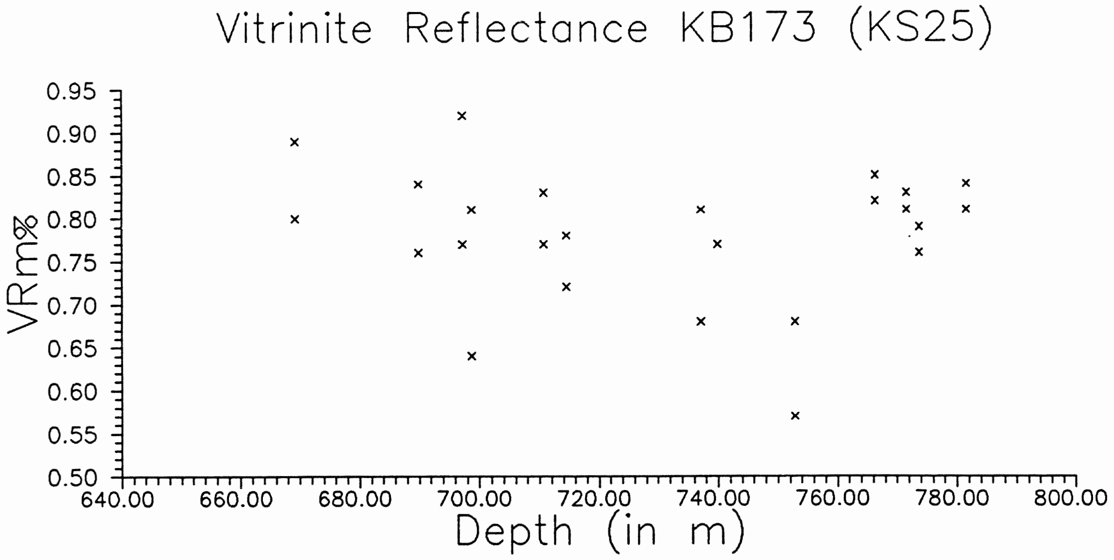


Fig.4. (continued).

III. STATISTICAL ANALYSIS.

Two different approaches to the problem of establishing coalification maps are possible. The first is to use VRm% values which were actually measured at certain stratigraphical levels as input data for the maps. Another approach was used in this study however. A regression analysis was carried out for each of the selected wells. The coalification values at the different stratigraphical levels were calculated using the obtained regression equation. This has several advantages on using measured values. Not only is it clear that the statistically derived values are less variable but the VRm% can also be calculated for any stratigraphical level without being dependent on one single analysis at that level. Furthermore were anomalously low VRm% values reported for coal seams overlain by marine bands and so were differences in VRm% depending on a shaly or sandy roof of the coal seam (Fermont, 1988, Price and Barker, 1985, Veld and Fermont, 1990). These lithological problems are also tackled by using the statistical approach.

The question remains which relation between VRm% and depth to expect. Although some authors advocated a logarithmic relation on a theoretical basis, it is already clear from many measured wells that when fairly long depth ranges are considered, the form of the VRm%-depth relation is almost always more or less logarithmic instead of linear (Teichmuller et al., 1979). A logarithmic regression was therefore carried out in all the wells since no complications to this general rule were expected in the Campine. It must be pointed out that in many cases the logarithmic curve was almost linear, especially in the lower VRm% ranges. This shows that for certain purposes a linear approach to the variation of VRm% with depth is allowed.

The actual calculation of the coalification trend in all the wells consisted of a number of consecutive logarithmic regressions. In many cases was the initial regression coefficient fairly low, due to a small number of abnormally high or low VRm% values. These are most probably operator errors during the volatile matter analysis (the difference between analyses from different labs within the K.S. collieries was generally within 3% volatile matter content (pers. comm. J. Tricot)) or sampling errors. The volatile matter analysis seems to come up with wrong values when the ash content of the sample is high (10% or more). On the contrary, very high volatile matter content and thus very low VRm% values are often indicative for cannel coals. These outliers have to be removed from the dataset before a correct calculation of the coalification trend can be done. The removal of these data points is allowed because a reasonable explanation can be given for the atypical behaviour of the samples and because the general nature of the coalification trend is known to be a logarithmic decrease of coalification (VRm%) with depth (Hilt's Law).

The removal of these false datapoints was done on the basis of the standard error of the VRm% estimate from the logarithmic regression. After all the datapoints which differed more than two times the standard error from the estimated VRm% trend were removed, a new regression was calculated. This procedure was carried out several times until no more data could be deleted. On average 15% of the data were removed from the datasets in this way. The regression coefficient constantly rises during this procedure while the standard error becomes smaller and smaller. This somewhat unorthodox statistical method was compared to a recently developed algorithm for dealing with outliers in regression analysis. This least median squares (LMS) (Rousseeuw and Leroy, 1987) algorithm is implemented in the software package Splus of StatSci(Seattle). The regression equations calculated using the LMS procedure were exactly the same as those obtained from our iterative method. This confirms the robustness of the method which was used. The problem with both methods is however that there is no exact measure of the variation in the original data set when compared to the calculated trend. The R^2 obtained in the method used in this study only relates the final data set, after deletion of the outliers, with the regression trend. Figure 5 shows the effect of the statistical treatment on the data of well KB155. Table 2 lists the well data for all the wells used in the study, as well as the statistical data.

IV. COALIFICATION MAPS.

The depths of all the relevant stratigraphical markers were gathered after a logarithmic regression equation was obtained for each well. Delmer (1963) was used as stratigraphical information for the older wells while the stratigraphical interpretations of the Belgian Geological Survey and the Kempense Steenkolenmijnen were followed for the recent boreholes. The depths of the stratigraphical levels were corrected when the well section was faulted. This correction was made because the maturity level of the Westphalian in the Campine was probably reached for the larger part before the formation of these faults. The VRm% was calculated for each of the stratigraphical levels in the well. When one of the marker beds was not reached in a well or had been eroded, its probable depth was calculated based on information from neighbouring wells. The VRm% was calculated when this extrapolation was within 100 m of the drilled section. The calculated VRm% are given in table 3.

Then all the datapoints for each of the following stratigraphical levels were put together and plotted on a map: Sarnsbank Marine Band, Finefrau Nebenbank Marine Band, Wasserfall Marine Band, Tonstein Karl (coal seam KS70), Quaregnon Marine Band, Wijshagen Marine Band (or top of coal seam KS45), Eisden Marine Band, Lanklaar Marine Band, Maurage Marine Band, Tonstein Nibelung (coal seam KS1G) and Base of the Neeroeteren Sandstone. These levels are situated on a simplified stratigraphical column of the Westphalian in the Campine Basin (Fig.6).

Finally the mapped data points were hand-contoured taking into account the position of the isoreflectance curves on the map for the stratigraphical levels which were immediately above and below. A concise description of the coalification maps will now be given.

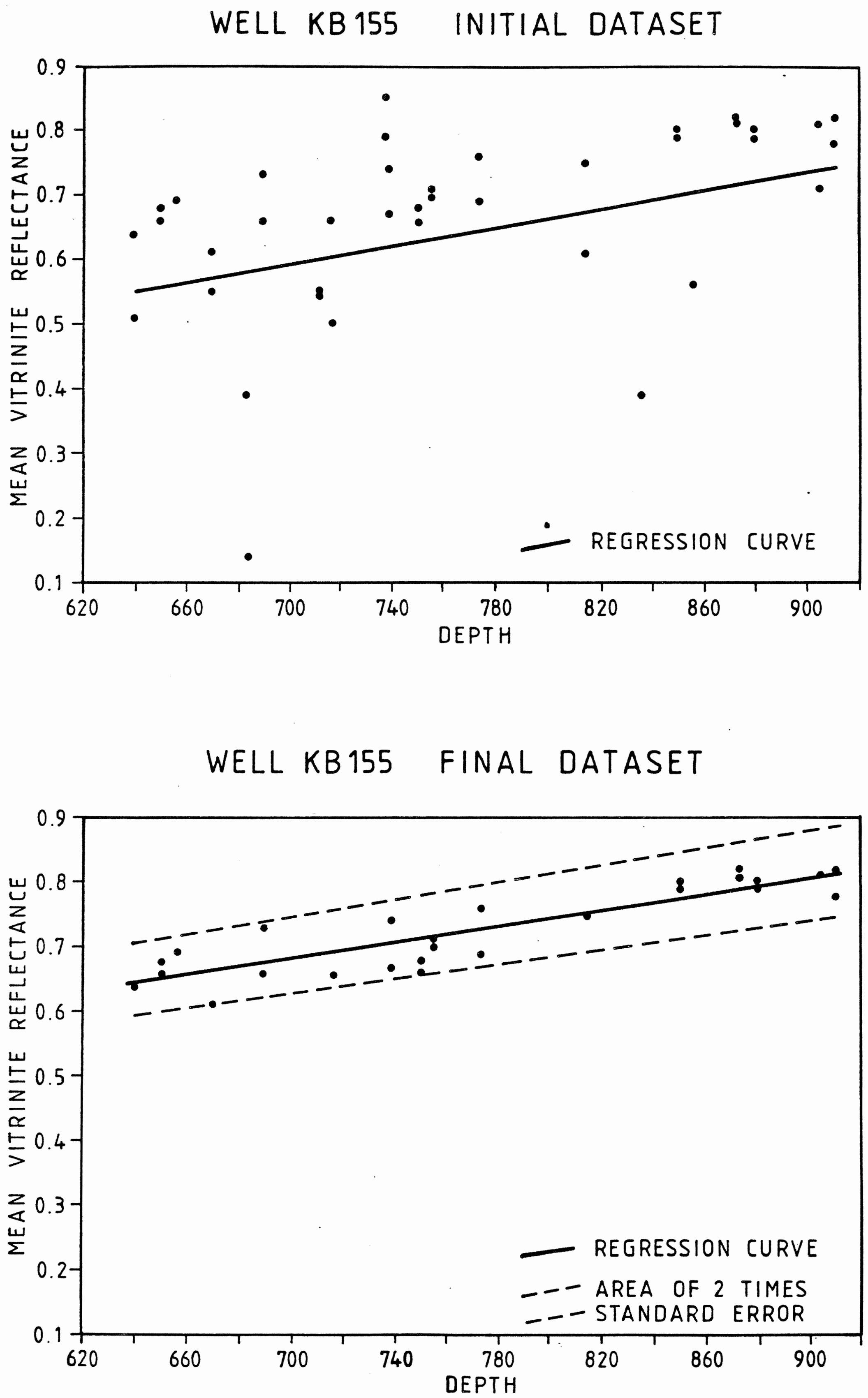


Fig.5. a: Complete dataset for well KB155 with initial regression line. b: Final dataset after elimination of outliers with regression line and range of 2 times the standard error.

Tab.2.: Borehole and statistical data. (KSnr is the number of the well according to the Kempense Steenkolenmijnen, ni is the number of regressions executed to obtain the final equation, n1 and n2 are the number of data points before and after the statistical treatment, Rsq. and std. Err. are the square regression coefficient and standard error for the final regression equation).

Well	KSnr.	X-Lambert	Y-Lambert	Regression eq.	ni	n1	n2	Rsq.	Std. Err.
14	-	228488	191740	ln(Y)=0.000868X-0.72617	2	26	24	0.625	0.074
20	-	242465	190385	ln(Y)=0.001166X-0.89075	3	26	24	0.612	0.079
21	-	242970	186733	ln(Y)=0.000751X-0.06386	3	35	31	0.926	0.031
23	-	217420	192722	ln(Y)=0.001023X-0.75779	3	35	33	0.664	0.045
28	-	208336	193052	ln(Y)=0.000652X-0.17783	3	17	14	0.806	0.035
32	-	241780	185595	ln(Y)=0.000408X+0.37763	2	17	16	0.802	0.024
42	-	245898	186766	ln(Y)=0.000954X-0.12154	2	33	30	0.867	0.018
48	-	212650	194468	ln(Y)=0.001127X-0.90230	8	70	50	0.755	0.052
52	-	247833	190207	ln(Y)=0.000721X-0.53076	12	95	67	0.810	0.047
53	-	246596	187138	ln(Y)=0.001426X-0.46982	1	16	16	0.917	0.022
54	-	209735	195922	ln(Y)=0.002716X-1.92855	3	19	16	0.902	0.027
62	-	210275	199143	ln(Y)=0.001332X-1.07636	5	139	120	0.445	0.063
63	-	243280	188510	ln(Y)=0.000786X-0.31679	3	60	54	0.815	0.032
69	-	229013	187040	ln(Y)=0.000739X-0.19865	2	28	25	0.925	0.026
72	-	212040	193930	ln(Y)=0.000718X-0.38654	5	39	35	0.791	0.060
74	-	229220	189890	ln(Y)=0.001016X-0.82689	2	40	39	0.948	0.045
75	-	228778	186471	ln(Y)=0.000749X-0.13076	3	29	27	0.797	0.030
76	-	243495	187602	ln(Y)=0.000586X+0.07106	1	18	18	0.759	0.063
77	-	209830	195525	ln(Y)=0.000551X-0.31446	3	25	23	0.805	0.063
78	-	232170	187886	ln(Y)=0.000777X-0.29343	2	34	32	0.932	0.042
79	-	217403	192704	ln(Y)=0.000719X-0.61665	7	75	28	0.874	0.042
81	-	243766	188775	ln(Y)=0.000826X-0.29790	2	20	19	0.951	0.027
86	-	217105	187372	ln(Y)=0.000643X-0.25649	2	23	22	0.839	0.076
89	-	234332	186210	ln(Y)=0.000735X-0.10851	2	26	25	0.748	0.044
90	-	233900	185289	ln(Y)=0.000601X+0.02643	2	18	17	0.972	0.025
91	-	221949	190950	ln(Y)=0.000845X-0.50128	4	33	27	0.634	0.057
93	-	222168	191122	ln(Y)=0.000768X-0.47626	4	24	19	0.911	0.051
94	-	221510	190948	ln(Y)=0.000782X-0.43484	3	26	24	0.834	0.046
95	-	220090	191115	ln(Y)=0.000874X-0.73450	3	52	44	0.932	0.045
96	-	215239	185544	ln(Y)=0.000470X+0.37410	3	45	42	0.705	0.030
101	-	220225	191178	ln(Y)=0.000853X-0.69678	5	40	34	0.623	0.051
103	-	208950	190912	ln(Y)=0.000647X-0.04777	3	14	12	0.881	0.045
105	-	233330	189437	ln(Y)=0.000837X-0.66629	2	66	64	0.967	0.040
106	-	212180	198055	ln(Y)=0.000908X-0.87990	1	27	27	0.821	0.060

110	-	243146	194885	no equation	-	-	-	-	-
111	-	237538	191254	ln(Y)=0.000670X-0.73220	4	51	44	0.930	0.060
112	-	238115	189350	ln(Y)=0.000846X-0.71301	3	40	37	0.907	0.066
113	-	242430	195725	no equation	-	-	-	-	-
114	-	237588	187590	ln(Y)=0.000749X-0.25972	2	35	33	0.957	0.033
115	-	235060	191412	ln(Y)=0.000793X-0.79157	3	52	47	0.967	0.044
116	-	230900	192734	ln(Y)=0.000608X-0.69137	4	65	56	0.888	0.060
117	-	241390	196970	no equation	-	-	-	-	-
118	-	214054	200885	ln(Y)=0.000591X-0.86109	2	31	30	0.904	0.057
119	-	236757	188402	ln(Y)=0.000783X-0.52550	2	51	49	0.970	0.040
121	-	229770	196680	ln(Y)=0.000923X-1.25663	1	19	19	0.823	0.071
137	KS5	225531	190196	ln(Y)=0.001070X-0.75968	5	78	66	0.768	0.066
138	KS4	243035	192482	ln(Y)=0.000400X-0.57755	5	51	41	0.615	0.026
139	KS3	241570	192135	ln(Y)=0.000340X-0.52711	5	96	76	0.595	0.046
140	KS2	246160	192365	ln(Y)=0.000310X-0.45788	3	57	50	0.453	0.043
146	-	238259	199321	ln(Y)=0.000635X-0.85279	4	72	63	0.717	0.055
147	KS6	239743	192154	ln(Y)=0.000450X-0.67170	4	73	66	0.401	0.071
148	KS7	243702	193172	ln(Y)=0.000610X-0.86887	5	98	83	0.657	0.063
151	KS11	223742	189108	ln(Y)=0.000670X-0.18855	1	18	18	0.760	0.041
152	KS10	217193	197814	ln(Y)=0.000750X-0.84347	5	30	21	0.636	0.042
153	KS9	223613	192668	ln(Y)=0.001360X-1.00384	3	39	26	0.929	0.036
154	KS14	226183	192034	ln(Y)=0.000620X-0.65596	4	64	56	0.651	0.060
155	KS12	220808	196448	ln(Y)=0.000840X-0.97518	7	42	27	0.772	0.043
159	KS13	215228	198276	ln(Y)=0.000530X-0.70513	5	74	62	0.569	0.066
160	KS16	239386	198648	ln(Y)=0.000440X-0.48593	5	119	99	0.631	0.068
161	-	238212	194690	ln(Y)=0.000356X-0.48470	6	81	69	0.597	0.052
162	KS17	233672	191248	ln(Y)=0.000710X-0.64287	6	98	82	0.853	0.056
163	KS18	235956	191512	ln(Y)=0.000650X-0.63723	7	126	99	0.728	0.072
164	KS19	233427	192715	ln(Y)=0.000440X-0.50901	7	131	93	0.660	0.056
166	KS20	236951	193223	ln(Y)=0.000770X-0.88963	3	164	145	0.863	0.063
167	KS22	238787	191238	ln(Y)=0.000730X-0.76704	7	98	68	0.883	0.050
168	-	240545	194697	ln(Y)=0.000408X-0.54232	2	52	49	0.696	0.044
169	-	233846	199437	ln(Y)=0.000844X-0.91618	4	38	34	0.827	0.025
171	KS21	245173	192013	ln(Y)=0.000450X-0.57903	5	120	106	0.663	0.057
172	-	234022	196268	ln(Y)=0.000537X-0.58945	3	58	53	0.903	0.034
174	-	220085	199406	ln(Y)=0.000614X-0.91600	4	54	50	0.717	0.070
175	KS26	236205	194558	ln(Y)=0.000430X-0.61115	4	98	86	0.471	0.069
176	KS23	234084	194433	ln(Y)=0.000550X-0.77418	4	142	126	0.787	0.062
177	KS28	220260	195841	ln(Y)=0.000450X-0.61090	6	92	76	0.550	0.071
178	KS38	217290	200260	ln(Y)=0.000540X-0.80541	5	90	81	0.681	0.073

179	KS40	216165	201892	ln(Y)=0.000570X-0.94910	5	109	92	0.697	0.112
181	KS31	218940	196287	ln(Y)=0.000770X-0.85827	6	104	84	0.778	0.060
182	KS39	212990	202710	ln(Y)=0.000760X-1.18026	4	102	94	0.680	0.102
183	-	224413	198118	ln(Y)=0.000550X-0.75561	3	45	43	0.503	0.080
184	KS34	213240	199935	ln(Y)=0.000570X-0.74996	3	41	37	0.683	0.067
185	KS36	209390	202578	ln(Y)=0.000860X-0.95255	3	82	79	0.856	0.061
187	KS42	211680	199547	ln(Y)=0.000700X-0.73385	4	86	73	0.825	0.058
188	KS35	207140	203240	ln(Y)=0.000840X-0.79586	2	64	60	0.917	0.054
189	KS30	211271	199933	ln(Y)=0.000520X-0.57897	5	86	75	0.647	0.063
190	KS15	207756	201813	ln(Y)=0.000860X-0.82604	2	46	44	0.926	0.039
191	KS37	210220	202945	ln(Y)=0.000510X-0.61098	4	113	97	0.845	0.051
193	KS41	209383	200552	ln(Y)=0.000680X-0.51584	4	58	51	0.640	0.069
194	KS29	224197	194612	ln(Y)=0.000970X-1.02586	3	46	43	0.485	0.169
196	KS46	219220	195310	ln(Y)=0.000490X-0.57037	3	40	34	0.597	0.058
199	KS45	219945	194204	ln(Y)=0.000830X-0.87260	7	81	52	0.801	0.064
200	KS47	216940	196912	ln(Y)=0.001040X-1.16687	10	59	32	0.870	0.073

Tab.3.: Calculated VRm% values for the different stratigraphical levels in the studied wells (BN: Base Neeroeteren Sandstone, TN: Tonstein Nibelung, MBM: Marine Band Maurage, MBL: Marine Band Lanklaar, MBE: Marine Band Eisden, W: Wijshagen, MBQ: Marine Band Quaregnon, TK: Tonstein Karl, MBW: Marine Band Wasserfall, MBFN: Marine Band Finefrau Nebenbank, MBS: Marine Band Sarnsbank).

Well	BN	TN	MBM	MBL	MBE	W	MHQ	TK	MHW	MHFN	MHS
14	-	-	0.82	0.885	1.06	-	-	-	-	-	-
20	-	-	0.89	-	-	-	-	-	-	-	-
21	-	-	-	-	-	-	-	1.41	1.73	-	-
23	-	-	-	-	-	-	0.87	-	-	-	-
28	-	-	-	-	-	-	-	-	1.23	1.63	-
32	-	-	-	-	-	-	-	-	-	1.90	2.05
42	-	-	-	-	-	-	1.28	1.49	-	-	-
48	-	-	-	-	-	0.72	0.865	-	-	-	-
52	-	-	0.87	0.93	1.035	-	-	-	-	-	-
53	-	-	-	-	0.97	1.18	-	-	-	-	-
54	-	-	-	-	-	-	0.77	-	-	-	-
62	-	-	-	-	-	-	0.84	1.06	-	-	-
63	-	-	-	-	1.02	1.13	1.30	-	-	-	-
69	-	-	-	-	-	-	1.26	1.41	1.68	-	-
72	-	-	-	-	-	-	-	-	1.41	-	-
74	-	-	0.725	0.79	0.95	1.08	1.26	1.46	-	-	-
75	-	-	-	-	-	-	1.33	1.48	-	-	-
76	-	-	-	-	-	-	-	1.57	1.81	2.17	2.43
77	-	-	-	-	-	-	-	-	1.35	1.65	-
78	-	-	-	-	1.08	1.21	1.37	-	1.86	-	-
79	-	-	-	-	-	-	0.83	0.95	1.19	-	-
81	-	-	-	-	1.03	1.16	1.32	1.52	-	-	-
86	-	-	-	-	-	-	-	-	-	1.59	1.82
89	-	-	-	-	-	-	1.31	1.47	1.75	-	-
90	-	-	-	-	-	-	-	1.46	1.69	2.07	-
91	-	-	-	-	-	-	-	1.02	1.295	-	-
93	-	-	-	-	-	-	-	0.98	1.24	1.59	-
94	-	-	-	-	-	-	-	1.01	1.31	-	-
95	-	-	-	-	-	-	0.86	1.00	1.29	1.76	-
96	-	-	-	-	-	-	-	-	-	1.88	2.06
101	-	-	-	-	-	-	0.87	1.00	-	-	-
103	-	-	-	-	-	-	-	-	-	1.66	1.88
105	-	-	0.80	0.86	1.03	1.15	1.31	1.49	1.82	-	-
106	-	-	-	-	-	-	0.81	0.96	1.27	-	-

110	0.72	-	-	-	-	-	-	-	-	-	-
111	-	0.73	0.90	0.96	1.08	1.19	1.33	-	-	-	-
112	-	-	0.78	0.86	1.03	1.17	1.34	1.54	-	-	-
113	0.73	-	-	-	-	-	-	-	-	-	-
114	-	-	-	-	-	1.14	1.305	1.475	1.79	2.29	-
115	-	0.67	0.855	0.92	1.10	1.23	1.36	1.54	-	-	-
116	-	0.74	0.90	0.94	1.05	1.14	1.24	1.37	-	-	-
117	0.77	-	-	-	-	-	-	-	-	-	-
118	-	-	0.67	0.71	0.78	0.84	0.94	1.06	1.27	-	-
119	-	-	-	0.89	1.06	1.19	1.35	1.53	1.84	2.39	-
121	-	0.68	0.91	0.99	-	-	-	-	-	-	-
137	-	-	-	-	0.79	0.92	1.02	1.21	-	-	-
138	-	0.71	-	-	-	-	-	-	-	-	-
139	-	0.74	0.84	0.90	-	-	-	-	-	-	-
140	-	-	0.84	-	-	-	-	-	-	-	-
146	0.82	1.075	-	-	-	-	-	-	-	-	-
147	-	0.73	-	-	-	-	-	-	-	-	-
148	-	0.72	-	-	-	-	-	-	-	-	-
151	-	-	-	-	-	-	-	1.15	1.43	-	-
152	-	-	-	-	0.66	0.74	0.84	0.95	-	-	-
153	-	-	-	-	-	0.71	0.90	1.10	-	-	-
154	-	-	0.73	0.775	0.855	0.93	1.02	-	-	-	-
155	-	-	-	-	0.68	0.77	0.87	-	-	-	-
159	-	-	-	0.68	0.74	0.80	0.88	0.96	-	-	-
160	-	0.75	0.87	0.92	1.00	-	-	-	-	-	-
161	0.82	0.975	-	-	-	-	-	-	-	-	-
162	-	0.72	0.90	0.96	1.10	1.21	-	-	-	-	-
163	-	0.69	0.85	0.91	1.02	1.13	-	-	-	-	-
164	-	0.80	0.91	0.95	1.03	-	-	-	-	-	-
166	-	0.71	0.92	0.99	1.14	-	-	-	-	-	-
167	-	0.68	0.86	0.92	1.07	-	-	-	-	-	-
168	0.77	0.925	-	-	-	-	-	-	-	-	-
169	0.95	-	-	-	-	-	-	-	-	-	-
171	-	0.72	0.85	0.88	-	-	-	-	-	-	-
172	0.93	1.14	1.32	-	-	-	-	-	-	-	-
174	-	-	-	-	0.74	0.78	0.88	0.98	-	-	-
175	0.69	0.82	-	-	-	-	-	-	-	-	-
176	0.62	0.80	0.96	-	-	-	-	-	-	-	-
177	-	-	-	0.72	0.775	0.83	0.88	0.95	-	-	-
178	-	-	-	0.645	0.71	0.77	0.84	0.92	-	-	-

179	-	-	0.635	0.67	0.76	0.80	0.88	0.965	-	-	-
181	-	-	-	-	0.68	0.76	0.86	0.98	-	-	-
182	-	-	0.65	0.695	0.79	0.89	1.01	-	-	-	-
183	-	-	-	-	0.85	0.92	1.00	1.06	-	-	-
184	-	-	-	0.69	0.755	0.82	0.91	1.01	-	-	-
185	-	-	-	-	0.74	0.83	0.94	1.08	-	-	-
187	-	-	-	-	0.74	0.83	0.93	1.06	-	-	-
188	-	-	-	-	-	0.80	0.90	1.03	1.205	-	-
189	-	-	-	-	0.81	0.87	0.945	1.04	-	-	-
190	-	-	-	-	-	0.82	0.94	1.08	-	-	-
191	-	-	-	0.79	0.86	0.93	1.01	1.11	-	-	-
193	-	-	-	-	-	0.86	0.96	1.08	1.34	-	-
194	-	-	-	-	0.64	0.71	0.84	0.98	-	-	-
196	-	-	-	-	0.75	0.80	0.865	0.94	-	-	-
199	-	-	-	-	0.66	0.74	0.845	0.98	-	-	-
200	-	-	-	-	0.64	0.735	0.88	-	-	-	-

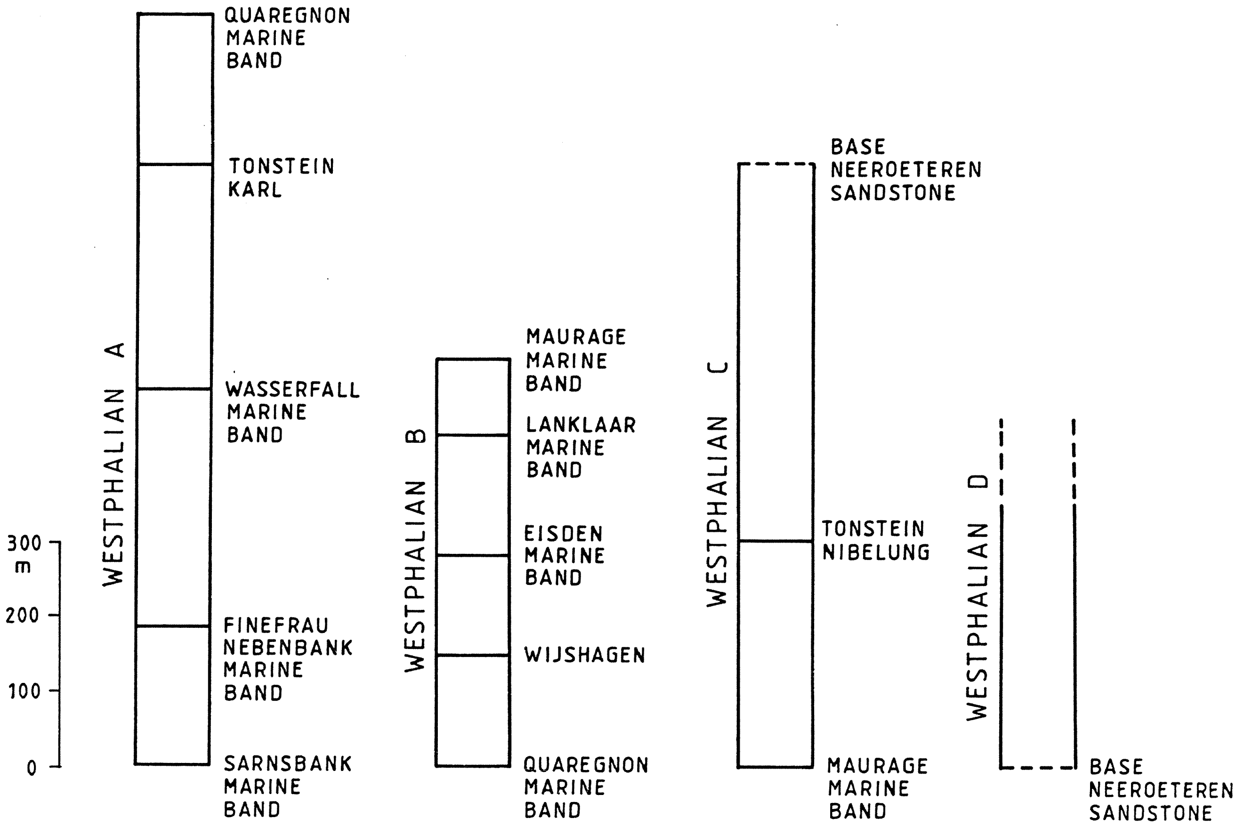


Fig.6. Simplified stratigraphical column of the Westphalian in the Campine Basin with the marker beds for which coalification maps were constructed.

IV.1. Sarnsbank Marine Band (Fig.7).

The Sarnsbank Marine Band defines the boundary between the Namurian and the Westphalian. Only five data are available (wells KB32, 76, 86, 96 and 103), which is insufficient to draw isoreflectance curves. The Vrm% varies between 2.43% in well KB76 and 1.82% in well KB86. The coalification is higher in the eastern part of the basin although the VRm% from well KB96 (2.06%) in the western part is also fairly high. A general remark is that the calculated coalification values for the lower part of the Westphalian A are less reliable due to the less frequent occurrence of coal seams and thus analyzed samples in this stratigraphical interval.

IV.2. Finefrau Nebenbank Marine Band (Fig.8).

Twelve wells have yielded VRm% values for this marine band in the lower Westphalian A. The Vrm% varies between 2.39% in well KB119 and 1.59% in wells KB86 and KB93. A clear trend could be recognized in the eastern part of the basin where isoreflectance lines were

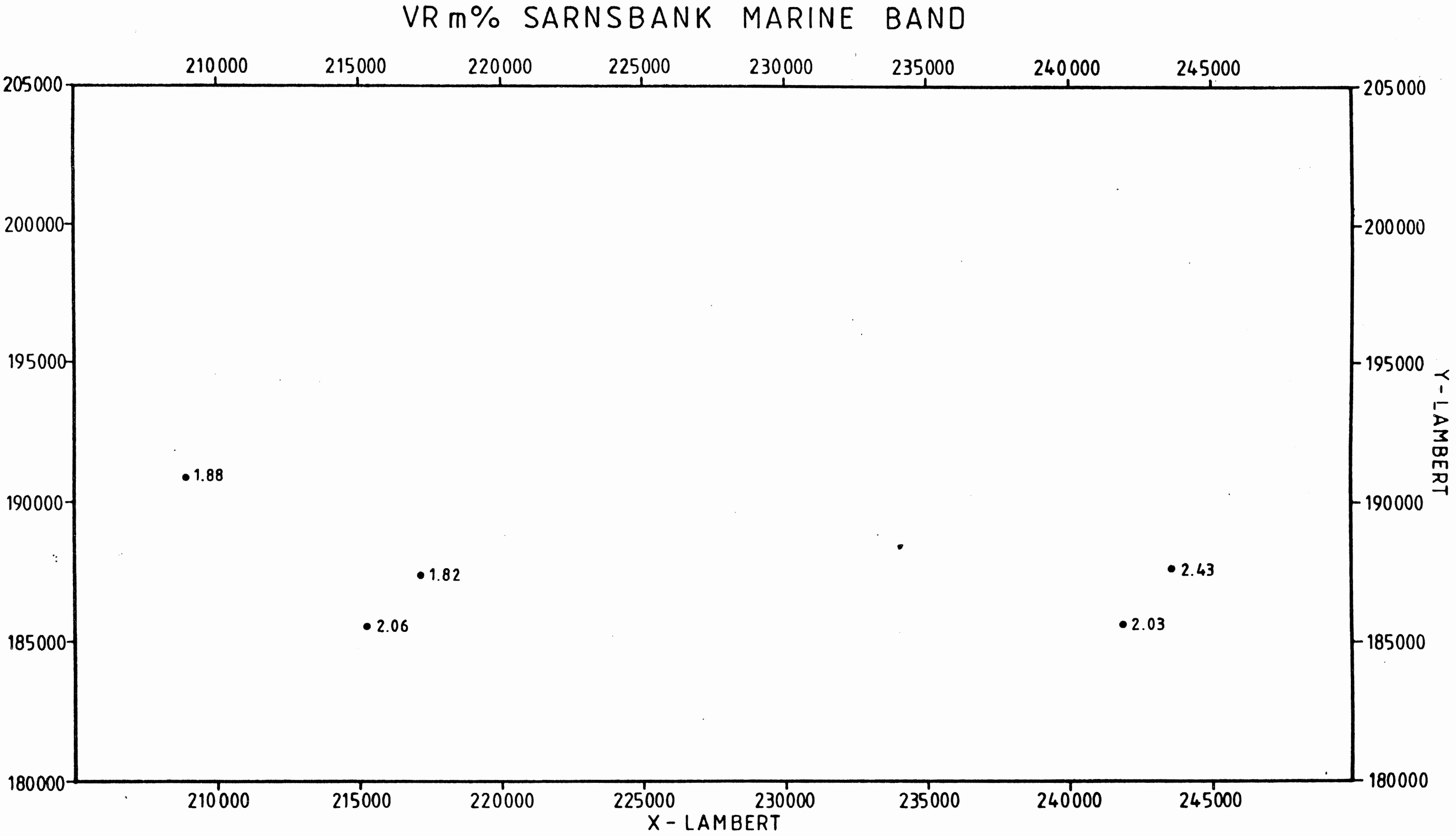


Fig.7. Coalification map for the Sarnsbank Marine Band.

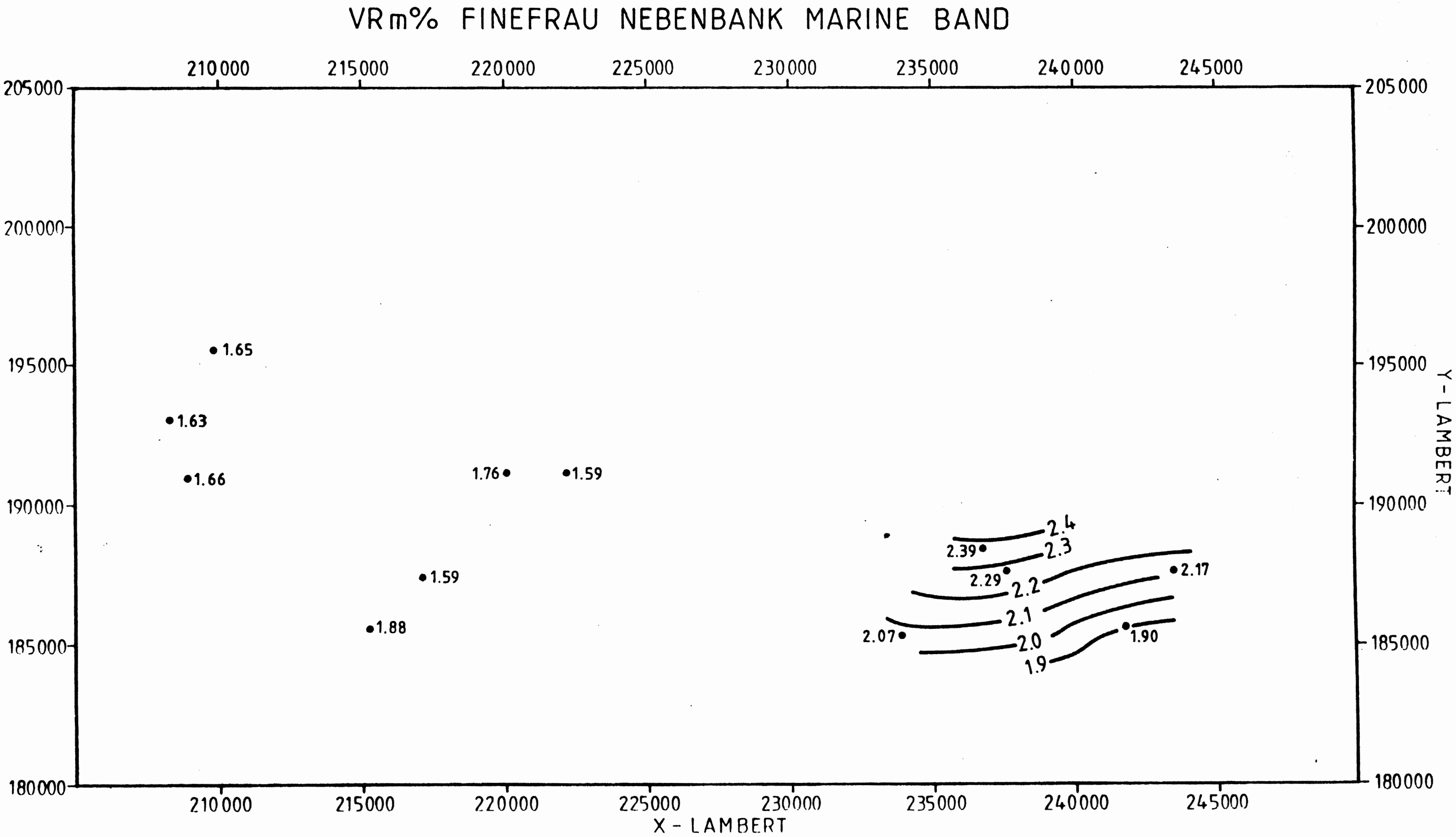


Fig.8. Coalification map for the Finefrau Nebenbank Marine Band.

constructed. This trend is much less obvious in the western part where especially well KB96 forms an outlier. In the west the values are in the 1.6-1.7% range while in the east they vary between 1.9% and 2.39%. The coalification in the eastern part of the basin is significantly higher than in the western part as will also be shown for all the following maps.

IV.3. Wasserfall Marine Band (Fig.9).

This marker level forms the boundary between the lower and upper part of the Westphalian A. VRm% values were available from 22 wells, varying between 1.86% in well KB78 and 1.19% in well KB79. The values range from 1.2% to 1.4% without a clear trend in the western part of the basin. Isoreflectance lines could be constructed for the eastern and central part where values vary between 1.43% and 1.86%.

IV.4. Tonstein Karl (Fig.10).

The Tonstein Karl is a volcanic ash layer situated in coal seam KS70 in the upper Westphalian A. VRm% values were available from 46 wells, ranging from 1.57% in KB76 to 0.92% in well KB178. Isoreflectance lines were constructed for the whole area. The dominant trend in the eastern and western part of the basin is N-S while in the central part the trend is ESE-WNW.

IV.5. Quaregnon Marine Band (Fig.11).

The Quaregnon Marine Band forms the Westphalian A/B boundary. VRm% values were available from 48 wells, varying between 1.37% in well KB78 and 0.77% in well KB54. The trends are again N-S in the eastern and western part of the basin but ESE-WNW in the central part. This trend in the central part seems to deflect towards ENE-WSW further to the north however (1.00 VRm% in well KB183).

IV.6. Wijshagen marker bed (Fig.12).

This is a fauna (Leaia) level in the lower Westphalian B, situated right on top of or a few metres above coal seam KS45. VRm% values were available from 41 wells, ranging from 1.23% in well KB115 to 0.72% in well KB48. The trend in the central part of the studied area is more E-W directed than on the previous maps. Relatively higher values were found in wells KB177 and 196 in the western area and well KB78 in the eastern part.

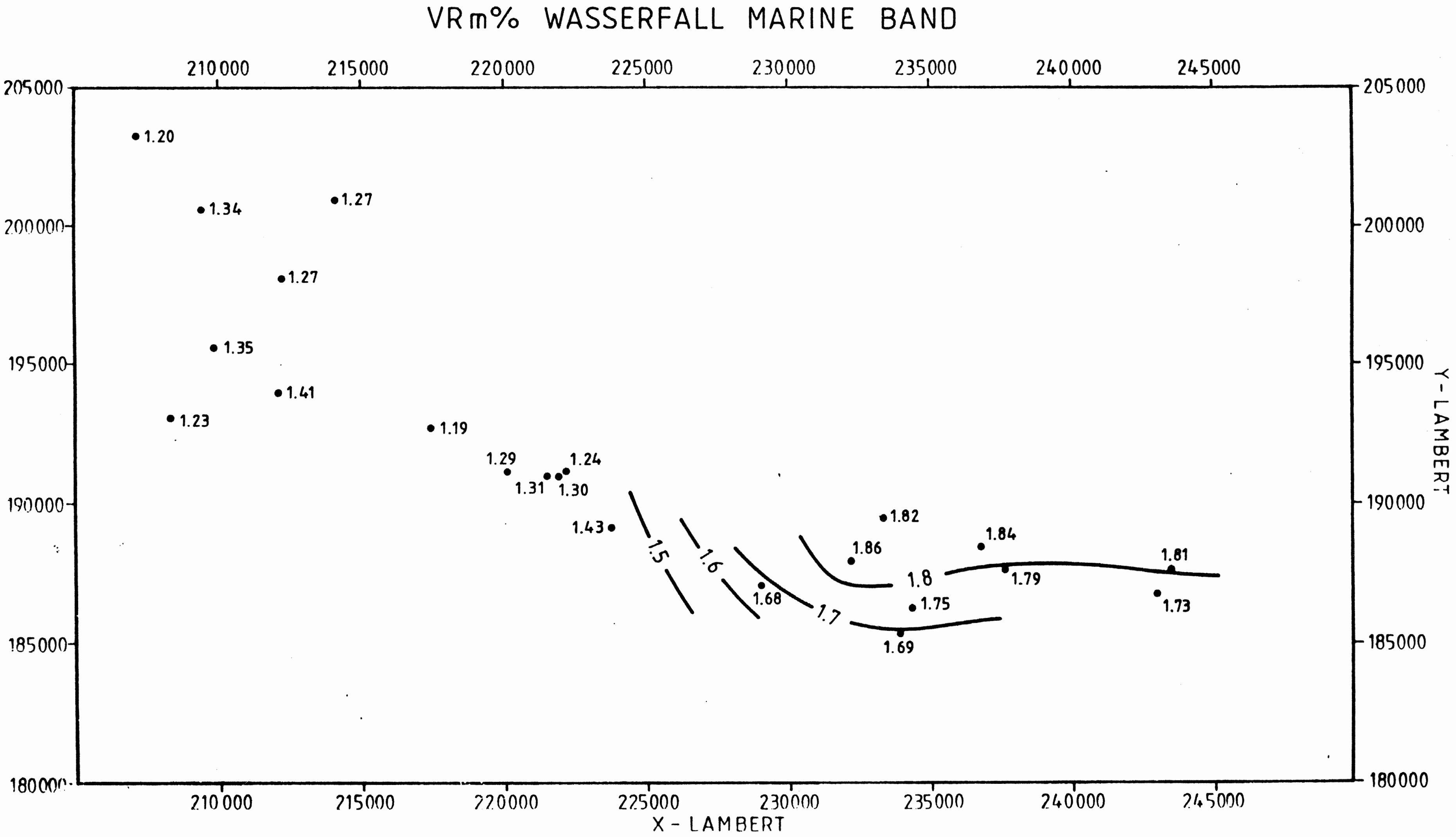


Fig.9. Coalification map for the Wasserfall Marine Band.

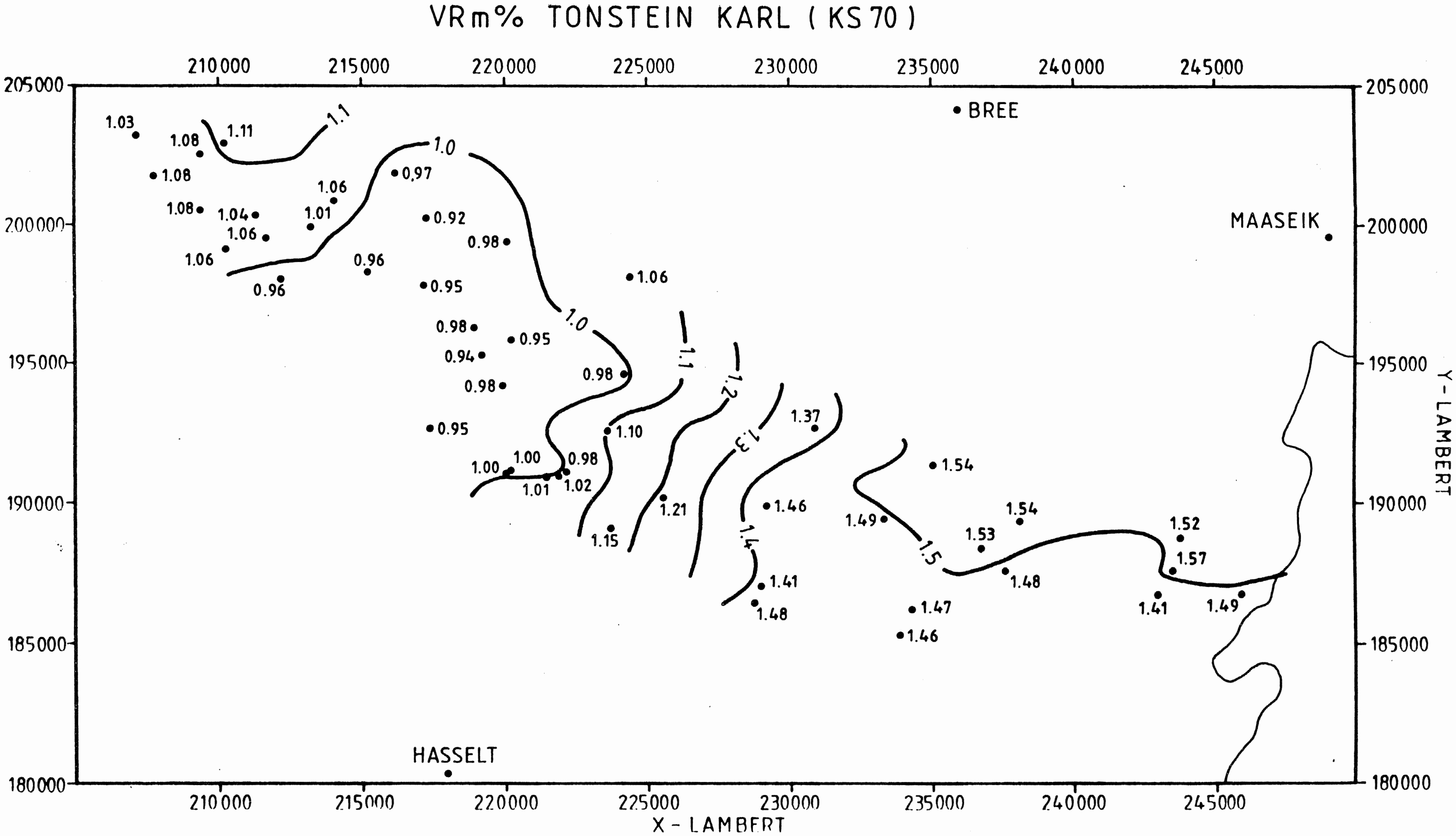


Fig.10. Coalification map for the Tonstein Karl.

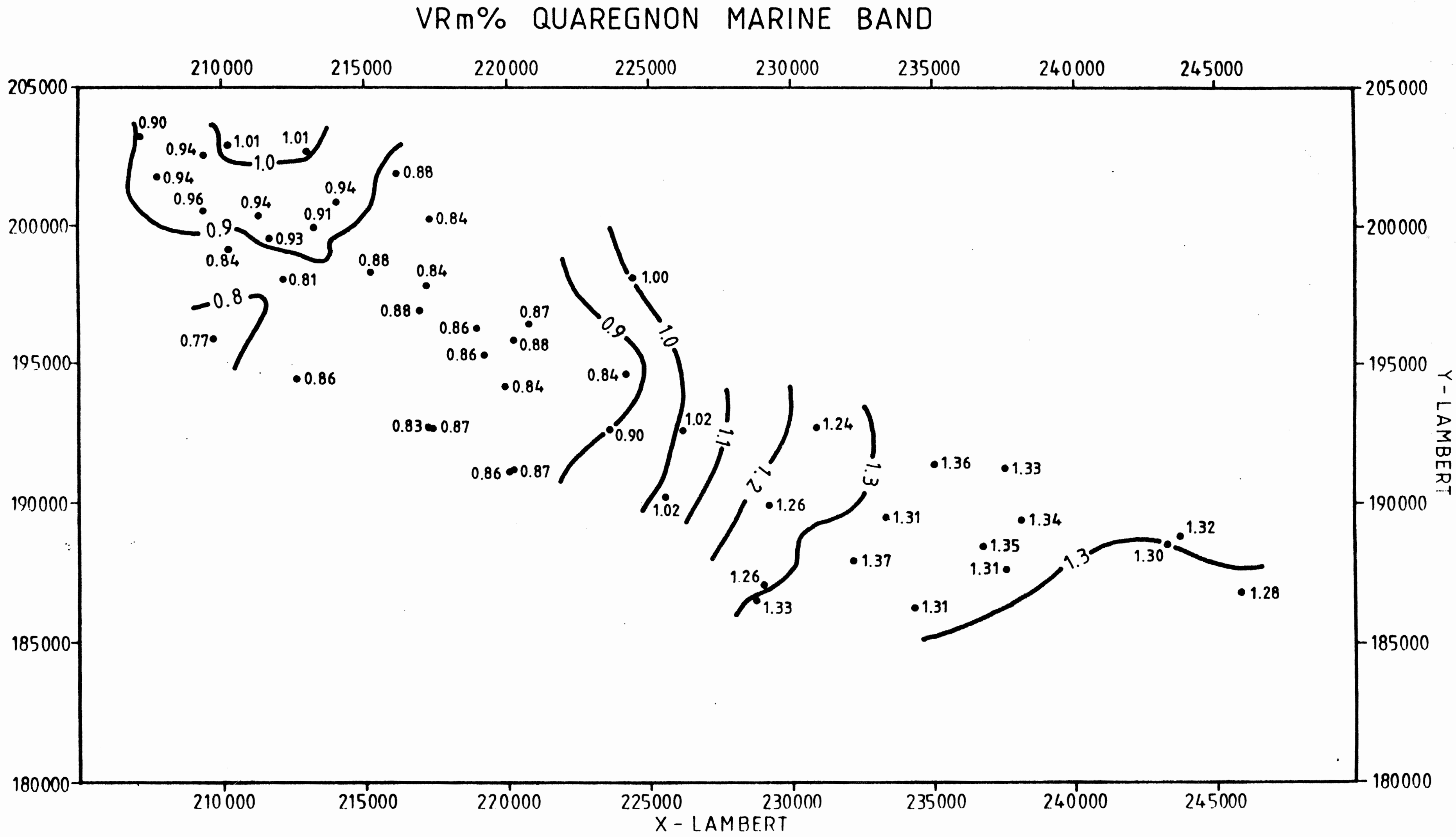


Fig.11. Coalification map for the Quaregnon Marine Band.

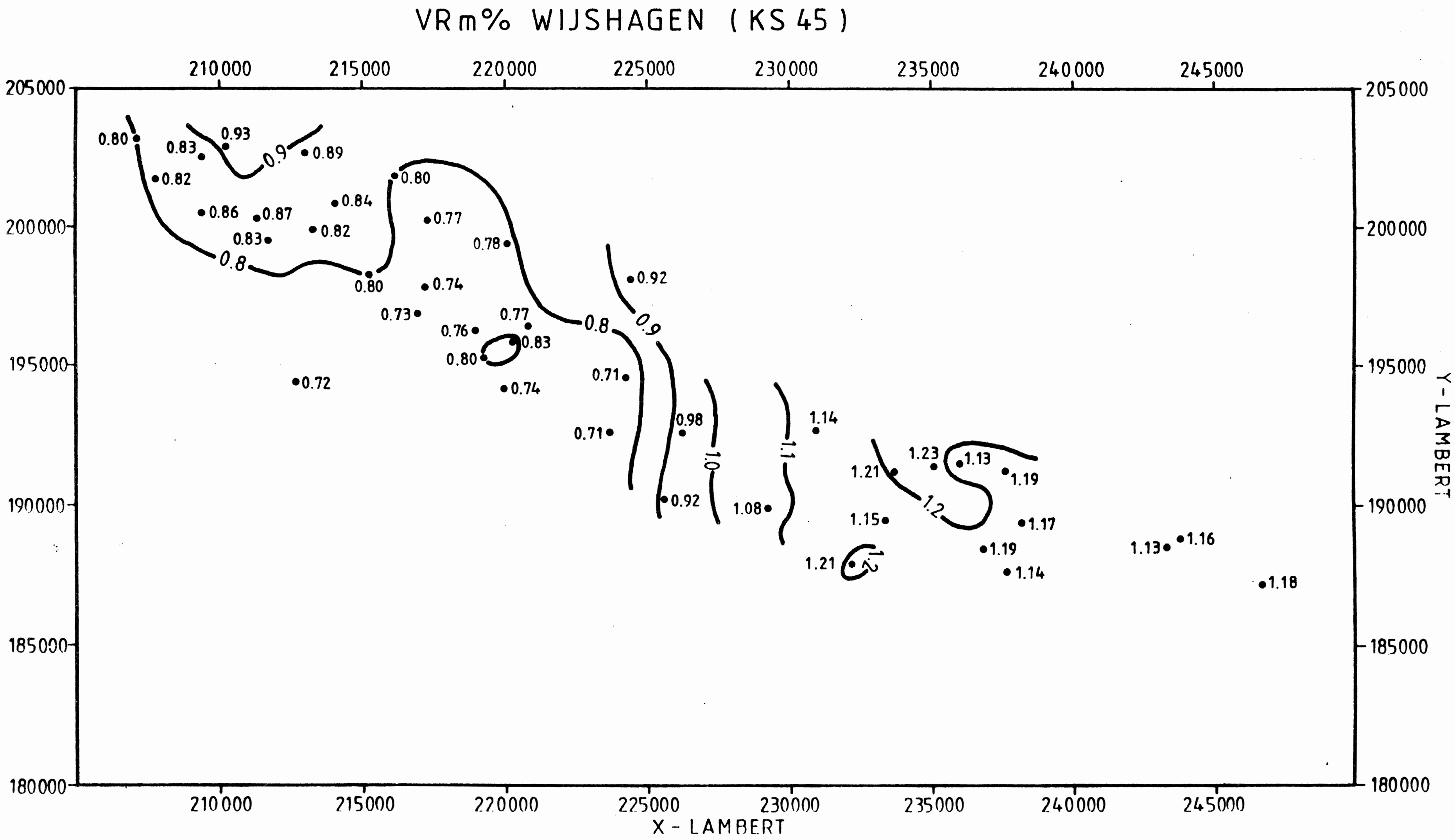


Fig.12. Coalification map for the Wijshagen level.

IV.7. Eisden Marine Band (Fig.13).

The Eisden Marine Band is the boundary between the lower and the upper part of the Westphalian B. VRm% values were available from 41 wells, varying between 1.14% in well KB166 and 0.64% in well KB200. The trend in the central part of the studied area now is clearly ENE-WSW. The wells KB177 and 196 still have relatively higher values in the western part.

IV.8. Lanklaar Marine Band (Fig.14).

This is a marine band in the upper part of the Westphalian B. VRm% values were available from 28 wells, ranging from 0.99% in wells KB121 and 166 to 0.64% in well KB185.

IV.9. Maurage Marine Band (Fig.15).

This marine band forms the Westphalian B/C boundary. VRm% values were available from 24 wells, varying between 1.32% in well KB172 to 0.635% in well KB179. Only 3 datapoints from the western part could be calculated. Isoreflectance curves were only drawn for the eastern part of the basin. There is a strong N-S trend in this part especially due to the high coalification in well KB172.

IV.10. Tonstein Nibelung (Fig.16).

This volcanic ash layer in coal seam KS1G (and not in KS6 as in Paproth et al., 1983) is the boundary between the lower and upper part of the Westphalian C. VRm% values were available from 21 wells ranging from 1.14% in well KB172 to 0.68% in well KB121. No data are available for the western part of the studied area.

IV.11. Base Neeroeteren Sandstone (Fig.17).

The base of the Neeroeteren Sandstone more or less coincides with the Westphalian C/D boundary (Paproth et al ,1983, Dusar, 1989). A VRm% value for this stratigraphical level could be calculated in 7 wells from which 4 traversed the Neeroeteren sandstone (KB146, 161, 168 and 172) and 3 start in the topmost Westphalian C (KB169, 175 and 176) so that the position of the base Neeroeteren Sandstone could be extrapolated in these wells. The VRm% values for 3 additional wells (KB110, 113 and 117) were not calculated in the above explained way because no clear trend could be recognised in the data. A comparison of the coalification data from these wells with those from KB146 is given in Dusar and Houlleberghs (1981). For the latter three wells the VRm% value was calculated by averaging a number of coalification

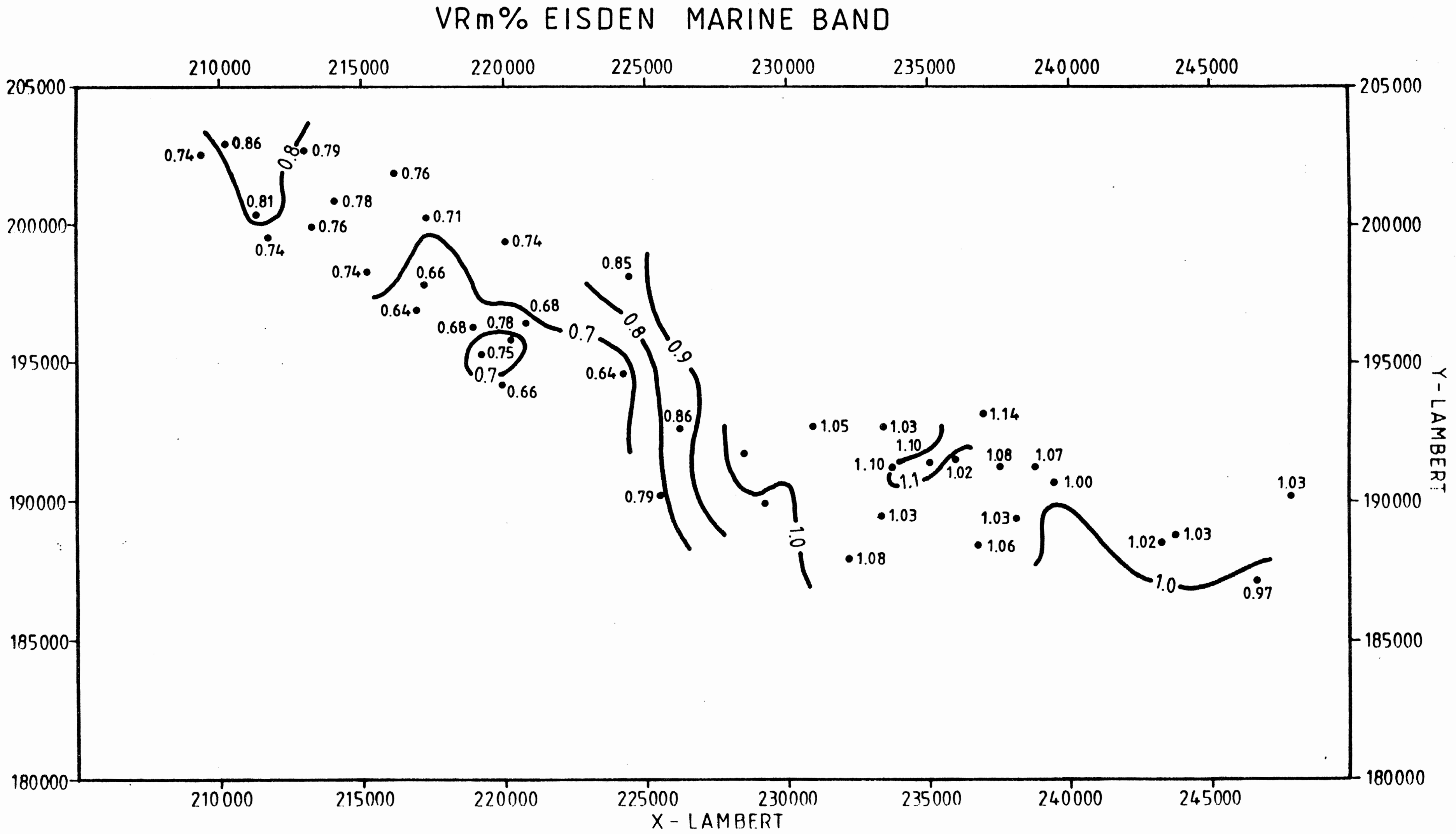


Fig.13. Coalification map for the Eisden Marine Band.

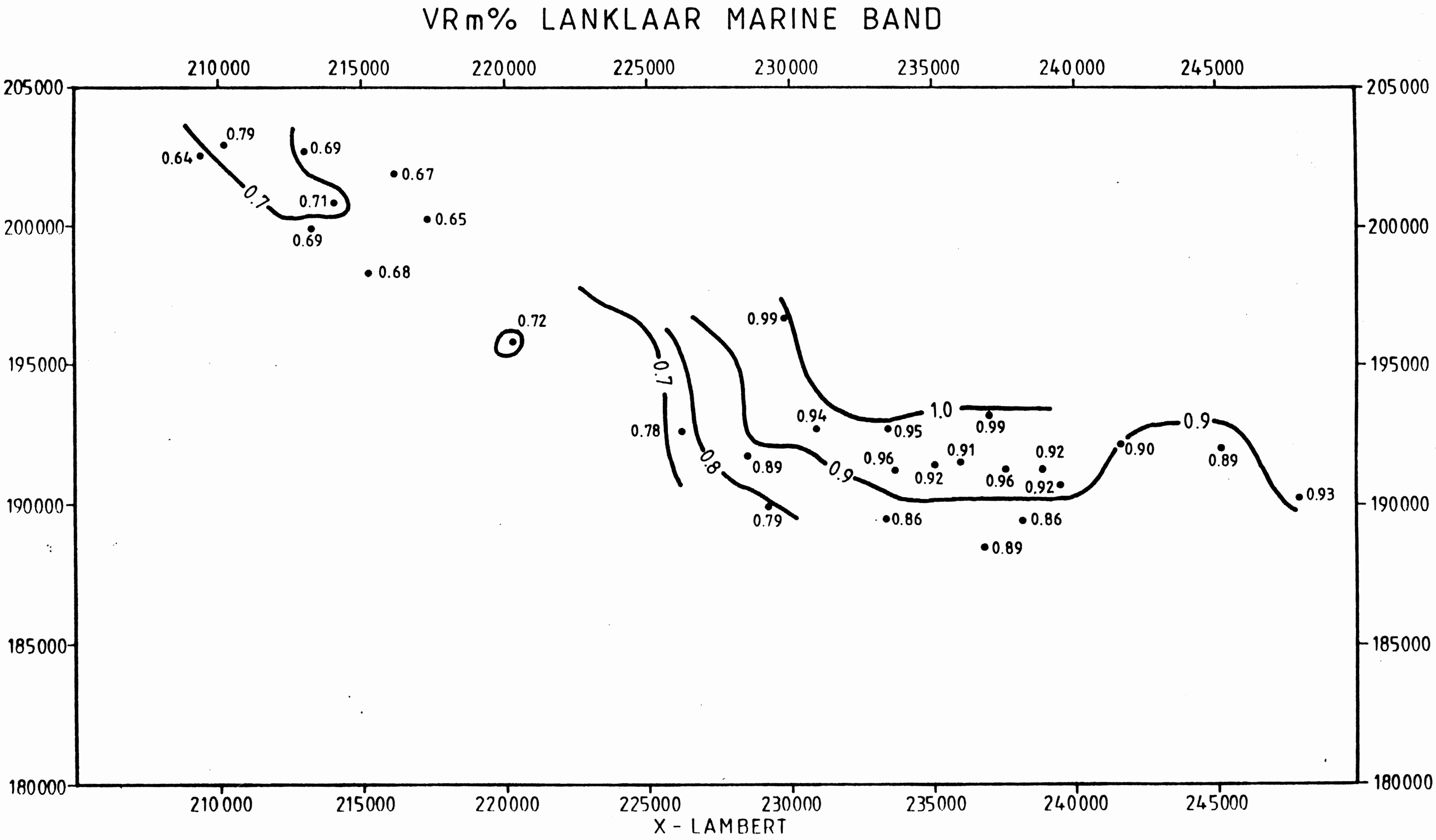


Fig.14. Coalification map for the Lanklaar Marine Band.

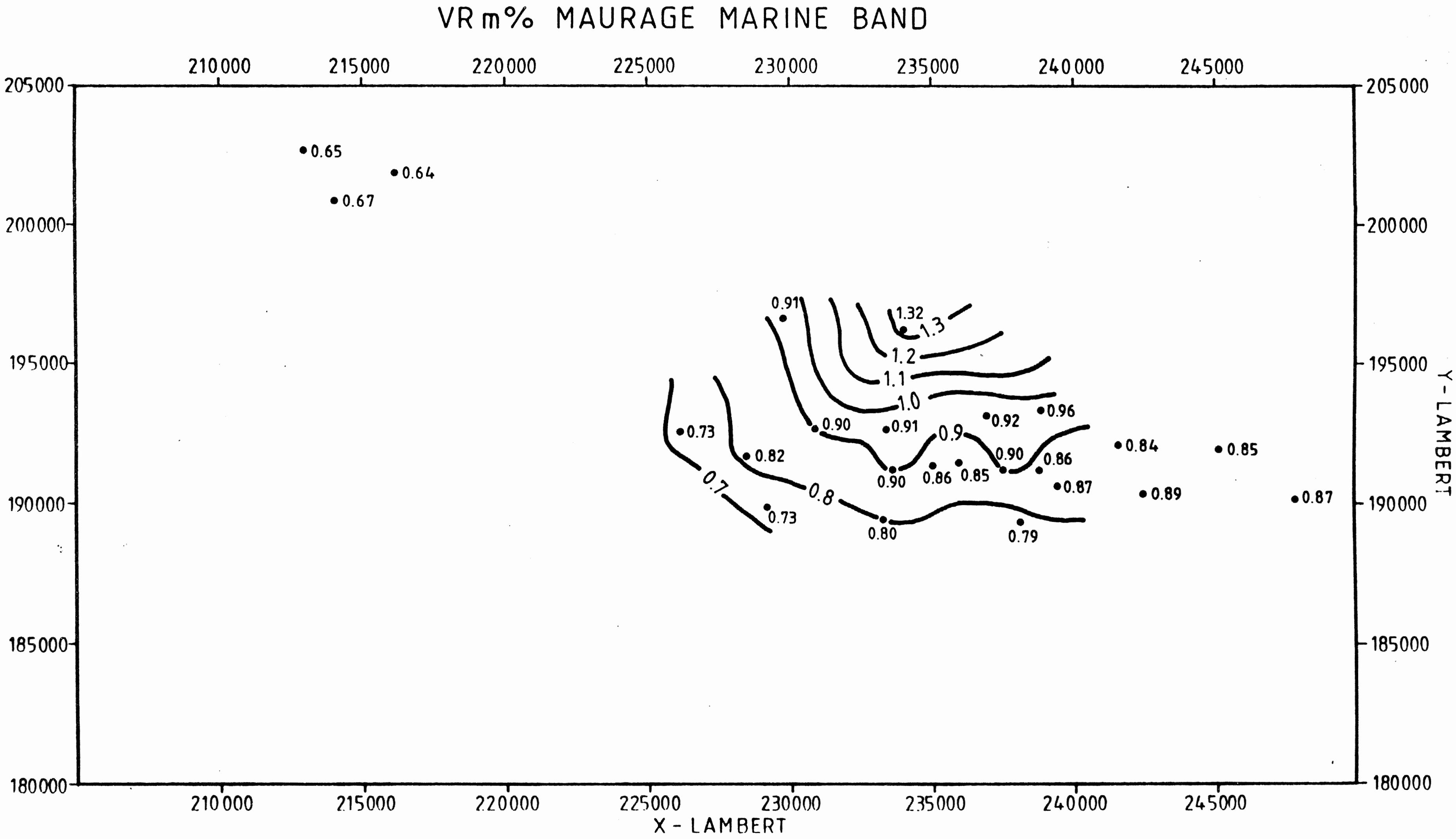


Fig.15. Coalification map for the Maurage Marine Band.

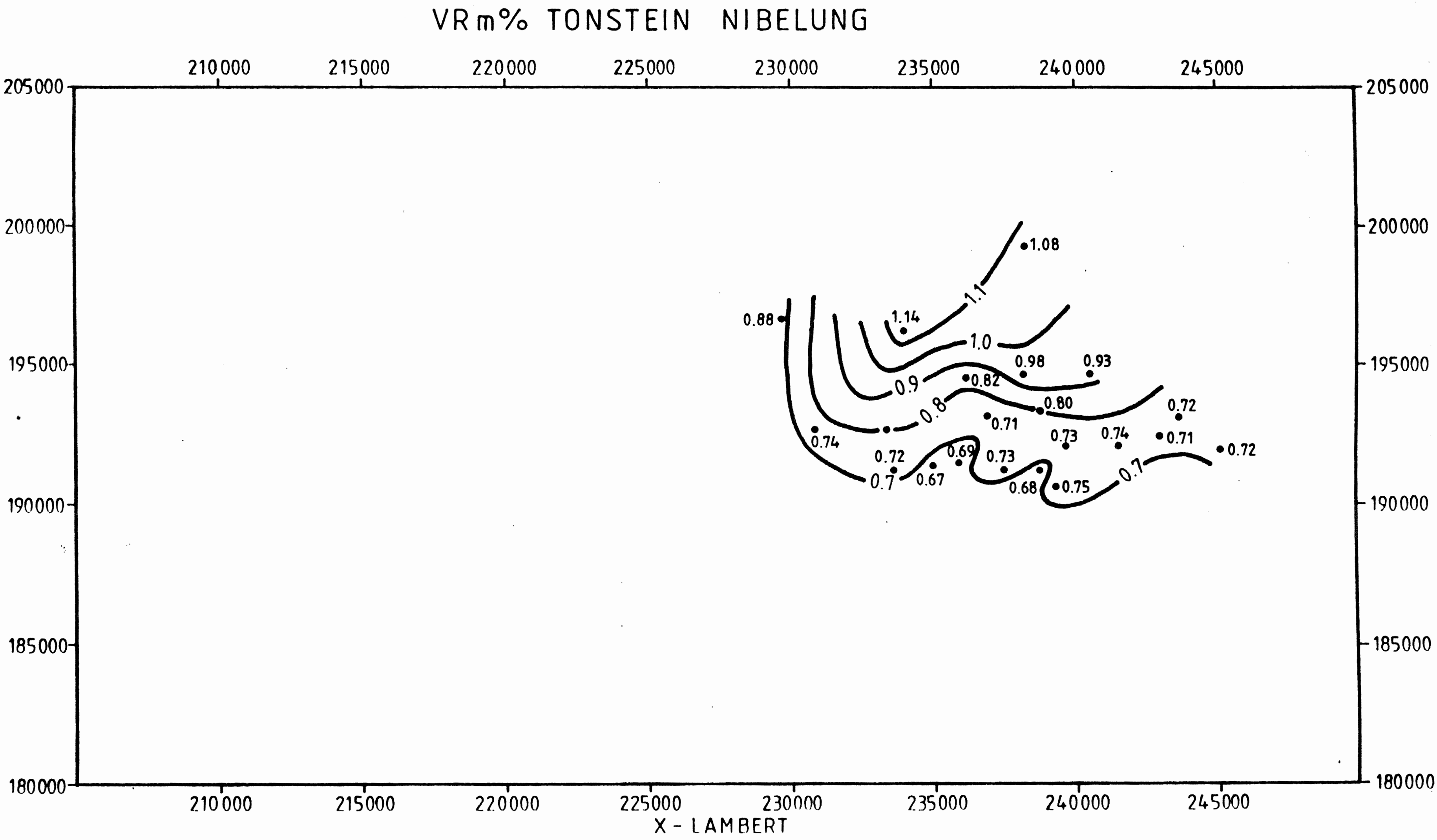


Fig.16. Coalification map for the Tonstein Nibelung.

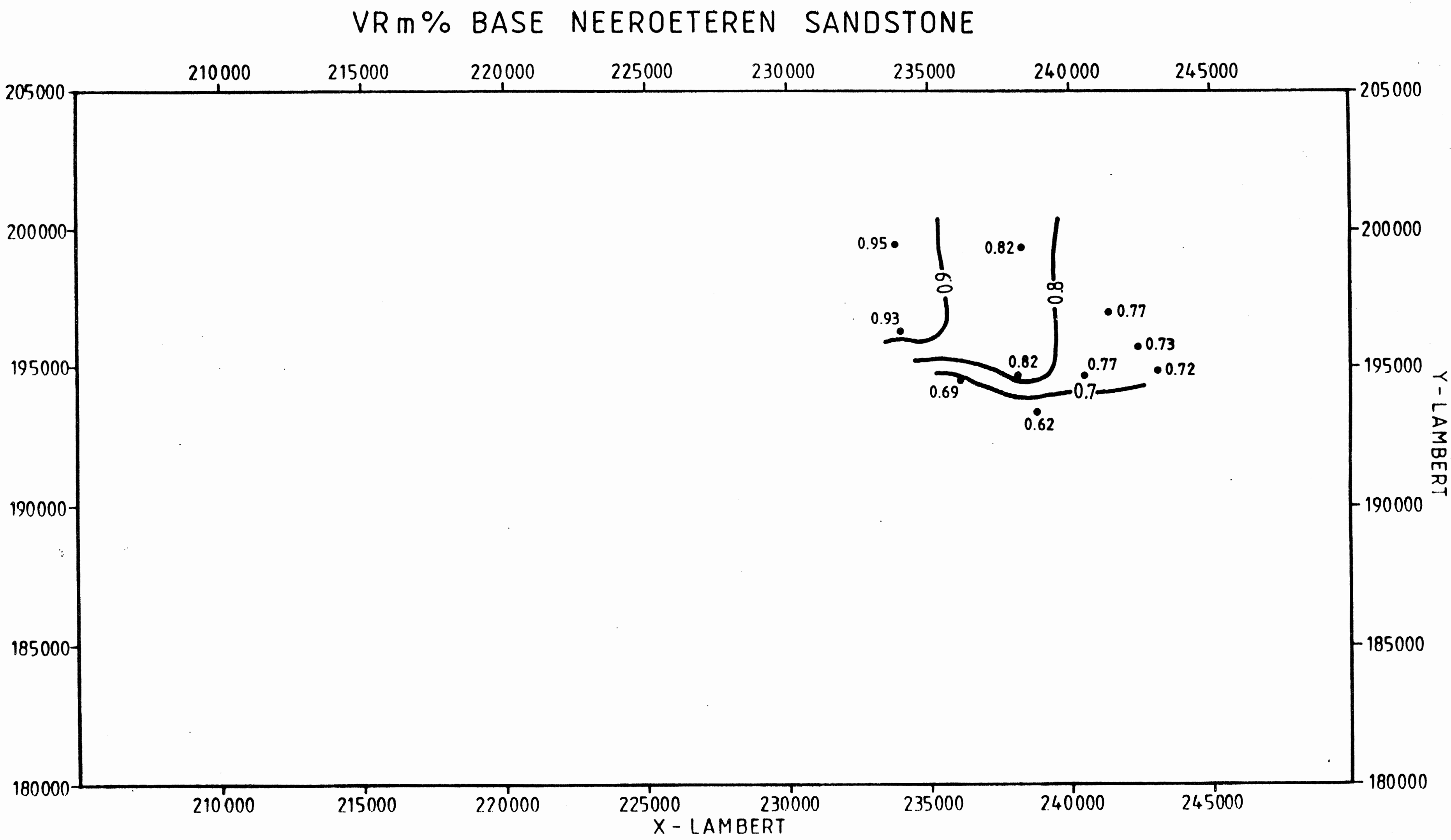


Fig.17. Coalification map for the base of the Neeroeteren Sandstone.

data around the base of the Neeroeteren sandstone. The VRm% values then range between 0.95% in well KB169 and 0.72% in well KB110.

V. LOCATION MAP 0.9% VRm ISOREFLECTANCE LINES (Fig.18).

The isoreflectance line of 0.9% VRm appears on all the coalification maps from the Quaregnon Marine Band until the Neeroeteren Sandstone . This reflectance value is situated in the middle of the oil window. A map with the position of this isoreflectance line for all the different stratigraphical levels was constructed in order to visualise the coalification differences in the studied area. This map shows the above mentioned and long known difference in coalification between the eastern and the western part of the coal basin. A second, generally North-South directed, trend is also recognisable however. Pillement, in his study of 1982, did not find this increase of coalification towards the north. The reason for this probably is that all the samples for this study were taken more or less along the strike of the coal basin while the North-South trend reflects the dip direction of the basin. It was already clear from the work of Muchez et al (1987) that this trend had to exist since VRmax% values of as little as 1.18 were found for the top Dinantian in the Halen well, situated to the southwest of the mining area near the boundary of the Brabant Massif. When this is compared with the VRm% data for the Westphalian in the mining area as outlined above, it is obvious that there has to exist a strong coalification increase towards the centre of the Campine Basin.

VI. CONCLUSIONS

The purpose of this study was to make an inventory of the coalification data in the Campine Basin and to display these data under the form of coalification maps. The interpretation of the maps is not dealt with in this publication. The coalification maps form the basis for a maturity modelling of the Campine Basin, based on reaction kinetics methods (Tissot et al ,1987, Sweeney and Burnham,1990) which will support the interpretation of the coalification differences in the studied area.

It is nevertheless clear that, apart from the coalification differences between the eastern and western part of the coal basin, there is also a coalification trend towards the depocenter of the basin. This trend was illustrated by comparing the position of the 0.9% VRm isoreflectance line for different stratigraphical levels in the Westphalian.

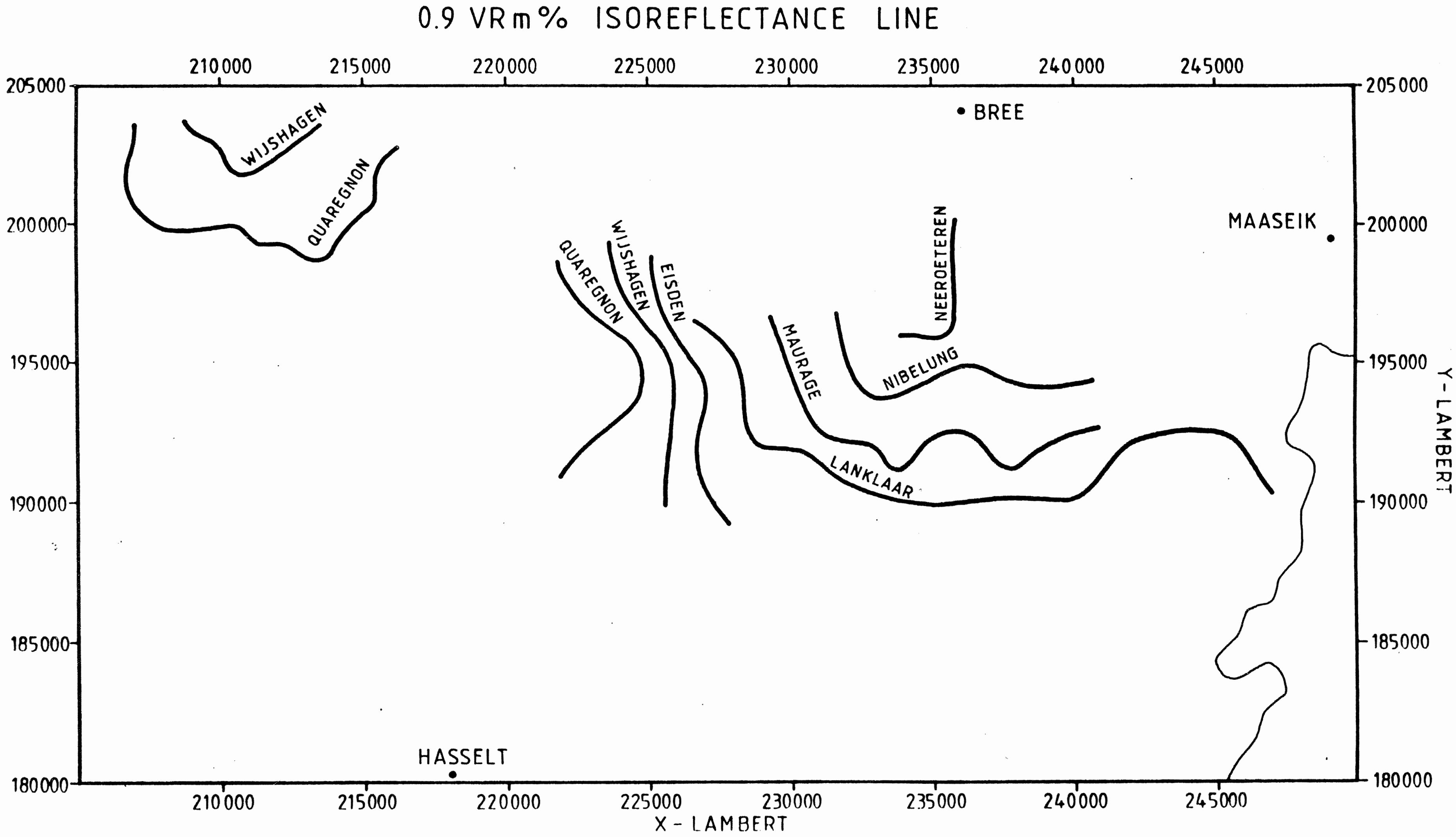


Fig.18. Map with the position of the 0.9 VRm% isoreflectance line for different stratigraphical markers.

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Primarily my thanks go to Prof. J. Bouckaert, director of the Belgian Geological Survey, and P. Verkaeren of the Kempense Steenkolenmijnen for making available the analyses from the recent wells. I wish to thank Y. Somers of the ISSEP for making the thesis of Pillement available and for doing most of the vitrinite reflectance measurements. Prof. N. Vandenberghe and M. Dusar are acknowledged for critically reading an earlier draft of the manuscript. A. Scott is thanked for the stimulating discussions on the coalification data. Prof. J. Beirlant is acknowledged for helping with the statistical treatment of the data. Finally I wish to thank G. Willems for drawing the figures.

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