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CONSERVATION AND RESTORATION OF MONUMENTS

PART B

MULTIPLE REGRESSION ANALYSIS BETWEEN DETERIORATION OF CALCAREOUS STONES AND ENVIRONMENTAL VARIABLES

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SUMMARY

The results from the NATO/CCMS project "Conservation and restoration of monuments" have been statistically analysed for correlations between environmental factors and the weight loss of sandstone and limestone.

The weight loss and the pollutants used are taken from the German main report from Zollern-Institut (Zallmanzig, 1985). The meteorological data are collected from the participating countries.

Some of the most interesting data like time of wetness were not available and some countries did not provide any data at all. For some of the stations data like rain days and frost days were therefore generated from climatological maps. This will reduce the possibilities for detailed analysis of the deterioration results and the validity of the regression lines found.

The analysis showed that the deterioration of both the limestone and the sandstone increased with the amount of SO_2 deposition as determined by an IRMA apparatus and rain days at the test sites. The best equations are

$$\text{weight loss sandstone} = -0.05*SO_2\ (\text{deposition}) -0.08*\text{rain days} + 1.9 \qquad R = 0.79$$

$$\text{weight loss limestone} = -0.03*SO_2\ (\text{deposition}) -0.01*\text{rain days} + 1.4 \qquad R = 0.69$$

Only 62% and 48% of the variances are explained by these equations.

Weight losses in the equations are given as per cent weight chances with negative values to distinguish the results from the weight gains measured on stones in sheltered positions.

CONTENTS

Page

SUMMARY 1

1 INTRODUCTION 5

2 STATISTICAL DATA 5

- 2.1 Data 5
- 2.2 Grouping of data 6
- 2.3 Correlation - inland 7
- 2.4 Correlation - coast 8
- 2.5 Multiple regression 8

3 DISCUSSION 11

4 CONCLUSIONS 11

5 REFERENCES 12

APPENDIX 1 27
APPENDIX 2 33

MULTIPLE REGRESSION ANALYSIS BETWEEN DETERIORATION OF CALCAREOUS STONES AND ENVIRONMENTAL VARIABLES

1 INTRODUCTION

As a part of the NATO/CCMS project "Conservation and Restoration of Monuments" it was decided to look for dose-response correlations by making regression analysis of the stone results. The analysis performed are based on the exposure program carried out at 25 sites in Europe and 2 sites in USA from 1980 to 1982. The deterioration results and the pollution data are taken from the main report from the FRG (Zallmanzig, 1985) and the meteorological data used were collected from nearby meteorological stations by the participating countries.

The Norwegian proposal for the meterological data needed was expressed in a letter of 27 October 1982 and later confirmed in a letter of 12 January 1984, Appendix 1. At the expert meeting in Münster 9 - 10 May 1984 it was agreed that the mathematical/statistical evaluation should be carried out as soon as the meterological data were received.

Data were received from FRG, Greece, Italy, Norway, Sweden and UK in due time. The rest of the data are still missing. In spring 1985 a decision was made to carry out the regression analyses on the data available.

2 STATISTICAL DATA

2.1 DATA

Table 1 gives the list of all parameters used and Table 2 gives the data available for the analysis from the measuring program. Since the main interest of the analysis was to find relations between weight loss and the other parameters, three stations were excluded: Stations Rouen (F2) and Ulmer Münster (D2) were excluded since the weight loss results were missing. The cathedral of Pisa (I2) was excluded because the test site was in a sheltered position.

Meteorological data were not reported from all stations. To complete some meteorological variables in the data base, the missing data were estimated for broader regions from climatological maps.

A preliminary correlation analysis of the remaining data sets gave the following conclusions:

- Good correlation between the amount of sulphate concentrations in the stone for the different test sites for the two stone materials.
- Good correlation between the weight losses found for the two stone materials.
- Good correlation between the weight increases of the sheltered samples found for the two stone materials.
- Fairly good correlation between frost days, ice days and snow days.
- Fairly good correlation between time of wetness, amount of rain, duration of rain, rain days and wet days.

For the first analysis performed, 24 data sets were used. Because of the lack of meteorological data and since fairly good correlations between several of the parameters were found, we decided to use rain days and frost days as the climatic parameters in the analysis.

2.2 GROUPING OF DATA

Different statistical methods have been used in the analysis of the data. For creation and completion of the data, correlation analysis combined with bivariate data plots was performed (Gram, 1972).

In order to detect unknown groupings in the data an exploratory data analysis of the data was performed by the Norwegian Computing Center. The results are given in Appendix 2. The main conclusion was that by removing the three stations GB3, NL2 and NL3 from the data sets the other stations seemed to be in one group where the weight losses were mainly effected by SO_2 and rain days. Table 3 gives the final data sets for stations affected by SO_2, called the inland stations.

Since a small number of stations were situated along the coast, a group of 7 stations was sorted out to form a coast group, Table 4. Besides the three stations excluded in Table 3, the group included the two last stations from the Netherlands (NL1) and (NL4), the Norwegian station in Bergen (N1) and La Rochelle in France (F3).

2.3 CORRELATIONS - INLAND

In all the correlation analyses carried out in this investigation the data sets were divided in two groups, one for sandstone and one for limestone. The correlation matrix for sandstone is shown in Table 5 and for limestone in Table 6.

In the correlation matrix shown in Table 5, the best correlation coefficients are found for variables which are related like "SO_2 in stone" and "log SO_2 in stone". The results also show that the IRMA values correlate fairly well with the "SO_2 in stone" results.

The greatest interest is to find variables which correlate with the weight loss results in Table 2. The most interesting correlation coefficients between the weight losses and environmental data will be for values close to -1. This is because the weight losses are given with negative values in the data base to distinguish them from the weight gain of the stones in the sheltered positions. Among the single correlations, the best correlation coefficients are found for the variables expressing the SO_2 flux.

The limestone results in Table 6 show the same trends as the sandstone results but the correlation coefficients are lower.

In Figures 1 and 2 the weight losses for sandstone are plotted against the SO_2 flux to sandstone. In Figures 3 and 4 the same plots are shown for limestone. One of the data sets seems to be quite different from the others. The point is marked with a square on the figures. Particularly the plot against "SO_2 in stone" seems to be special. The station is Lelystad in the Netherlands. The main reason seems to be that Lelystad also has a substantial weight loss for the sheltered stone samples. The weight loss is probably caused by a washing out of gypsum by "horizontal rain" and the amount of sulphate analysed will then be too low. A similar effect will occur with the IRMA apparatus if the drops from the paper housing are blown away in the wind instead of falling back into the reservoir. It is possible that the Lelystad results should have been taken out of the data base. This has not been done mainly because some of the other stations also have weight losses for the sheltered limestone and with the same argument we should then exclude several stations in the data base.

Except for Lelystad none of the other data sets have the same tendency to be outliers in all the correlation plots. The Greek stations seem to have less corrosion than expected from the SO_2 concentration of the IRMA apparatus. Differences in the climate pattern between Greece and the other countries will probably explain this.

2.4 CORRELATION - COAST

Tables 7 and 8 give the correlation for sandstone and limestone for the seven selected coast stations.

The small number of data sets used, gave a high unexplained variance. The chloride effect seems to be more dominating for the coast results but the chloride values are completely dominated by the high chloride result from Texel as shown i Figure 5.

2.5 MULTIPLE REGRESSION

Multiple regression of the coast data sets was not performed since the data sets were so few and many of the remaining missing climatic data were grouped to the same value.

The results of the multiple regression analysis (Gram, 1972) of the inland data are shown in Tables 9-14. The variables selected for the tests were weight loss open exposured, SO_2 deposition on IRMA, SO_2 deposition on stone, log SO_2 deposition on IRMA, log SO_2 deposition on stone, chloride deposition on IRMA, chloride deposition on stone, NO_2 deposition on IRMA, NO_2 deposition on stone, frost days and rain days.

All the regressions are carried out with the weight losses as the main parameter. Because of fewer data sets in the regression analyses than in the correlation analysis the correlation coefficient for the variables will change. However, the dominating factor is still the SO_2 concentration.

The F-tests for the regression with two or three variables showed that only a few of the combinations gave a substantial increase in the correlation. Some of best regressions found had to be excluded because of intercorrelation between the variables. For sandstone the only regression with two separate variables which gave a sufficient increase in the correlation coefficient according to the F-test are:

$$OWS = - 0.05*SOI - 0.08*RD + 1.97 \qquad R= 0.79$$

The limestone results are very similar to those for sandstone. Only two of the regressions with two variables gave sufficient increase in the correlation coefficient according to the F-test.

$$OWL = - 0.03*SOI - 0.01*RD + 1.39 \qquad R = 0.69$$

$$OWL = - 3.4*Log\ SOI - 0.01*RD + 5.31 \qquad R = 0.68$$

The most interesting of the combinations with three variables are the combination with SO_2, rain days and frost days. Both for sandstone and limestone this combination will increase the correlation coefficient but not sufficiently to be valid in the F-test. The regression equalions are

$$OWS = 1.87 - 0.05*SOI + 0.003*FD - 0.01*RD \qquad R= 0.81$$

$$OWL = 1.31 - 0.03*SOI + 0.004*FD - 0.01*RD \qquad R= 0.73$$

SO_2 and rain days affect the stones as expected. Both give an increased deterioration with higher concentrations or higher amount of rain. Frost days can affect the stone detoriation in two different ways. Geologically the effect of frost shattering are well known and the possibility that this effect also plays a major part in stone deterioration of monuments in colder areas of the world has been discussed. The other possible effect is that the chemical reactions on the surface are highly reduced at low temperatures and that low temperatures will reduce the deterioration. Both for limestone and sandstone the frost days came out with possitive sign showing that frost reduces the deterioration of the stone.

There are several reasons for this result. First of all, two years is a very short time for frost shattering to occur. Secondly the stone samples selected were all very homogeneous and cracks or cleavage normally found in stones will hardly occur on the samples exposed in this research program. In stones with differences in the chemical compositions, the parts with high lime content will normally be attacked more then other parts, leaving cracks sensitive for frost shattering at a later stage.

In some of the regressions nitrogen dioxide will slightly improve the regression. The coefficients are sometimes positive and sometimes negative leaving no clue for a nitrogen dioxide effect. However, the nitrogen dioxide fluxes measured are very small and the exposure places situated in areas where the concentration and effect of nitrogen dioxide is minor.

In Figures 6 and 7 the calculated values for the weight losses of stones as a function of SO_2 and rain days are plotted against the observed values. The correlation is expressed by the equations

Limestone $Ycal = 0.64 \cdot Yobs - 1.2 \quad R = 0.70$

Sandstone $Ycal = 0.48 \cdot Yobs - 1.85 \quad R = 0.80$

With equality between calculated and observed data, the first constant should be 1 and the second 0. Figures 6 and 7 show that sulphate concentration in the stone and rain days alone can only partly describe the stone deterioration. However, none of the other variables available will improve the equations found.

3 DISCUSSION

The data used in the statistical calculations have a high degree of uncertainty. The weight losses are not only affected by the SO_2 deposition but also by the regularity of rain. If the rain only comes in seasons and the SO_2 exposure time from the last rain to the intake is long, it will affect the weight loss.

Rain days are not the best variable for expressing the water effect. Duration of rain or time of wetness are probably better terms but this was not possible to generate from the data available.

Frost days or ice days can be fairly good parameters for reduced chemical reactions. Frost shattering, however, is more affected by fluctuations in the temperature and the freezing point will most probably differ from zero. Frost days will therefore be less effective as a variable sensitive for possible frost shattering.

The SO_2 effect is expressed both with the IRMA apparatures and by increased SO_4^{2-}-concentration of the sheltered stone samples. SO_4^{2-}-concentration in the stone is affected by horizontal rain in the coastal area as can be seen in several of the results from the Netherlands. The uncertainty in the SO_2 in stone results can therefore be substantial.

The IRMA results are based on the assumption that SO_2 is adsorbed in alkaline solution and stays in the solution. The reduced amount of electrolyte left at the end of the 14 days period is therefore caused by evaporation of water. Many investigations of different types have proved that this assumption is valid. However, in strong wind, there is a danger that some droplets will blow away from the paper housing instead of dripping back into the bottle. This will reduce the accuracy of the results in some areas. Still we find that the IRMA results give the best SO_2 results available in this project.

4 CONCLUSIONS

In the NATO/CCMS project the meteorological data were not measured. To get these data we had to use data from nearby meteorological stations or to interpolate from climatological maps. This increased the uncertainties of the data. However, even if we take into account all the uncertainties in the data used for the analysis performed, some important conclusions can be drawn.

Baumberger sandstone seems to give higher and more homogeneous deterioration than the Krensheimer limestone.

The weight losses of both the sandstone and limestone have a good correlation with the SO_2 concentration measured by the IRMA apparatus and the SO_2 in stone.

The best correlations with multiple regression were found for the combination of SO_2 and rain days. The equations for the weight loss for sandstone (OWS) and limestone (OWL) were

$$OWS = -0.05*SO_2\ (IRMA) - 0.08*RD + 2.0 \qquad R = 0.79$$
$$OWL = -0.03*SO_2\ (IRMA) - 0.01*RD + 1.4 \qquad R = 0.69$$

The equations therefore only explain 62% and 48% of the variance.

None of the other variables measured increased the correlation coefficient substantial according to a normal F-test. This equation do not apply to sites with high chloride levels which will be important at some coastal sites (see Appendix 2). However, the number of available data from coastal sites was too small for a regression analysis.

5 REFERENCES

Gram, F. (1972) Program MULREG. Lillestrøm (NILU TR 22/72).

Zallmanzig, J. (1985) Investigation on the rate of immission and effects in selected places in Europe for the quantitative examination of the influence of air pollution in the destruction of ashlar. Part A. Measuring values and summary Zollern-Institut at Deutsches Bergbau-Museum (NATO/CCMS no. 158).

Table 1: List of all the parameters used in the regression analysis and the codes used for the parameters in the following tables and figures. All meteorological data are given as yearly values.

VARIABLE 1 -	OPEN W.LOSS SAND	OWS	WEIGHT CHANGE IN PER CENT
VARIABLE 2 -	SHEL W.LOSS SAND	SWS	WEIGHT CHANGE IN PER CENT
VARIABLE 3 -	OPEN W.LOSS LIME	OWL	WEIGHT CHANGE IN PER CENT
VARIABLE 4 -	SHEL W.LOSS LIME	SWS	WEIGHT CHANGE IN PER CENT
VARIABLE 5 -	SO_2 DEP IRMA	SOI	mg m^{-2} d^{-1}
VARIABLE 6 -	SO_2 DEP SANDST 1	SOS1	mg m^{-2} d^{-1}
VARIABLE 7 -	SO_2 DEP SANDST 2	SOS2	mg m^{-2} d^{-1}
VARIABLE 8 -	SO_2 DEP LIMEST 1	SOL1	mg m^{-2} d^{-1}
VARIABLE 9 -	SO_2 DEP LIMEST 2	SOL2	mg m^{-2} d^{-1}
VARIABLE 10 -	CL DEP IRMA	CLI	mg m^{-2} d^{-1}
VARIABLE 11 -	CL DEP SANDST 1	CLS1	mg m^{-2} d^{-1}
VARIABLE 12 -	CL DEP SANDST 2	CLS2	mg m^{-2} d^{-1}
VARIABLE 13 -	CL DEP LIMEST 1	CLL1	mg m^{-2} d^{-1}
VARIABLE 14 -	CL DEP LIMEST 2	CLL2	mg m^{-2} d^{-1}
VARIABLE 15 -	NO_2 DEP IRMA	NOI	mg m^{-2} d^{-1}
VARIABLE 16 -	NO_2 DEP SANDST 1	NOS1	mg m^{-2} d^{-1}
VARIABLE 17 -	NO_2 DEP SANDST 2	NOS2	mg m^{-2} d^{-1}
VARIABLE 18 -	NO_2 DEP LIMEST 1	NOL1	mg m^{-2} d^{-1}
VARIABLE 19 -	NO_2 DEP LIMEST 2	NOL2	mg m^{-2} d^{-1}
VARIABLE 20 -	F DEP IRMA	F1	days
VARIABLE 21 -	FROST DAYS	FD	days
VARIABLE 22 -	ICE DAYS	ID	days
VARIABLE 23 -	MEAN RH	MRH	%
VARIABLE 24 -	TIME RH>80%	T80	hours
VARIABLE 25 -	AMOUNT RAIN	ARA	mm
VARIABLE 26 -	DURATION RAIN	DRA	hours
VARIABLE 27 -	RAIN DAYS	RD	days
VARIABLE 28 -	WET DAYS	WD	days
VARIABLE 29 -	SNOW DAYS	SD	days
VARIABLE 30 -	HAIL	HAIL	days

Table 2: List of all data sets gathered in the measuring program.

STEN-TALL:PRNT

	WEIGHT-LOSS				SO2-deposition					Cl-deposition					NO2-deposition					F-dep.
	sand-stone		lime-stone																	
STATION	open	shel	open	shel	IRMA	sand1	sand2	lime1	lime2	IRMA	sand1	sand2	lime1	lime2	IRMA	sand1	sand2	lime1	lime2	IRMA
GB 1	-8.0	1.9	-7.2	.6	108.7	49.9	43.1	22.3	23.4	8.0	4.9	3.3	2.2	2.4	3.4	2.5	1.8	1.5	1.5	.2
GB 2	-6.4	1.4	-5.3	.5	99.7	37.5	37.9	20.5	21.1	7.4	4.6	4.6	2.8	2.9	3.2	2.8	2.3	1.6	1.8	.1
GB 3	-3.1	-1.6	-3.0	-1.4	10.2					40.7			.4	.6	2.2				.1	.1
NL 1	-4.6	-2.2	-5.4	-2.5	34.9	13.0	12.7	2.6	2.5	12.7	.4	.3	.8	.8	6.1	.2	.5	.0	.1	.1
NL 2	-7.3	-5.6	-6.3	-6.4	68.6	.3	.3	2.1	1.9	365.9	.2	.2	1.7	1.6	5.0				.2	.1
NL 3	-6.8	.6	-7.4	-.5	63.6	34.4	33.9	20.9	20.6	40.2	6.1	6.4	3.1	3.3	8.7	.4	.5	.1	.3	.1
NL 4	-3.9	1.0	-4.9	.2	80.8	31.5	31.7	21.3	20.1	28.6	6.3	7.8	3.1	2.9	9.3	1.2	1.2	.5	.4	.3
I 1	-3.3	.8	-2.7	.1	69.1	35.3	32.8	13.5	13.6	4.3			.3	.2	2.1	.9	.7	.6	.5	.2
I 2	.3	1.0	-.2	.4	32.0	17.4	17.3	9.1	8.9	5.8	2.9	3.2	2.6	3.3	2.5	1.3	1.3	.9	1.0	.1
I 3	-3.2	1.0	-4.2	.6	47.2	28.3	25.3	14.5	15.2	7.9	2.9	2.8	1.6	1.7	2.6	2.3	2.0	1.0	1.1	.4
I 4	-6.2	.2	-4.3	-1.0	110.7	32.9	33.7	11.0	11.7	8.9	1.2	.6	.2	.3	4.1	.8	.5	.4	.4	.1
N 1	-2.7	.6	-3.8	.2	24.5	15.6	15.1	12.0	12.2	10.1	7.0	6.7	2.1	1.4	2.9	.4	.6	.2	.2	.1
S 1	-3.9	.6	-4.2	-.2	80.4	30.9	29.8	12.1	13.3	4.8		.2	.9	.9	2.4	.8	1.0	1.0	1.1	.1
S 2	-.9	.1	-1.3	-.2	7.3	5.1	4.8	2.8	2.9	1.2			.1	.1	1.3	.5	.5	.5	.4	.1
F 1	-3.1	1.1	-3.1	.4	44.5	29.0	28.8	12.1	12.4	7.6	.9	.6	1.0	1.0	6.5	.2	.5	.0	.1	.1
F 2					39.3					1.7					2.8	1.0	1.0	.9	1.0	.2
F 3	-2.2	.8	-2.9	-.9	20.4	10.2	10.0	2.4	1.9	13.8					6.1					.1
F 4	-2.3	.6	-2.9	.4	66.6	39.2	41.3	16.7	17.5	1.8			.6	.7	8.3				.1	.1
US 1	-2.9	.7	-3.1	.3	61.1	23.9	22.8	10.5	10.8	7.3	1.9	2.0	1.4	1.4	9.0	2.4	2.3	1.9	1.7	.1
US 2	-2.3	.6	-1.8	.3	59.1	24.8	23.5	11.9	10.7	7.1	2.7	2.1	1.8	1.6	6.6	3.7	4.0	2.5	2.7	.2
GR 1	-1.6	.7	-2.1	.3	53.2	18.1	19.3	8.1	6.8	8.0	2.8	3.0	1.6	1.2	7.8	4.0	4.3	2.8	2.7	.2
GR 2	-2.4	.9	-2.3	.5	76.8	21.8	20.2	12.9	12.4	16.5	5.4	4.7	1.8	2.1	3.7	1.9	2.2	1.0	1.1	.1
GR 3	-1.2	.7	-1.4	.2	48.2	17.1	18.2	4.7	5.3	2.4	.3	.2	.4	.3	2.1	1.7	1.7	.8	.8	.1
D 1	-2.6	.8	-2.6	.7	72.3	28.5	30.5	14.5	14.6	4.3	1.0	1.1	.7	.8	7.3	1.5	1.5	.7	.7	.1
D 2					42.3	4.5	3.7	1.2	.5	2.6					3.8	2.8	2.6	1.5	1.6	.5
D 3	-5.0	1.0	-6.3	.7	61.8	31.0	32.6	15.7	15.4	2.5	1.1	1.0	1.0	1.2	2.3	.1		.1		.1
D 4	-2.2	.6	-3.3	.4	22.2	20.8	22.0	11.0	10.9	1.3	.2	.2	.5	.6	1.5	1.5	1.3	1.1	1.2	.3

STATION	Frost-days	Ice-days	Rel. hum.	Hours >80%	Mm rain	Hours rain	Days rain	Wet days	Snow days	Hail	*
GB 1	38	3		7358	1248	817	315	222	40	20	
GB 2	52	3		7358	1363	817	334	252	40	20	
GB 3	65	3		12502	3492		504	419	54	3	
NL 1											
NL 2											
NL 3											
NL 4											
I 1											
I 2											
I 3											
I 4	6	0	57.5	1105	1172	335			0		
N 1	131	36	73.0	7913	5023	3801	483	399	110	40	
S 1	270	121		7269	1265		372	224	178	1	
S 2	376	133			1385		345	230	199	10	
F 1											
F 2											
F 3											
F 4											
US 1											
US 2											
GR 1	0	0	63.0	2884	789	687	190	130	10	3	
GR 2	0	0	63.0	2884	780	687	190	130	10	3	
GR 3	0	0	63.0	2884	780	687	190	130	10	3	
D 1	115	19	75.0	6492	1851		372	* 50	59	1	
D 2	239	82	79.0	8450	1641		264	* 41	127	5	
D 3	137	28	79.0	7626	1941		389	* 52	60	15	
D 4	141	28	77.0	7452	1583		329	* 34	70	1	

Table 3: The data used for all the calculations of the inland stations.

			OWS	SWS	OWL	SWL	SOI	SOSM	SOLM	LOGSOI	LOGSOSM	LOGSOLM	CLI	CLSM	CLLM	NOI	NOSM	NOLM	FD	RD
1	GB	1	-8.0	1.9	-7.2	.0	108.7	46.50	22.85	2.0363	1.6675	1.3590	8.7	4.10	2.30	3.4	2.15	1.50	38	315
2	GB	2	-6.4	1.4	-5.3	.5	99.7	37.70	20.80	1.9987	1.5763	1.3181	7.4	4.60	2.85	3.2	2.55	1.70	52	334
4	NL	1	-4.6	-2.2	-5.4	-2.5	34.9	12.85	2.55	1.5428	1.1089	.4065	12.7	.35	.80	6.1	.35	.05	60	330
7	NL	4	-3.9	1.0	-4.9	.2	80.8	31.60	20.70	1.9074	1.4997	1.3160	28.6	7.05	3.00	9.3	1.20	.45	60	330
8	I	1	-3.3	.8	-2.7	.1	69.1	34.05	13.55	1.8395	1.5321	1.1319	4.3	-99.90	.25	2.1	.80	.55	30	200
10	I	3	-3.2	1.0	-4.2	.6	47.2	26.80	14.85	1.6739	1.4281	1.1717	7.9	2.85	1.65	2.6	2.15	.40	30	200
11	I	4	-6.2	.2	-4.3	-1.0	110.7	33.30	11.35	2.0440	1.5224	1.0550	8.9	.90	.25	4.1	.65	.40	6	200
12	N	1	-7.7	.6	-5.8	.2	24.5	15.35	12.10	1.3892	1.1861	1.0828	10.1	6.35	1.75	2.9	.50	.20	131	483
13	S	1	-3.9	.6	-4.2	-.2	80.4	30.35	12.70	1.9053	1.4822	1.1038	4.8	.20	.90	2.4	.90	1.05	270	372
14	S	2	-.9	.1	-1.3	-.2	7.3	4.95	2.85	0.8633	.6946	.4548	1.2	-99.90	.10	1.3	.50	.45	376	345
15	F	1	-3.1	1.1	-3.1	.4	44.5	28.90	12.25	1.6484	1.4609	1.0881	7.6	.75	1.00	6.5	1.00	.95	60	330
17	F	3	-2.2	.8	-2.9	-.9	20.4	10.10	2.15	1.3096	1.0043	.3324	13.8	-99.90	-99.90	6.1	-9.99	-9.99	6	340
18	F	4	-2.3	.6	-2.9	.4	66.6	40.25	17.10	1.8235	1.6048	1.2330	1.8	-99.90	.65	8.3	2.35	1.80	100	300
19	US	1	-2.9	.7	-3.1	.3	61.1	23.35	10.65	1.7860	1.3683	1.0273	7.3	1.95	1.40	9.0	3.85	2.60	160	214
20	US	2	-2.3	.6	-1.8	.3	59.1	24.15	11.30	1.7716	1.3829	1.0531	7.1	2.40	1.70	6.6	4.15	2.75	160	214
21	GR	1	-1.6	.7	-2.1	.3	53.2	18.70	7.45	1.7259	1.2718	.8722	9.0	2.00	1.40	7.3	2.05	1.05	0	199
22	GR	2	-2.4	.9	-2.3	.5	76.8	21.00	12.65	1.8854	1.3222	1.1021	16.5	5.05	1.95	5.7	1.70	.80	0	190
23	GR	3	-1.2	.7	-1.4	.2	48.2	17.65	5.00	1.6830	1.2467	.6990	2.4	.25	.35	2.1	1.50	.70	0	199
24	D	1	-2.6	.8	-2.6	.7	72.3	29.50	14.55	1.8591	1.4698	1.1629	4.3	1.05	.75	7.3	2.70	1.55	115	372
26	D	3	-5.0	1.0	-6.3	.7	61.8	31.80	15.55	1.7910	1.5024	1.1917	2.5	1.05	1.10	2.3	1.40	1.15	137	382
27	D	4	-2.2	.6	-3.3	.4	22.2	21.40	10.95	1.3464	1.3304	1.0394	1.3	.20	.55	1.5	.85	.75	141	329

Table 4: The data used for all the calculations of the coast stations.

			OWS	SWS	OWL	SWL	SOI	SOSM	SOLM	LOGSOI	LOGSOSM	LOGSOLM	CLI	CLSM	CLLM	NOI	NOSM	NOLM	FD	RD
3	GD	3	-3.1	-1.6	-3.0	-1.4	10.2	-99.90	-99.90	1.0086	-99.0000	-99.0000	40.7	-99.90	.50	2.2	-9.99	-9.99	65	504
4	NL	1	-4.6	-2.2	-5.4	-2.5	34.9	12.85	2.55	1.5428	1.1089	.4065	12.7	.35	.80	6.1	.35	.05	60	330
5	NL	2	-7.3	-5.6	-6.3	-6.4	68.6	.30	2.00	1.8363	-.5229	.3010	365.9	.20	1.65	5.0	-9.99	-9.99	40	330
6	NL	3	-6.8	.6	-7.4	-.5	63.6	34.15	20.75	1.6035	1.5334	1.3170	40.2	6.25	3.20	8.7	.45	.20	60	330
7	NL	4	-3.9	1.0	-4.9	.2	80.8	31.60	20.70	1.9074	1.4997	1.3160	28.6	7.05	3.00	9.3	1.20	.45	60	330
12	N	1	-2.7	.6	-3.8	.2	24.5	15.35	12.10	1.3892	1.1861	1.0828	10.1	6.85	1.75	2.9	.50	.20	131	483
17	F	3	-2.2	.8	-2.9	-.9	20.4	10.10	2.15	1.3096	1.0043	.3324	13.8	-99.90	-99.90	6.1	-9.99	-9.99	6	340

Table 5: The correlation matrix for sandstone on the inland stations.

OWS	1.000											
SWS	-.170	1.000										
SOI	-.722	.390	1.000									
SOSM	-.678	.529	.829	1.000								
LSOI	-.605	.352	.930	.818	1.000							
LSSM	-.593	.491	.805	.949	.891	1.000						
CLI	-.170	-.033	.185	-.045	.206	.018	1.000					
CLSM	-.130	.366	.186	.128	.143	.092	.692	1.000				
NOI	.108	-.087	.128	.092	.256	.160	.452	.173	1.000			
NOSM	.039	.368	.285	.275	.382	.331	-.074	.072	.484	1.000		
FD	.245	-.152	-.335	-.254	-.480	-.377	-.384	-.231	-.208	-.058	1.000	
RD	-.148	-.040	-.254	-.058	-.316	-.136	-.004	.168	-.112	-.354	.442	1.000
	OWS	SWS	SOI	SOSM	LSOI	LSSM	CLI	CLSM	NOI	NOSM	FD	RD

Table 6: The correlation matrix for limestone at the inland stations.

OWL	1.000											
SWL	.096	1.000										
SOI	-.468	.211	1.000									
SOLM	-.566	.604	.715	1.000								
LSOI	-.420	.248	.930	.690	1.000							
LSLM	-.402	.693	.685	.945	.714	1.000						
CLI	-.236	-.225	.185	.163	.206	.050	1.000					
CLLM	-.454	.326	.394	.652	.406	.554	.668	1.000				
NOI	.092	-.069	.128	.072	.256	.052	.452	.281	1.000			
NOLM	.105	.435	.299	.296	.351	.354	-.243	.228	.433	1.000		
FD	.160	.044	-.335	-.152	-.480	-.130	-.384	-.267	-.208	.155	1.000	
RD	-.378	-.041	-.254	.123	-.316	.013	-.004	.115	-.112	-.168	.442	1.000
	OWL	SWL	SOI	SOLM	LSOI	LSLM	CLI	CLLM	NOI	NOLM	FD	RD

Table 7: The correlation matrix for sandstone at the coast stations.

OWS	1.000											
SWS	.573	1.000										
SOI	-.692	-.126	1.000									
SOSM	-.016	.714	.412	1.000								
LSOI	-.612	-.188	.944	.206	1.000							
LSSM	-.701	.382	.923	.994	.795	1.000						
CLI	-.683	-.850	.431	-.580	.448	.895	1.000					
CLSM	.478	.909	.099	.783	-.127	.658	-.594	1.000				
NOI	-.372	.336	.761	.739	.703	.702	-.107	.279	1.000			
NOSM	.274	.580	.752	.529	.862	.560	.283	.538	.525	1.000		
FD	.148	.194	-.125	.221	-.097	.200	-.251	.546	-.374	-.215	1.000	
RD	.527	.113	-.681	-.096	-.739	-.233	-.258	.428	-.830	-.215	.625	1.000
	OWS	SWS	SOI	SOSM	LSOI	LSSM	CLI	CLSM	NOI	NOSM	FD	RD

Table 8: The correlation matrix for limestone at the coast stations.

OWL	1.000											
SWL	.348	1.000										
SOI	-.759	-.212	1.000									
SOLM	-.339	.646	.534	1.000								
LSOI	-.694	-.286	.944	.342	1.000							
LSLM	-.253	.704	.414	.983	.239	1.000						
CLI	-.415	-.905	.431	-.371	.448	-.433	1.000					
CLLM	-.595	.359	.788	.922	.655	.844	-.050	1.000				
NOI	-.577	.198	.761	.594	.703	.450	-.107	.799	1.000			
NOLM	.163	.771	.767	.787	.780	.770	.420	.734	.506	1.000		
FD	.020	.361	-.125	.393	-.097	.544	-.251	-.046	-.374	-.101	1.000	
RD	.609	.293	-.681	.084	-.739	.259	-.258	-.511	-.830	-.101	.625	1.000
	OWL	SWL	SOI	SOLM	LSOI	LSLM	CLI	CLLM	NOI	NOLM	FD	RD

Table 9: The relations for the sandstone weight losses with one variable.
R = correlation coefficient RR = unexplained variance

```
OWS  =   -.0481*SOI   +   -.5379                    R= -.6963 ,RR=  .5151
OWS  =   -.1657*SOSM  +    .7362                    R= -.7693 ,RR=  .4081
OWS  =  -5.2592*LSOI  +   5.6204                    R= -.5811 ,RR=  .6624
OWS  =  -8.4177*LSSM  +   8.1392                    R= -.6611 ,RR=  .5630
OWS  =   -.0287*CLI   +  -3.4137                    R= -.0990 ,RR=  .9902
OWS  =   -.1050*CLSM  +  -3.3962                    R= -.1301 ,RR=  .9831
OWS  =    .1236*NOI   +  -4.2700                    R=  .1790 ,RR=  .9680
OWS  =    .2080*NOSM  +  -4.0217                    R=  .1241 ,RR=  .9846
OWS  =    .0022*FD    +  -3.8405                    R=  .0885 ,RR=  .9922
OWS  =   -.0059*RD    +  -2.2079                    R= -.2389 ,RR=  .9429
```

Table 10: The ten best relations for the sandstone weight losses with two variables. The equations with two independent variables are underlined.
R = correlation coefficient RR = unexplained variance
F = F-test

```
OWS  =   -.6847*SOSM +  31.2814*LSSM + -29.3419                R=  .9064, RR=  .1785
                                           OVERGANG FRA SOSM (R= -.7693) TIL TO VARIABLE: F= 18.01** NOBS=  17

OWS  =   -.1769*SOSM +    .4651*NOSM +    .2212                R=  .8162, RR=  .3338
                                           OVERGANG FRA SOSM (R= -.7693) TIL TO VARIABLE: F=  3.12   NOBS=  17

OWS  =   -.1515*SOI  +  13.9866*LSOI + -18.6602                R=  .7936, RR=  .3702
                                           OVERGANG FRA SOI  (R= -.6963) TIL TO VARIABLE: F=  5.48*  NOBS=  17

OWS  =   -.0526*SOI  +   -.0077*RD   +   1.9744                R=  .7875, RR=  .3799
                                           OVERGANG FRA SOI  (R= -.6963) TIL TO VARIABLE: F=  4.99*  NOBS=  17

OWS  =   -.1619*SOSM +   -.0031*RD   +   1.5349                R=  .7833, RR=  .3865
                                           OVERGANG FRA SOSM (R= -.7693) TIL TO VARIABLE: F=   .78   NOBS=  17

OWS  =   -.0153*SOI  +   -.1274*SOSM +    .6977                R=  .7806, RR=  .3906
                                           OVERGANG FRA SOSM (R= -.7693) TIL TO VARIABLE: F=   .63   NOBS=  17

OWS  =   -.1636*SOSM +    .0825*NOI  +    .2895                R=  .7778, RR=  .3951
                                           OVERGANG FRA SOSM (R= -.7693) TIL TO VARIABLE: F=   .46   NOBS=  17

OWS  =   -.1656*SOSM +   -.0275*CLI  +    .9690                R=  .7752, RR=  .3991
                                           OVERGANG FRA SOSM (R= -.7693) TIL TO VARIABLE: F=   .32   NOBS=  17

OWS  =   -.1658*SOSM +    .0022*FD   +    .5504                R=  .7748, RR=  .3998
                                           OVERGANG FRA SOSM (R= -.7693) TIL TO VARIABLE: F=   .29   NOBS=  17

OWS  =   -.1648*SOSM +   -.0260*CLSM +    .7777                R=  .7700, RR=  .4071
                                           OVERGANG FRA SOSM (R= -.7693) TIL TO VARIABLE: F=   .04   NOBS=  17
```

Table 11: The ten best relations for the sandstone weight losses with three variables.

```
OWS  =    -.6443*SOSM +  28.5052*LSSM +     .2373*NOSM + -26.9352   R=  .9160,  RR=  .1610
                                        OVERGANG FRA SOSM OG LSSM (R=  .9064) TIL TRE VARIABLE: F=  1.42

OWS  =    -.0124*SOI  +    -.6475*SOSM +  30.9094*LSSM + -29.0154   R=  .9127,  RR=  .1670
                                        OVERGANG FRA SOSM OG LSSM (R=  .9064) TIL TRE VARIABLE: F=   .89

OWS  =    -.6771*SOSM +    -.8721*LSOI +  31.7620*LSSM + -28.6774   R=  .9086,  RR=  .1745
                                        OVERGANG FRA SOSM OG LSSM (R=  .9064) TIL TRE VARIABLE: F=   .30

OWS  =    -.6725*SOSM +  30.9742*LSSM +    -.0153*CLI  + -28.9173   R=  .9079,  RR=  .1757
                                        OVERGANG FRA SOSM OG LSSM (R=  .9064) TIL TRE VARIABLE: F=   .20

OWS  =    -.6957*SOSM +  31.8589*LSSM +     .0420*CLSM + -29.9640   R=  .9078,  RR=  .1759
                                        OVERGANG FRA SOSM OG LSSM (R=  .9064) TIL TRE VARIABLE: F=   .19

OWS  =    -.5769*SOSM +  30.8607*LSSM +     .0307*NOI  + -29.1039   R=  .9073,  RR=  .1767
                                        OVERGANG FRA SOSM OG LSSM (R=  .9064) TIL TRE VARIABLE: F=   .13

OWS  =    -.6943*SOSM +  31.8639*LSSM +    -.0008*FD   + -29.8318   R=  .9070,  RR=  .1774
                                        OVERGANG FRA SOSM OG LSSM (R=  .9064) TIL TRE VARIABLE: F=   .08

OWS  =    -.6779*SOSM +  30.9101*LSSM +    -.0004*RD   + -28.8685   R=  .9066,  RR=  .1781
                                        OVERGANG FRA SOSM OG LSSM (R=  .9064) TIL TRE VARIABLE: F=   .03

OWS  =    -.1091*SOI  +    -.1042*SOSM +  11.3813*LSOI + -14.8883   R=  .8425,  RR=  .2901
                                        OVERGANG FRA SOI  OG LSOI (R=  .7936) TIL TRE VARIABLE: F=  3.59

OWS  =    -.0186*SOI  +    -.1308*SOSM +     .4926*NOSM +     .1437   R=  .8318,  RR=  .3081
                                        OVERGANG FRA SOSM OG NOSM (R=  .8162) TIL TRE VARIABLE: F=  1.09
```

Table 12: The relations for the limestone weight losses with one variable.

```
OWL   =     -.0269*SOI   +   -1.9540                                  R= -.4623 ,RR=  .7863

OWL   =     -.1702*SOLM  +   -1.4678                                  R= -.5759 ,RR=  .6683

OWL   =   -2.4021*LSOI   +     .5360                                  R= -.4122 ,RR=  .8301

OWL   =   -2.6014*LSLM   +    -.8957                                  R= -.4145 ,RR=  .8282

OWL   =     -.0678*CLI   +   -3.0924                                  R= -.2642 ,RR=  .9302

OWL   =     -.3629*CLLM  +   -2.5357                                  R= -.4544 ,RR=  .7935

OWL   =      .0490*NOI   +   -3.8367                                  R=  .0815 ,RR=  .9934

OWL   =      .2265*NOLM  +   -3.8463                                  R=  .1047 ,RR=  .9890

OWL   =      .0031*FD    +   -3.9084                                  R=  .1847 ,RR=  .9659

OWL   =     -.0075*RD    +   -1.4295                                  R= -.3956 ,RR=  .8435
```

Table 13: The ten best relations for the limestone weight losses with two variables. The equations with two independent variables are underlined.

```
OWL  =    -.5040*SOLM +   7.5083*LSLM +  -5.1005                            R=  .6975,  RR=  .5134
                                                  OVERGANG FRA SOLM (R= -.5759) TIL TO VARIABLE: F=  5.13*  NOBS=   20

OWL  =    -.0340*SOI  +   -.0100*RD   +   1.3896                            R=  .6916,  RR=  .5216
                                                  OVERGANG FRA SOI  (R= -.4623) TIL TO VARIABLE: F=  8.62** NOBS=   20

OWL  =  -3.3650*LSOI  +   -.0107*RD   +   5.3104                            R=  .6792,  RR=  .5387
                                                  OVERGANG FRA LSOI (R= -.4122) TIL TO VARIABLE: F=  9.20** NOBS=   20

OWL  =    -.1536*SOLM +   -.0056*RD   +   -.0382                            R=  .6457,  RR=  .5831
                                                  OVERGANG FRA SOLM (R= -.5759) TIL TO VARIABLE: F=  2.48   NOBS=   20

OWL  =    -.1965*SOLM +    .6521*NOLM +  -1.8166                            R=  .6438,  RR=  .5855
                                                  OVERGANG FRA SOLM (R= -.5759) TIL TO VARIABLE: F=  2.40   NOBS=   20

OWL  =    -.1764*SOLM +    .0962*NOI  +  -1.8345                            R=  .5974,  RR=  .6431
                                                  OVERGANG FRA SOLM (R= -.5759) TIL TO VARIABLE: F=   .67   NOBS=   20

OWL  =    -.1609*SOLM +   -.0293*CLI  +  -1.3613                            R=  .5863,  RR=  .6563
                                                  OVERGANG FRA SOLM (R= -.5759) TIL TO VARIABLE: F=   .31   NOBS=   20

OWL  =    -.1437*SOLM +   -.2650*CLLM +  -1.4760                            R=  .5853,  RR=  .6574
                                                  OVERGANG FRA SOLM (R= -.5759) TIL TO VARIABLE: F=   .28   NOBS=   20

OWL  =    -.0078*SOI  +   -.1435*SOLM +  -1.3260                            R=  .5843,  RR=  .6586
                                                  OVERGANG FRA SOLM (R= -.5759) TIL TO VARIABLE: F=   .25   NOBS=   20

OWL  =     .0082*FD   +   -.0112*RD   +   -.9204                            R=  .5831,  RR=  .6600
                                                  OVERGANG FRA RD   (R= -.3956) TIL TO VARIABLE: F=  4.73*  NOBS=   20
```

Table 14: The ten best relations for the limestone weight losses with three variables. The equations with three independent variables are underlined.

```
OWL  =    -.0283*SOI  +    .0043*FD   +   -.0122*RD   +   1.2189   R=  .7295,  RR=  .4679
                                          OVERGANG FRA SOI   OG RD   (R=  .6916) TIL TRE VARIABLE: F=  1.84

OWL  =    -.4813*SOLM +   6.5746*LSLM +    .4663*NOLM +  -4.8980   R=  .7256,  RR=  .4735
                                          OVERGANG FRA SOLM OG LSLM (R=  .6975) TIL TRE VARIABLE: F=  1.35

OWL  =    -.4474*SOLM +   6.4959*LSLM +   -.0039*RD   +  -3.6172   R=  .7245,  RR=  .4751
                                          OVERGANG FRA SOLM OG LSLM (R=  .6975) TIL TRE VARIABLE: F=  1.29

OWL  =    -.0374*SOI  +    .4577*NOLM +   -.0096*RD   +    .2980   R=  .7201,  RR=  .4814
                                          OVERGANG FRA SOI   OG RD   (R=  .6916) TIL TRE VARIABLE: F=  1.34

OWL  =  -3.8348*LSOI  +    .5281*NOLM +   -.0104*RD   +   5.4746   R=  .7164,  RR=  .4868
                                          OVERGANG FRA LSOI OG RD    (R=  .6792) TIL TRE VARIABLE: F=  1.70

OWL  =    -.4994*SOLM +  -1.2733*LSOI +   8.3443*LSLM +  -3.9331   R=  .7159,  RR=  .4876
                                          OVERGANG FRA SOLM OG LSLM (R=  .6975) TIL TRE VARIABLE: F=   .85

OWL  =    -.0237*SOI  +   -.3922*CLLM +   -.0092*RD   +   1.3046   R=  .7155,  RR=  .4880
                                          OVERGANG FRA SOI   OG RD   (R=  .6916) TIL TRE VARIABLE: F=  1.10

OWL  =    -.5045*SOLM +   7.3938*LSLM +    .0862*NOI  +  -5.3736   R=  .7119,  RR=  .4933
                                          OVERGANG FRA SOLM OG LSLM (R=  .6975) TIL TRE VARIABLE: F=   .65

OWL  =  -3.7359*LSOI  +    .1264*NOI  +   -.0105*RD   +   5.3145   R=  .7079,  RR=  .4989
                                          OVERGANG FRA LSOI OG RD    (R=  .6792) TIL TRE VARIABLE: F=  1.28

OWL  =    -.0083*SOI  +   -.4771*SOLM +   7.5451*LSLM +  -4.9659   R=  .7054,  RR=  .5024
                                          OVERGANG FRA SOLM OG LSLM (R=  .6975) TIL TRE VARIABLE: F=   .35
```

```
X= SOI          , Y= OWS

XMIN=      7.50, XMAX=    110.70
YMIN=     -8.00, YMAX=      -.90

X MIDDEL=   59.50, Y MIDDEL=   -3.38    21 OBSERVASJONSPAR

KORRELASJON R= -.722

OWS  =      -.046 * SOI  +     -.660
```

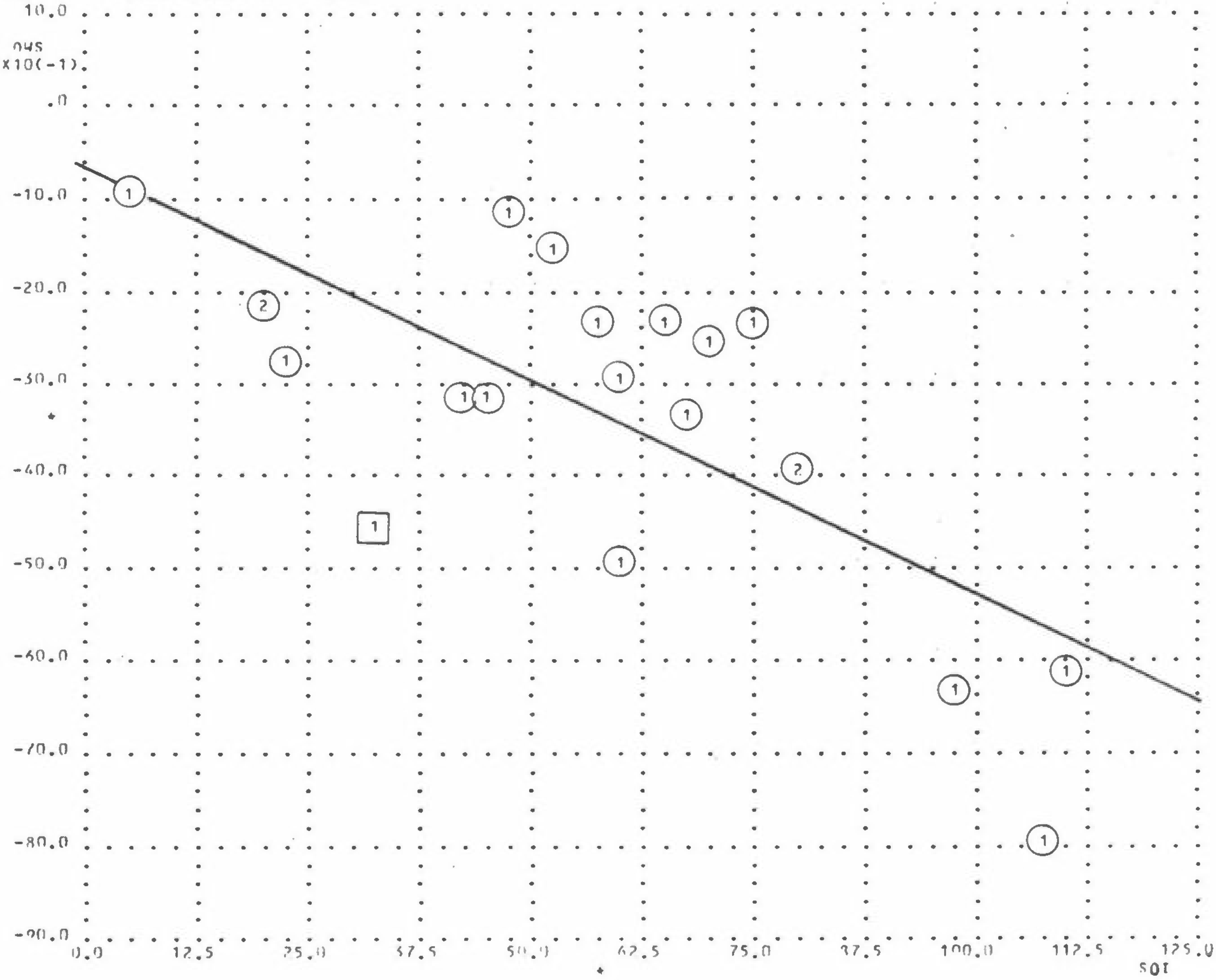

Figure 1: **The weight loss for sandstone of inland stations against the SO_2 flux to the IRMA apparatus.**

```
X= SOSM        , Y= OWS

XMIN=      4.95, XMAX=     46.50
YMIN=     -8.00, YMAX=      -.90

X MIDDEL=   25.73, Y MIDDEL=   -3.38   21 OBSERVASJONSPAR

KORRELASJON R= -.678

OWS   =     -.118 * SOSM +     -.347
```

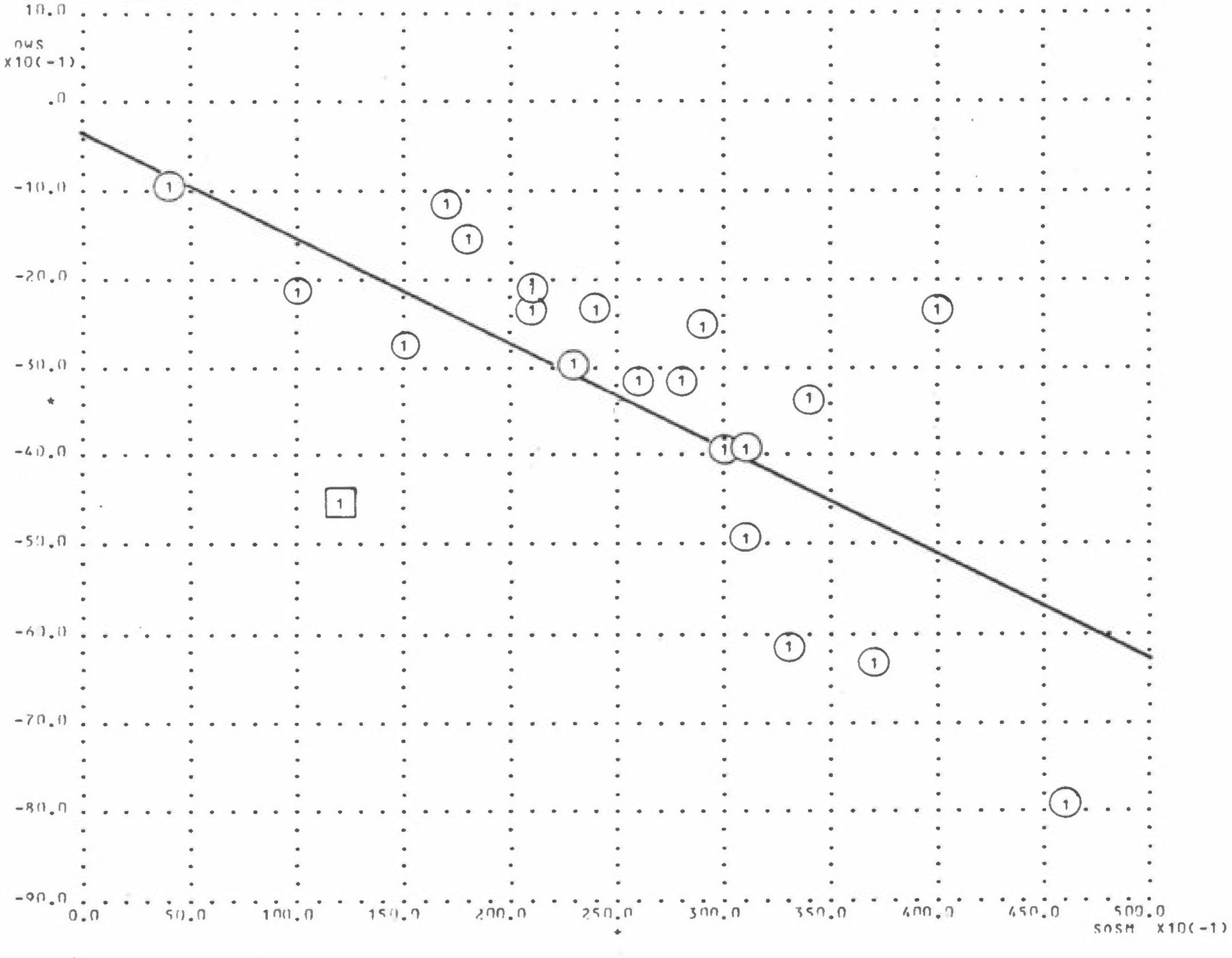

Figure 2: The weight loss for sandstone at inland stations against the SO_2 flux to the sheltered sandstone samples.

```
X= SOLM          , Y= OWL

XMIN=      2.15, XMAX=      22.85
YMIN=     -7.20, YMAX=     -1.30

X MIDDEL=    12.09, Y MIDDEL=    -3.58    21 OBSERVASJONSPAR

KORRELASJON R= -.566

OWL   =      -.154 * SOLM +    -1.710
```

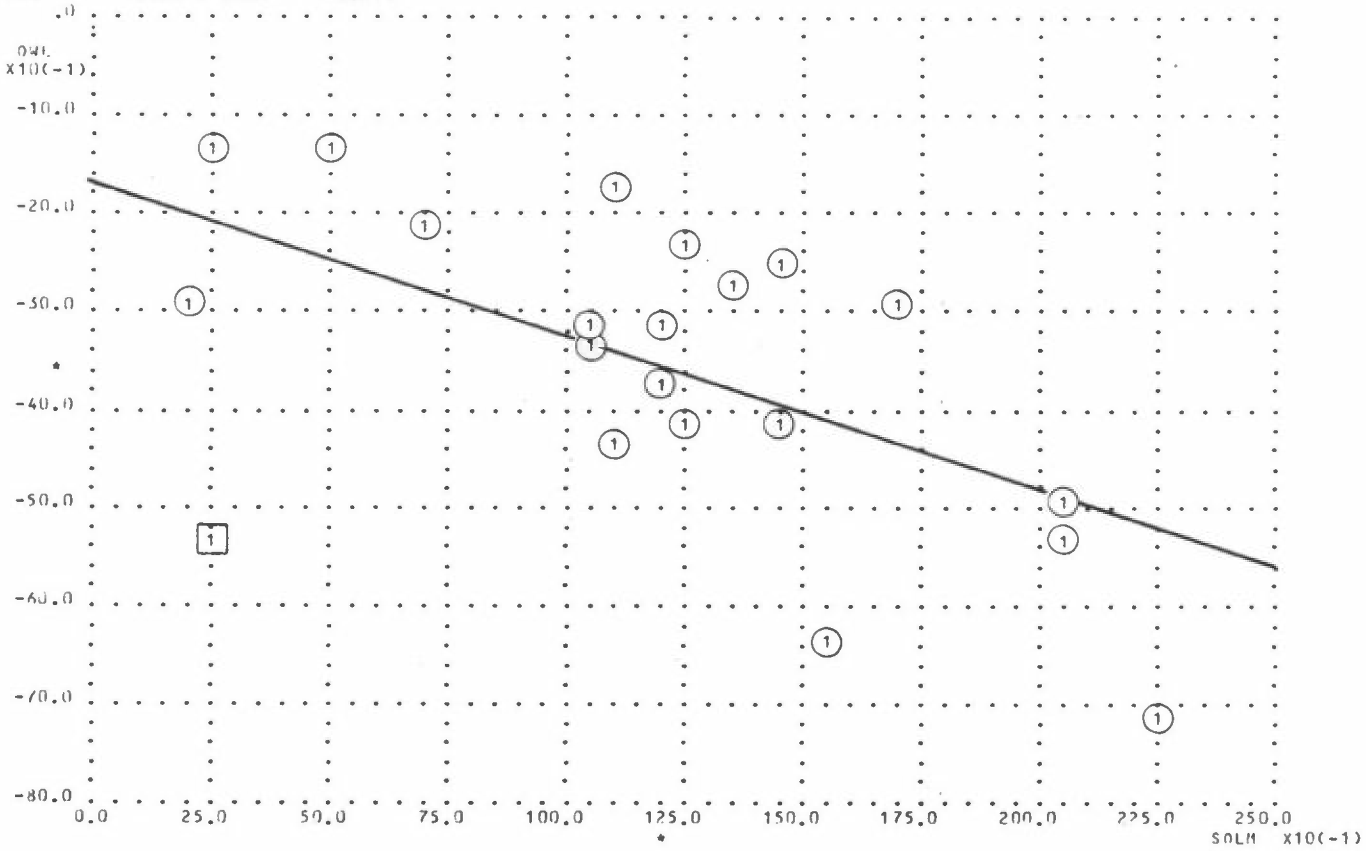

Figure 3: The weight loss for limestone at inland stations against the SO_2 flux to the IRMA apparatus.

```
X= SOI          , Y= OWL

XMIN=      7.50,  XMAX=    110.70
YMIN=     -7.20,  YMAX=     -1.50

X MIDDEL=   59.50, Y MIDDEL=   -3.58   21 OBSERVASJONSPAR

KORRELASJON R= -.468

OWL   =    -.026 * SOI  +   -2.030
```

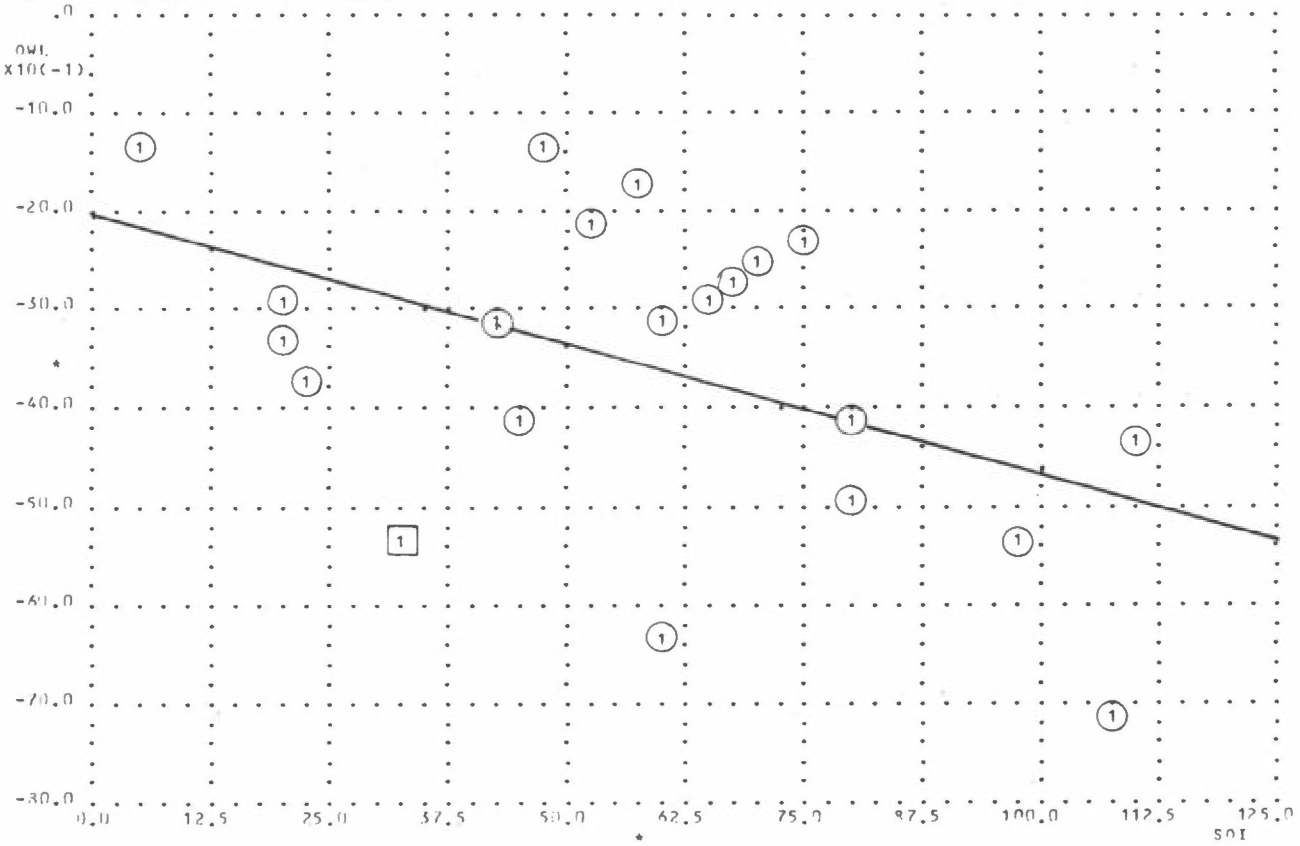

Figure 4: The weight loss for limestone at inland stations against the SO_2 flux to the sheltered limestone samples.

```
X= CLI          . Y= OWS

XMIN=     10.10, XMAX=    365.90
YMIN=     -7.30, YMAX=     -2.20

X MIDDEL=    73.14, Y MIDDEL=    -4.37      7 OBSERVASJONSPAR

KORRELASJON R= -.683

OWS   =     -.010 * CLI  +    -3.604
```

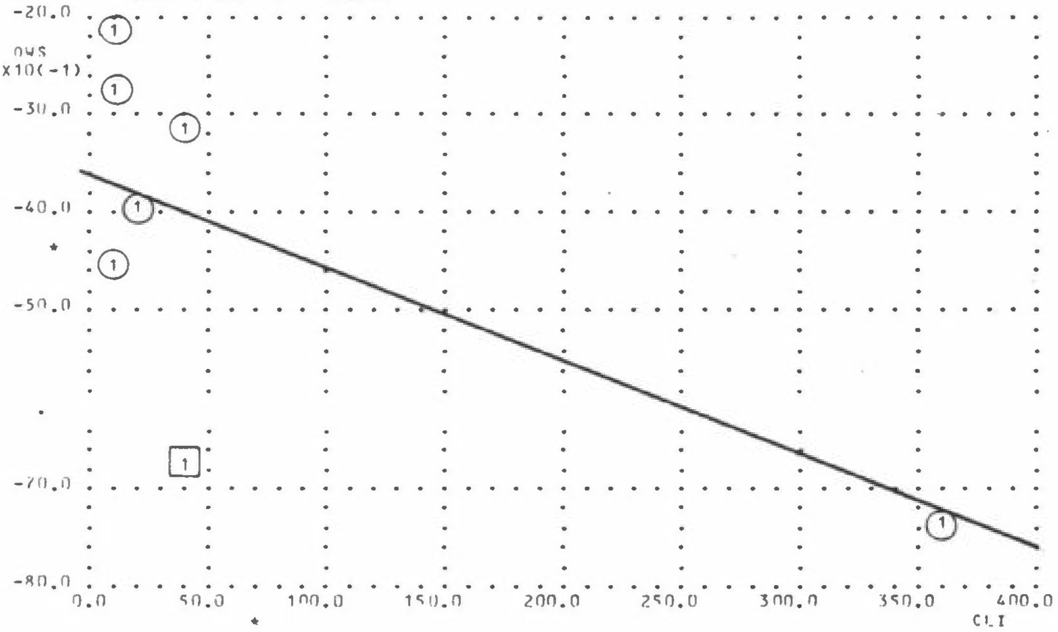

Figure 5: The weight loss for sandstone at coast stations against the Cl^- flux to the IRMA apparatus.

```
X= YOBS          , Y= YBER

XMIN=     -8.00, XMAX=       -.90
YMIN=     -6.06, YMAX=      -1.09

X MIDDEL=    -3.38, Y MIDDEL=    -3.38    21 OBSERVASJONSPAR

KORRELASJON R=   .799

YBER =       .639 * YOBS +    -1.218
```

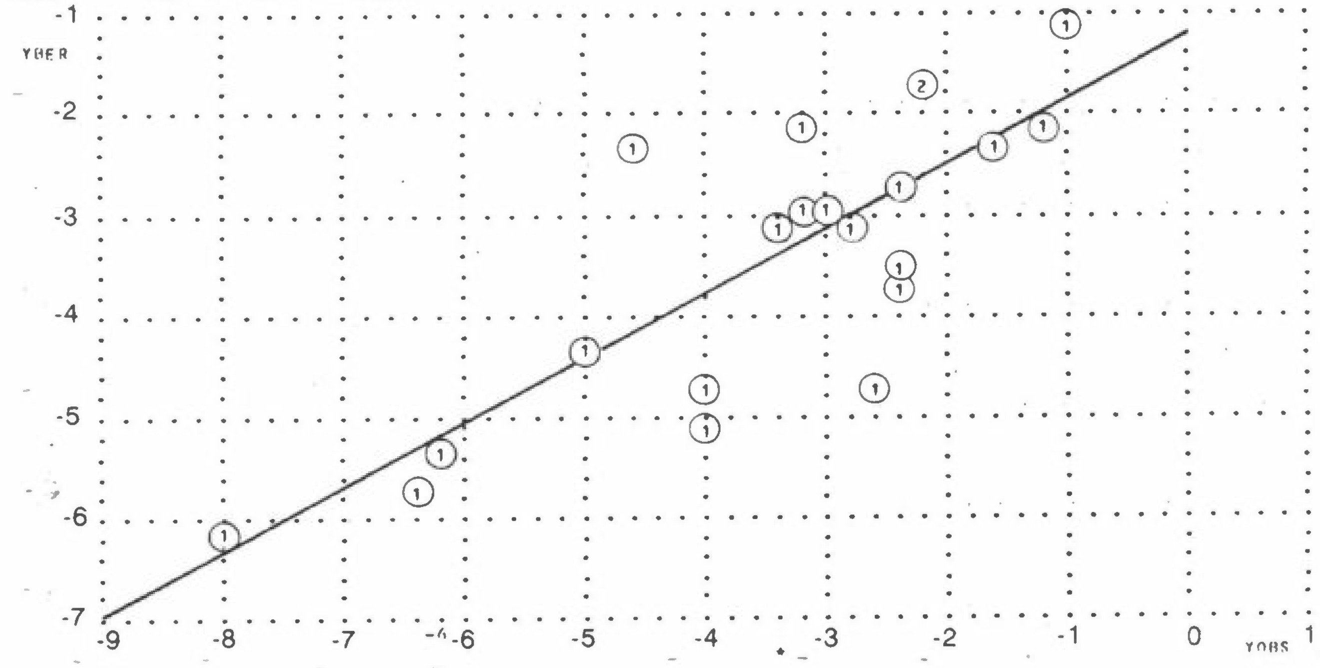

Figure 6: The observed weight loss for sandstone at inland stations plotted against the calculated weight losses for the same stations using the equation:

$$OWS = -0.05\ SO_2\ (IRMA) - 0.008\ RD + 1.9$$

```
X= YOBS          , Y= YBER

XMIN=     -7.20, XMAX=     -1.50
YMIN=     -5.44, YMAX=     -2.16

X MIDDEL=   -3.58, Y MIDDEL=   -3.53    21 OBSERVASJONSPAR

KORRELASJON R=   .625

YBER =       .433 * YOBS +    -1.350
```

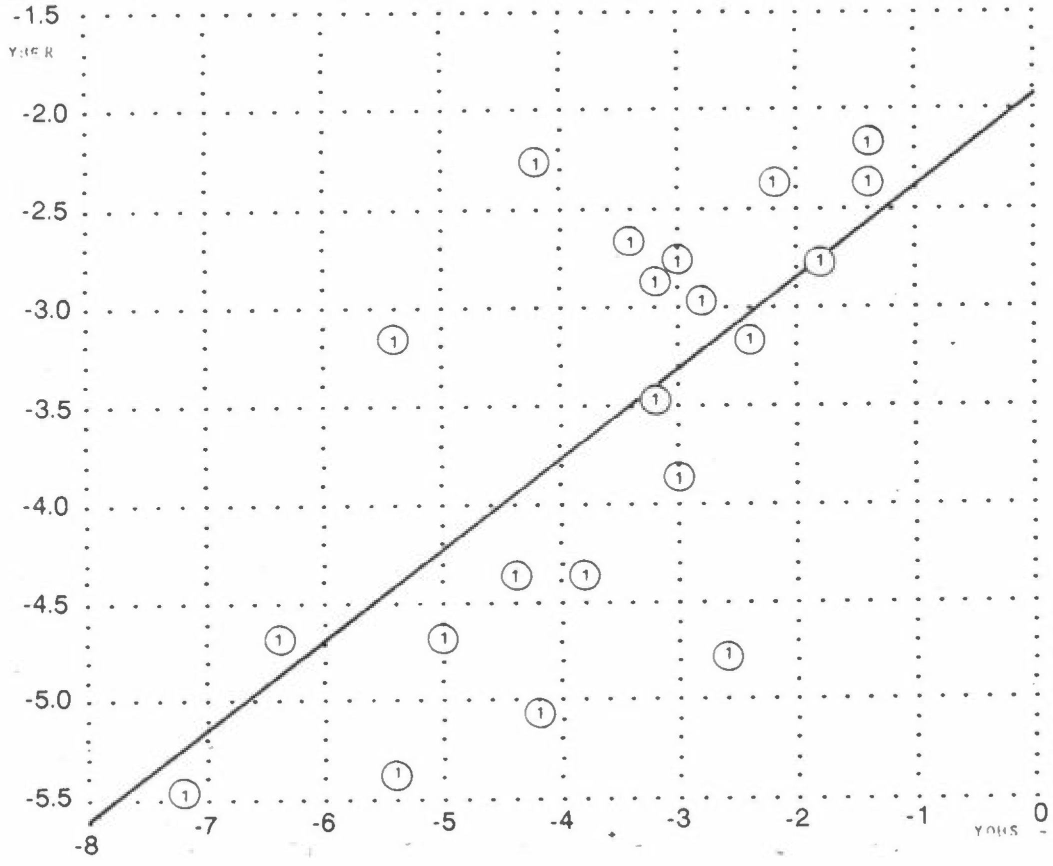

Figure 7: The observed weight loss for limestone at inland stations plotted against the calculated weight losses for the same stations using the equation:

$$OWL = -0.03\ SO_2\ (IRMA) - 0.01\ RD + 1.4$$

APPENDIX 1

NORWEGIAN INSTITUTE FOR AIR RESEARCH

NILU

ROYAL NORWEGIAN COUNCIL FOR SCIENTIFIC AND INDUSTRIAL RESEARCH

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Members of the NATO/CCMS study
"Restoration and Conservation of Monuments"

Your ref.:
Our ref.:
JFH/SBH/O-8068
Lillestrøm, 12 January 1984

Dear colleagues,

NATO/CCMS RESTORATION AND CONSERVATION OF MONUMENTS

Before the expert meeting in the Federal Republic of Germany in 1984, we will again draw your attention to the Norwegian Proposal for regression analysis of our joint results on stone detoriation and pollution data together with normal available meteorological data (ref. our letter, 27 October 1982, JFH/MAa/02280).

Until now I have received positive answers from FRG, UK, France (Strasbourg) and Sweden. So far, no one has been against our proposal, but we are still missing replys from some countries.

Norway is still willing to do the analysis in 1984. Particularly since we can see an increasing interest for stone detoriation caused by air pollution the last years, we find both the main program and the regression analysis to be of great importance for the general knowledge about this topic. However, the comments given by Dr. Ross in FRG, has got me to realize that I must try to specify my parameters in more exact terms in this letter.

In the following I will refer to the same numeration as in my last letter. In table 1 I have also made a table which will cover the information we need for the analysis.

No 1 and 2 will give us information which will be useful for the classification of the general climatic conditions for the test stations and will not be used in the regression analysis.

1. Annual average daily mean temperature (many years)
2. Annual average daily min and max temperature (many years)

Enclosure: 2

PLEASE REPLY TO THE INSTITUTE

For the regression analysis we need information about temperature around zero, relative humidity, amount of precipitation and "time of wetness" for the exposure period of 25 months (Oct 1980 - Oct 1982). We would preferably have the values as monthly values.

3. "Number of days with temperature below 0^{0} C". According to Dr. Ross, the German Weather Service distinguishes between frost days T min <0^{0} C and ice days T max < 0^{0} C. We would prefer to have both information if possible.

4. "Annual average relative humidity". We will prefer to get the average of the exposure period (25 months) or the monthly average values for the same period.

5. "Time with RH > 80%. It would have been a great help to find a way to express the "time of wetness" parameter for the exposed period. The time of wetness is the percentage of time where the surface has a substantial water film on the surface. For metals, the time of wetness is shown to follow the time with the relative humidity higher than 80% RF. We have proposed to use the same parameter but understand that this parameter could be difficult to obtain from normal meteorological data. We hope that we can find time during our next meeting to discuss this problem and hopefully find a possible solution.

6. "Total amount of rain". The information shall preferably be expressed for the exposure period.

7. "Duration of rain"

   This information is normally only available if your meteorological stations are equipped with pluviograf. Often this information can't be found. From UK we have got some other type of information which can be of great help. They have given monthly values number of "Rain days" (> 0,2 mm) "Wet days" (> 1,0 mm), "Snow/sleet days" and "Hail".

We will appreciate if you all can think about your own country's possibilities for producing such information, and if you can be responsible for filling in the data in table 1.

We hope that most of the countries will be interested in the proposed regression analysis and we look forward to a more detailed discussion about the analysis at the next expert meeting in FRG.

Enclosed you will find the distribution list.

Yours sincerely

Jan F Henriksen

J.F. Henriksn
Research scientist

		Many years annual average
Average daily mean		
Average daily min		
Average daily max		

	1980			1981												1982										Total over the period	Average of the period
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct		
Frost days																											
Ice days																											
Average RH																											
Time RH >80%																											
Amount rain (mm)																											
Duration of rain																											
Rain days																											
Wet days																											
Snow/sleet days																											
Hail																											

APPENDIX 2

EXPLORATORY DATA ANALYSIS

Rolf Volden

Norwegian Computing Center

Different principal component analyses have been carried out on the data given in Table 3 and 4. The tool for these analyses has been the PRINCOMP procedure in the SAS program package (SAS USER´GUIDE 1982).

Principal component analysis is a multivariate technique very often used in exploratory data analysis for examining relationships among several quantitative variables in a given data set. The method is used for summarizing multivariate data or for detecting underlying structures in a data set. It can be used to cluster variables or data units (objects), or to reduce the number of variables in a regression.

Application of principal components is discussed by Cooley and Lohnes (1971) and Gnanadesikan (1977).

The first principal component analysis for the data in Table 3 and 4 showed that there were two outliers among the data units. The stations Texel (NL2) and Floda (S2) where therefore excluded from the data set for the next principal component analyses to remove the effects from these two outliers.

Texel was removed because the extreme chloride value of IRMA caused a dominating effect in the three most significant principal components. Floda was not extreme in a single variable, but since this station had the smallest or largest value for most of the variables, Floda was an outlier station in a multivariate sense.

The results of the final analysis for the sandstone based on the 22 remaining stations are shown i Table B1 and Figure B1. Table B1 tells us that the 3 most significant principal components explain approximately 76% of the variation in the data. The contributions from the components are respectively 28.8%, 25.4% and 21.8%, which are the ratios between the eigen values and the number of variables.

Table B1 also shows the linear relations between the variables and the principal components by a normalized loading matrix. The first principal component is essentially defined by the variables SOI, RD and OWS. Negative SOI values, positive RD or positive OWS values for station will give positive scores for the first principal component.

In the same way, the second principal component is mainly defined by CLI, OWS and RD, while the third component is defined from FD, NOI and CLI.

Figure B1 shows the different stations projected onto the axes defined by the first and second principal components. This score plot indicates 4 clusters or groups among the stations. The main group contains 15 stations which are characterized by negative scores or small positive scores on the second axis and scores around zero for the first axis. This group corresponds therefore essentially to smaller CLI, smaller RD or larger OWS values.

The other three groups seem in different ways to represent more extreme stations. Rome (I4) and the two stations in London (GB1 and GB2) are one group characterized by high amount of SO_2 and high weight loss. The second group is N1 and GB3 mostly effected by low SO_2, low weight loss and high number of rain days. GB3 is also affected by high amount of chloride. The third group is mainly affected by high chloride concentration, particularly NL3.

References:

SAS USER´S GUIDE: Statistics, 1982 Edition, SAS INSTITUTE INC., Box 8000, Cary, North Carolina 27511.

Cooley, W.W. and Lohnes, P.R. (1971) Multivariate Data Analysis, John Wiley & Sons, New York.

Gnanadesikan, R. (1977) Methods for Statistical Data Analysis of Multivariate Observations, John Wiley & Sons, New York.

Table B1: Results of the cluster analysis of sandstone with 22 data sets and 6 variables.

```
                              PRINCIPAL COMPONENT ANALYSIS

22 OBSERVATIONS
 6 VARIABLES


                                   SIMPLE STATISTICS

                  OWS          SOI          CLI          MOI          FD          RD

MEAN         -3.63182      59.8182      11.1909      4.91818     76.4091     302.545
ST DEV        1.91092      27.5174      11.1784      2.66112     63.7775      93.035


                                     CORRELATIONS

                OWS          SOI          CLI          MOI          FD          RD

OWS          1.0000      -0.6071      -0.2463       0.0545      0.0591     -0.1663
SOI         -0.6071       1.0000      -0.1854       0.0989     -0.0541     -0.3671
CLI         -0.2463      -0.1854       1.0000       0.2534     -0.2172      0.3539
MOI          0.0545       0.0989       0.2534       1.0000     -0.0184     -0.1433
FD           0.0591      -0.0541      -0.2172      -0.0184      1.0000      0.3916
RD          -0.1663      -0.3671       0.3539      -0.1433      0.3916      1.0000


                   EIGENVALUE     DIFFERENCE     PROPORTION     CUMULATIVE

        PRIN1         1.73013       0.207606       0.288356        0.28836
        PRIN2         1.52253       0.214532       0.253755        0.54211
        PRIN3         1.30800       0.317431       0.217999        0.76011
        PRIN4         0.99057       0.703901       0.165094        0.92520
        PRIN5         0.29665       0.124552       0.047777        0.97298
        PRIN6         0.16211        .             0.027019        1.00000


                                     EIGENVECTORS

                PRIN1          PRIN2          PRIN3          PRIN4          PRIN5          PRIN6

OWS       3  0.411198     2  -.586733       0.279936       0.120213       0.161173       0.606941
SOI       1  -.663978        0.135149       -.272758       0.172700       0.103784       0.647464
CLI          0.140354     1  0.611156    3  0.463753       -.093211       0.502603       0.141083
MOI          -.117614        0.123039    2  0.493415       0.778930       -.334801       -.093453
FD           0.313181        0.034210    1  -.571938       0.582994       0.459610       -.153492
RD        2  0.501776     3  0.497582       -.249317       -.023418       -.525980       0.400273
```

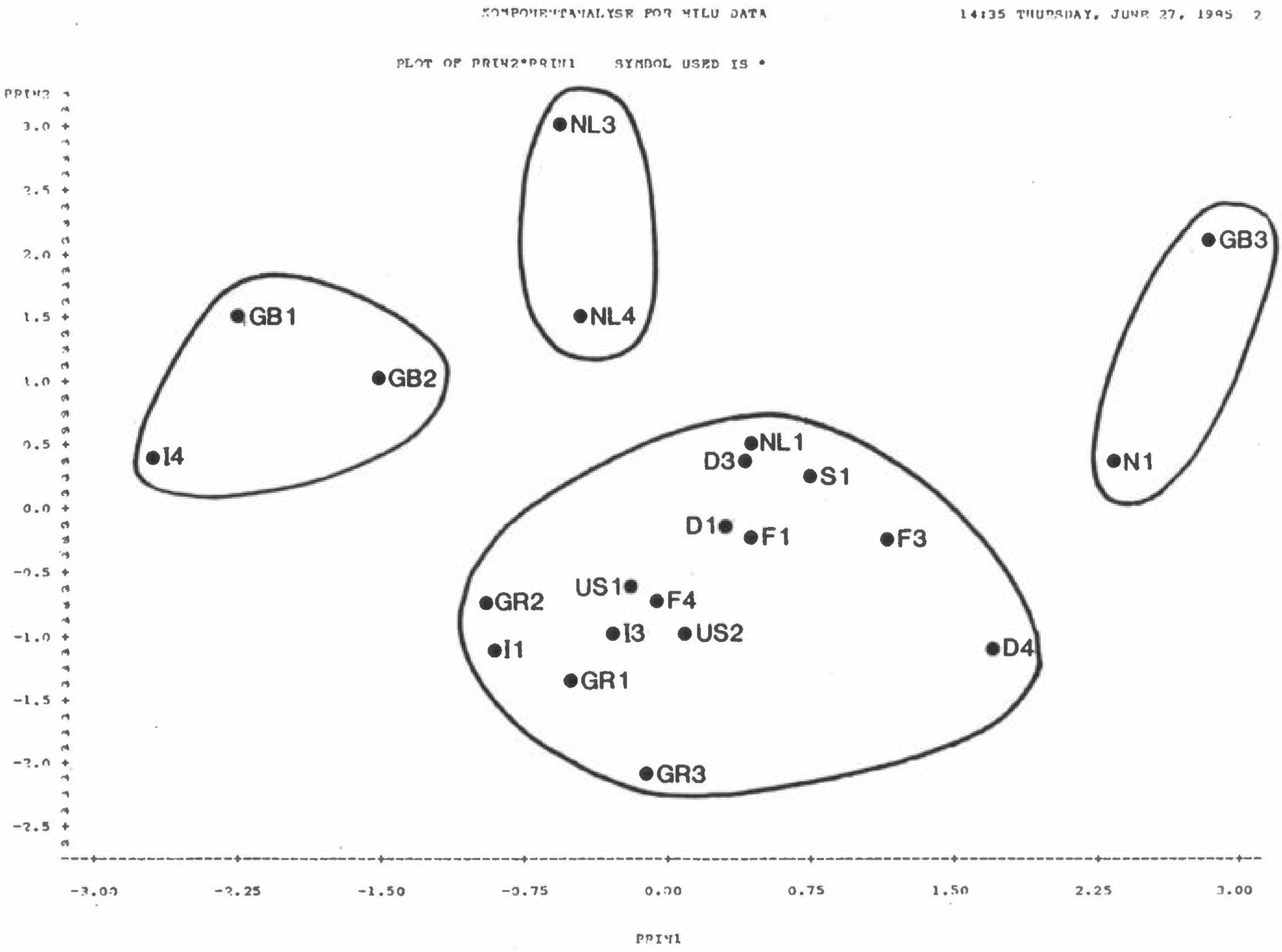

Figure B1: Cluster analyses of sandstone with principal component 1 and 2 as the axis.

NORSK INSTITUTT FOR LUFTFORSKNING (NILU)
NORWEGIAN INSTITUTE FOR AIR RESEARCH
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TITTEL
Conservation and restoration of monuments
Part B - Multiple regression analysis between deterioration of calcareous stones and environmental variables.

PROSJEKTLEDER
J. F. Henriksen

NILU PROSJEKT NR.
0-8068

FORFATTER(E)
J.F. Henriksen
S.E. Haagenrud
F. Gram

TILGJENGELIGHET
A

OPPDRAGSGIVERS REF.

OPPDRAGSGIVER (NAVN OG ADRESSE)
Miljøverndepartementet/
Riksantikvaren

3 STIKKORD (å maks. 20 anslag)

Stone deterioration	Regression analysis	Air pollution

REFERAT (maks. 300 anslag, 7 linjer)

Resultatene fra NATO/CCMS prosjektet "Restoration and preservation of monuments" er blitt statistisk behandlet for å finne fram til korrelasjoner mellom vekttap på stein og miljøparametrene. Den beste korrelasjonen for sandsteiner og kalksteiner ble funnet ved en kombinasjon av SO_2 og antall regndager.

TITLE

ABSTRACT (max. 300 characters, 7 lines)

The results from NATO/CCMS project "Restoration and preservation of monuments" have been statistically analysed for correlations between the weight loss of sandstone and limestone to environmental factors. The best correlations for weight loss found were with SO_2 deposition and number of raindays.

* Kategorier:	Åpen - kan bestilles fra NILU	A
	Må bestilles gjennom oppdragsgiver	B
	Kan ikke utleveres	C