FINAL REPORT

CONTRACT SPA 7103

Characterization of Hydrous Minerals in the Duluth Complex - Copper-Nickel Study Area

by

Paul W. Weiblen III

Robert J. Stevenson

March 31, 1978

TABLE OF CONTENTS

ABSTRACT

The immediate product and results of the hydrous mineral study fall into six categories: 1) A catalogued collection of 980 rock slabs, and ∿450 polished thin sections. 2) A catalogued collection of 1300 color and black and white photographs of the sawed rock slabs, thin sections, and hand samples. 3) Data from 360 petrographic determinations of minerals in the 450 thin sections. 4) 60 electron microprobe analyses of individual minerals in 20 representative polished thin sections. 5) A systematic and manipulable set of computer files of all the numerical data associated with categories 1-4. 6) A first-order analysis of the data available in categories 1-5 presented in this report. In addition, the material and information in the six categories above have provided a new basis for the following on-going studies of problems associated with copper-nickel mineralization in the Duluth Complex: A) The relationships between asbestiform and nonasbestiform amphibole in the hydrous mineral occurrences. B) The relationship between structure and copper-nickel mineralization. C) The emplacement and cooling history of individual intrusions. D) The nature and extent of reaction between the contact (and included) rocks and the Duluth Complex magmas.

INTRODUCTION

Although initiated to provide the first systematic analysis of hydrous minerals in rocks from the Duluth Complex, the Hydrous Mineral study (Contract SPA#7103) evolved into a major sample collection activity. This was a result of the fact that AMAX Shaft sample (1250 rock samples from 174 rounds and 225 rock slabs) became available during the course of the study. In the view of the principal investigator, preservation of this sample is a landmark in the on-going studies of the Duluth Complex. It provides a unique 500 meter vertical section of gabbro. Because of the coarse average grain size of the gabbro and centimeter to meter scale mineralogic and textural variations (Weiblen & Cooper, 1977), drill core samples tend to be nonrepresentative whereas the 10 kilogram individual samples provide excellent material for combined bulk chemical, electron-microprobe, and petrographic analyses.

The AMAX Shaft samples will be stored in a permanent collection in The Mineral Resources Research Center at the University of Minnesota. The rock sample, sawed slab and polished thin section numbers have all been crossed referenced in the computer catalogue file (Appendices I and II). Thus these samples will be readily accessible for future studies. The initial visual inspection of the AMAX Shaft samples by Robert Stevenson during the course of cataloguing, slabbing, and sectioning of samples resulted in the discovery of the trace occurrences of distinctly asbestiform amphibole in the gabbro. Asbestiform amphibole has been shown to be associated with an increase in cancer occurrence (Zoltai; 1977).

The importance of the recognition of actual asbestiform amphibole in contrast to the more common bladed or massive textured amphibole in

the Duluth Complex rocks cannot be overemphasized. First of all, it has made it possible for Stevenson to direct his studies toward establishing objective criteria for recognizing this type of amphibole in air and water samples. Secondly, it establishes the nature of occurrence of this potentially hazardous mineral in mineralized rocks, and provides criteria for recognizing occurrences by visual examination of rock surfaces (This is discussed further in a separate section of this report). Finally, based on the total surface area of rock examined by Stevenson in the course of this study, it may be concluded that at the INCO, AMAX, U. S. Steel, and Dunka Pit localities the occurrence of visible asbestiform amphibole is rare (0.50 gms in 5×10^6 gms of gabbro) and associated with rare cm-sized cavities in mineralized rocks.

If the AMAX Shaft samples are representative, asbestiform amphibole occurs at levels of less than 0.1 parts per million by weight in mineralized parts of the Duluth Complex. As discussed below, major occurrences cannot be ruled out, but at least the criteria are available for monitoring this potential environmental hazard during any developmental or mining operation. This aspect of the hydrous mineral study is being pursued by Robert Stevenson in a PhD.thesis in the Department of Geology and Geophysics at the University of Minnesota and results will be made available as the thesis research progresses.

Along with the expanded role that collection and preservation of the AMAX sample assumed, a number of products and results in addition to characterization of hydrous minerals emerged during the course of this study. They may be conveniently categorized as follows:

1. A catalogued collection of rock samples, sawed rock slabs, and polished thin sections.

2. A catalogued collection of color and blackandwhite photographs of sawed rock slabs, thin sections, and hand samples

3. Data from petrographic examination of polished thin sections.

4. Data from electron microprobe analyses.

5. A set of systematic and manipulable computer files of the numerical data from categories 1-4 above.

6. A first-order analysis of the data available in categories 1-5 above.

Each of these categories will be discussed separately below. The new information on the Duluth Complex rocks sheds light on the following aspects of the on-going studies of the copper-nickel mineralization in the Duluth Complex:

A) The relationships between asbestiform and nonasbestiform amphibole in the hydrous mineral occurrences.

B) The relationship between structure and copper-nickel mineralization.

C) The emplacement and cooling history of individual intrusions.

D) The nature and extent of reaction between the contact (and included) rocks and the Duluth Complex magmas.

PRODUCTS AND RESULTS OF THE STUDY

1. Collection and cataloguing of rock samples, sawed slabs, and polished thin sections.

Procedures

Because of the apparent textural and mineralogic variation of Duluth Complex rocks on a centimeter to meter scale (Weiblen & Cooper, 1976) representative sampling has been a recurring problem in laboratory studies of Duluth Complex rocks. For this study random sampling techniques at selected sites was deemed the best procedure.

At the AMAX site, samples were selected from the shaft round samples (a waste pile from a 2 meter thick section of the 4 meter diameter shaft) by throwing a looped rope on the waste pile. An approximately 18 kgm sample set which consisted of 1-10 blast fragments was collected from each round. Samples were collected by the Dept. of Natural Resources (DNR) and delivered to the University of Minnesota.

At the Dunka Pit site samples of similar size to the AMAX shaft samples were collected by DNR. A visual selection of unmineralized gabbro was made for one set of samples (DP9001) and mineralized samples for another set (DP9002).

The U.S. Steel sample set consists of samples of similar size to the AMAX samples. The samples were collected by DNR from the U.S. Steel mill sample.

The INCO Pit sample set was taken from a minus three mesh (1-2 cm-sized fragments) fraction of the INCO mill sample obtained by the Mineral Resources Research Center at the University of Minnesota.

Each individual sample fragment was visually examined by Bob

Stevenson. Features such as contacts between coarse and fine grained rock types or major changes in mineral proportions were noted and slabs were cut of representative sample fragments. The approximately one centimeter thick sawed slabs were numbered and examined visually to select representative areas for diamond drill coring for thin sections. One inch diameter thin sections were made from cores of the different rock types noted in the initial examination.

Product

The unused rock samples and the 980 rock slabs, at the date of submission of this report, are stored in the sub basement of Pillsbury Hall at The University of Minnesota. Arrangements have been made for permanent storage at The Mineral Resources Research Center (MRRC) at the University. The 450 polished thin sections are presently in use in The Electron Microprobe Laboratory in the Microscopy Center in The Space Science Center at the University of Minnesota and will also be permanently stored with the rock slabs.

A sample computer printout of cross-referenced rock samples, slabs and thin sections is presented in Appendix 1.

The sample, sawed slab and thin section numbers are cross referenced in the computer file listed in Appendix 1.

2. Photography of Sawed Rock Slabs.

Procedure

The sawed rock slabs were photographed under water with a 35 mm camera before thin section cores were removed to provide a permanent record of the textural relations of individual thin sections to the textures apparent on the larger (generally 5-20 cm-sized) rock slabs.

Fig. 2-1. Examples of AX9001-lean ore

A. Slab photograph of average lean ore.

B. Slab photograph of average lean ore.

C. Slab photograph of average lean ore with chlorite veins.

Fig. 2-2. Examples of US9001 disseminated ore.

A. Slab photograph of average ore, note gram-size variation.

B. Slab photograph of average ore, note gram-size variation.

C. Detail of (B).

Fig. 2-3. Examples of AX9002 upper shaft disseminated ore.

A. Slab photograph of average ore.

B. Detail of (A).

C. Slab photograph of highly altered average ore.

Fig. 2-4. Examples of AX9003 lower shaft disseminated ore.

A. Slab photograph of average ore.

B. Slab photograph of average ore.

C. Detail of (B).

Fig. 2-5. Examples of AX9005 disseminated ore from A drift.

A. Slab photograph of average picrite (inclusion?)

B. Slab photograph of average gabbro.

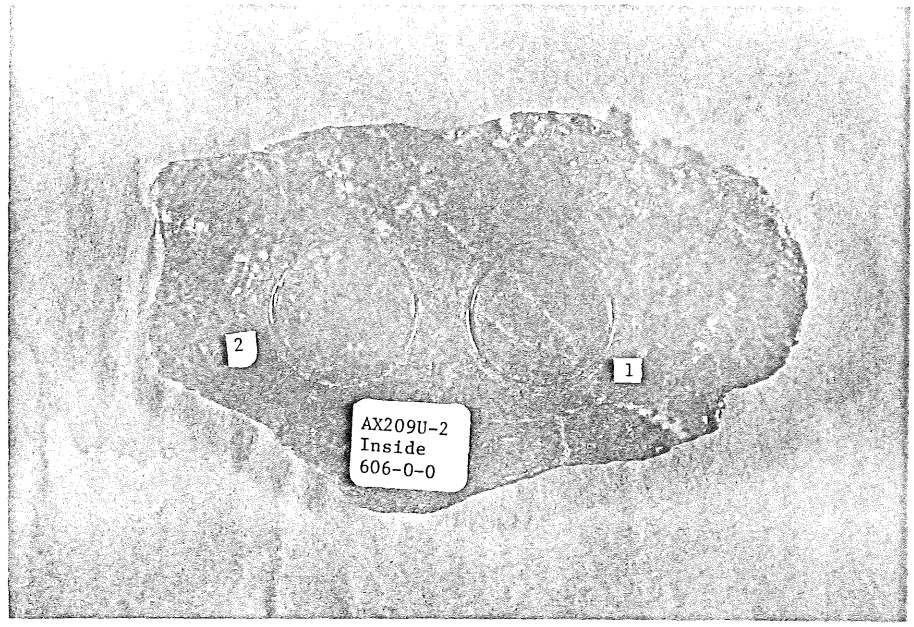
C. Detail of (B).

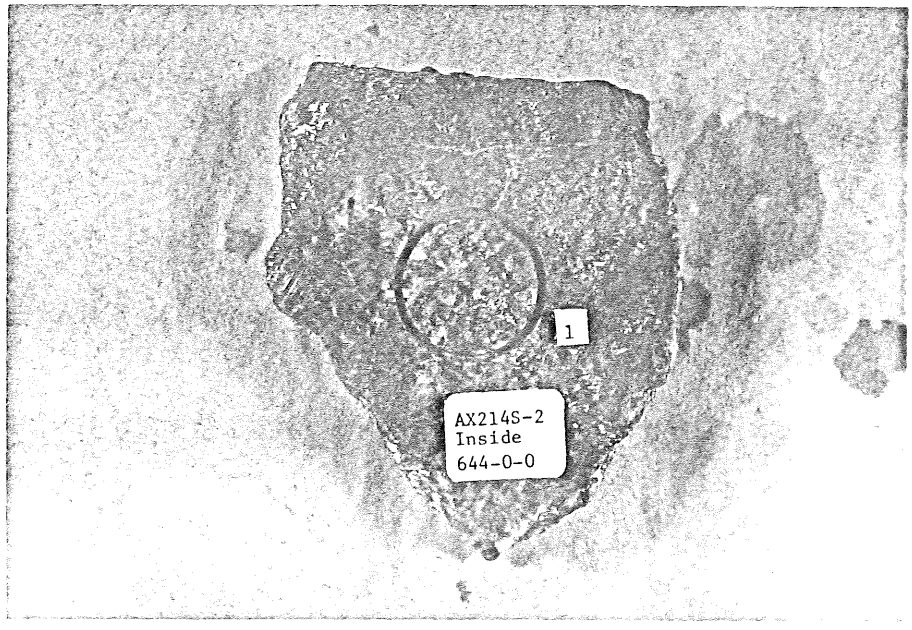
Fig. 2-6. Examples of DP9002 disseminated ore from Erie pit.

A. Slab photograph of average ore.

B. Slab photograph of average ore.

C. Detail of (B).


2
1
AX209U-2
Inside
606-0-0


1
AX214S-2
Inside
644-0-0

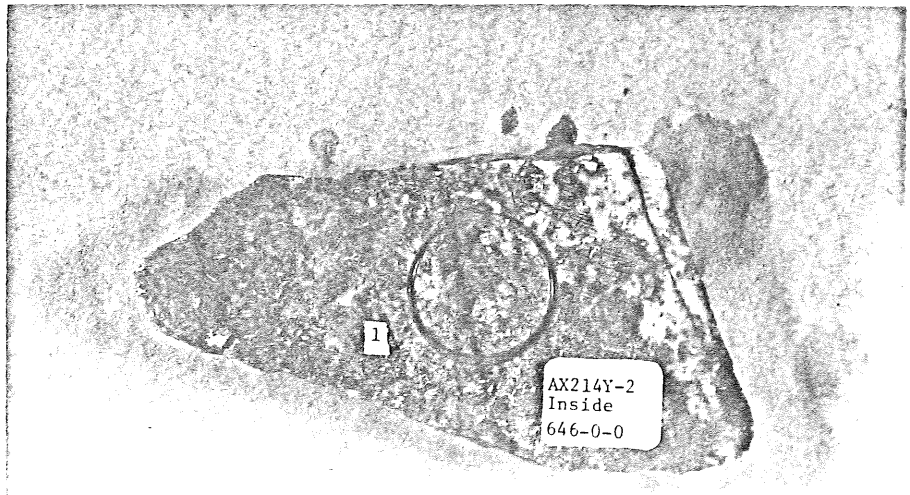
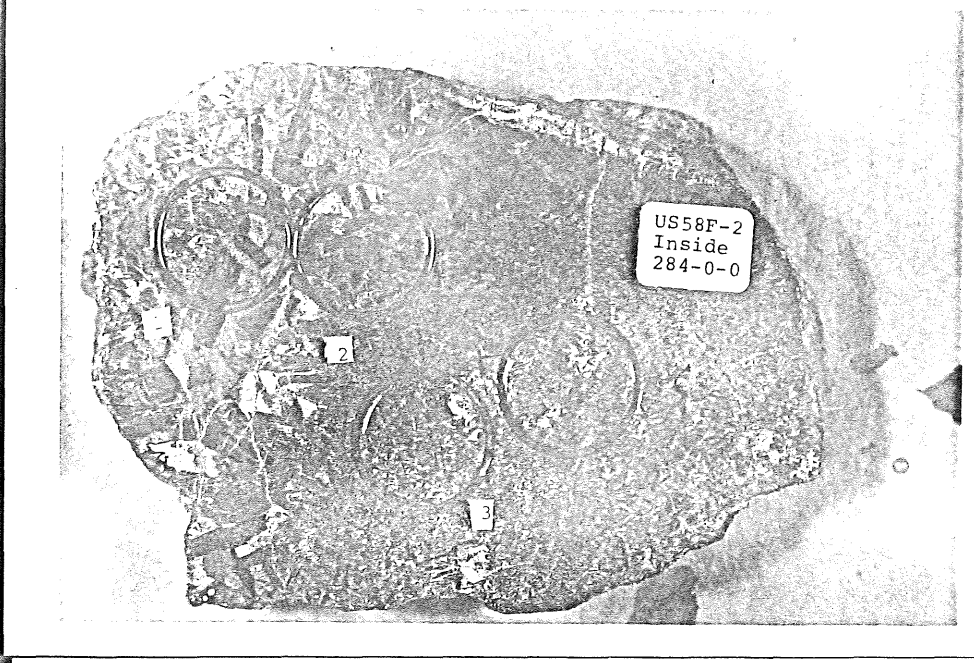
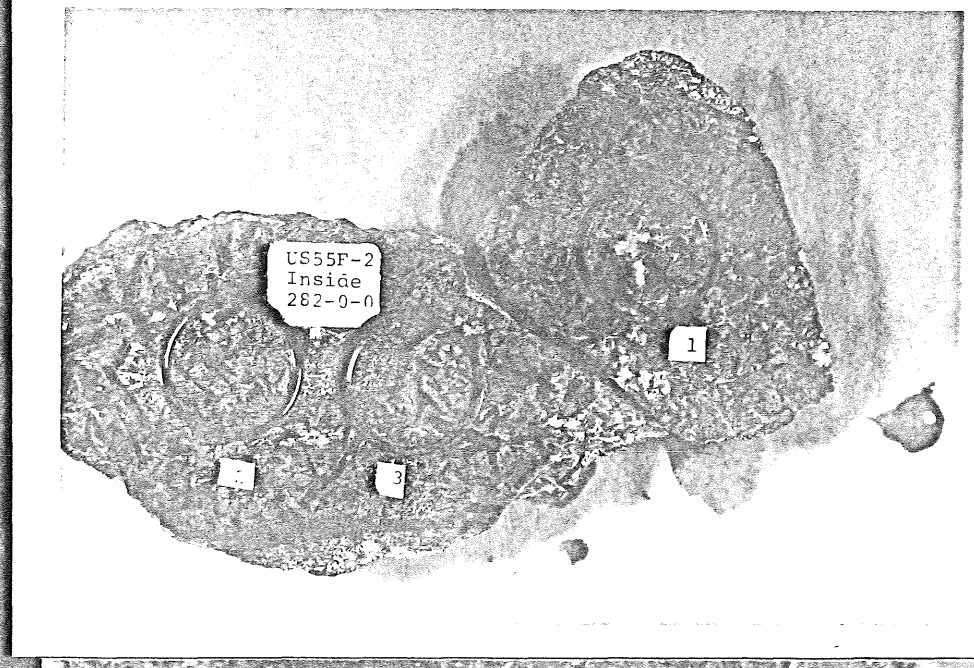

1
AX214Y-2
Inside
646-0-0

Fig 4

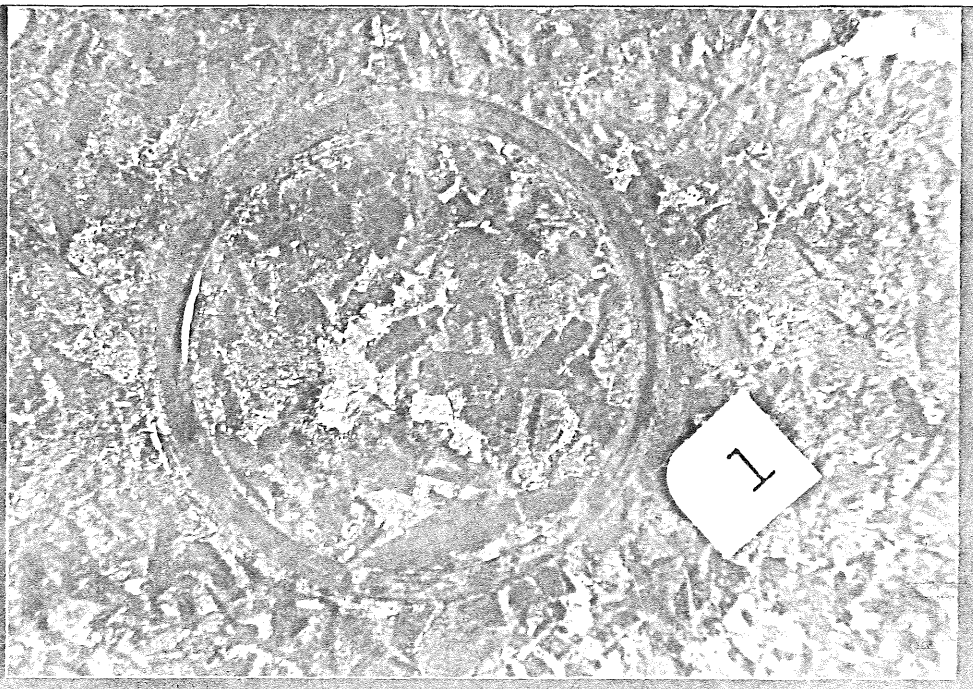
US9001



A



B

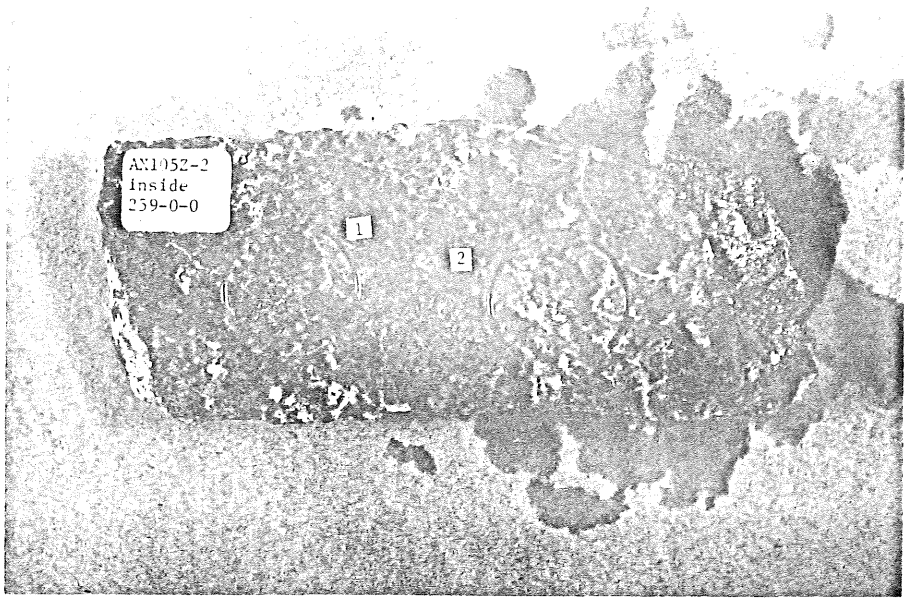


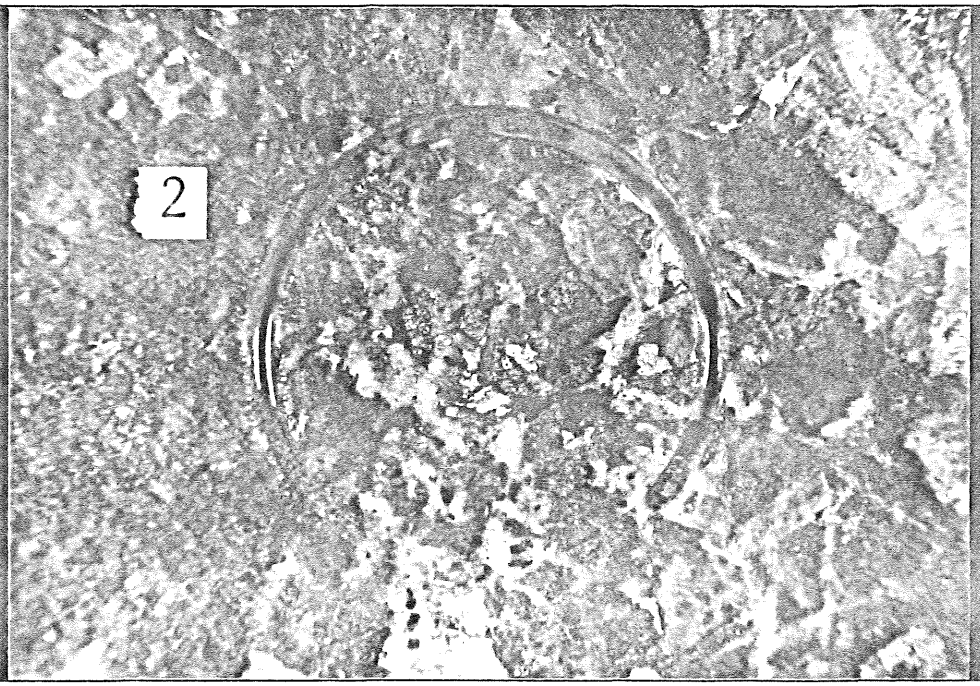
C

Fig 5

AX1007

A





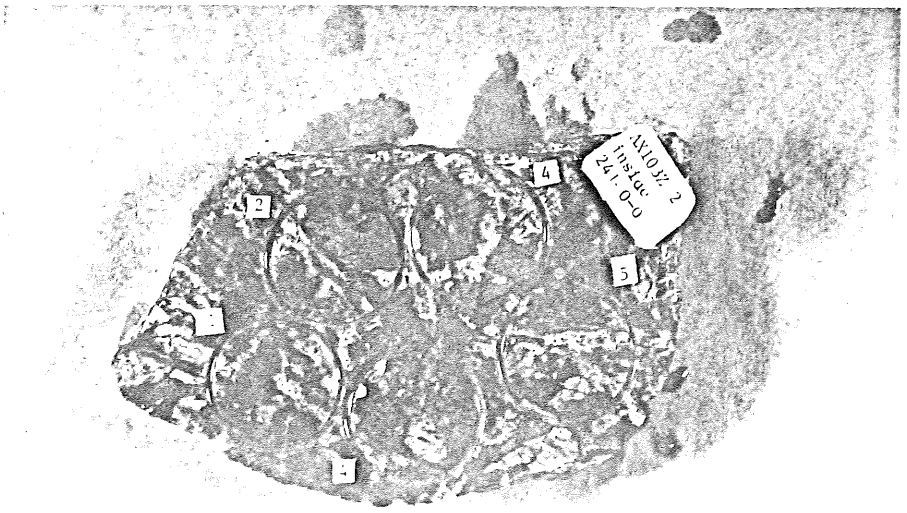
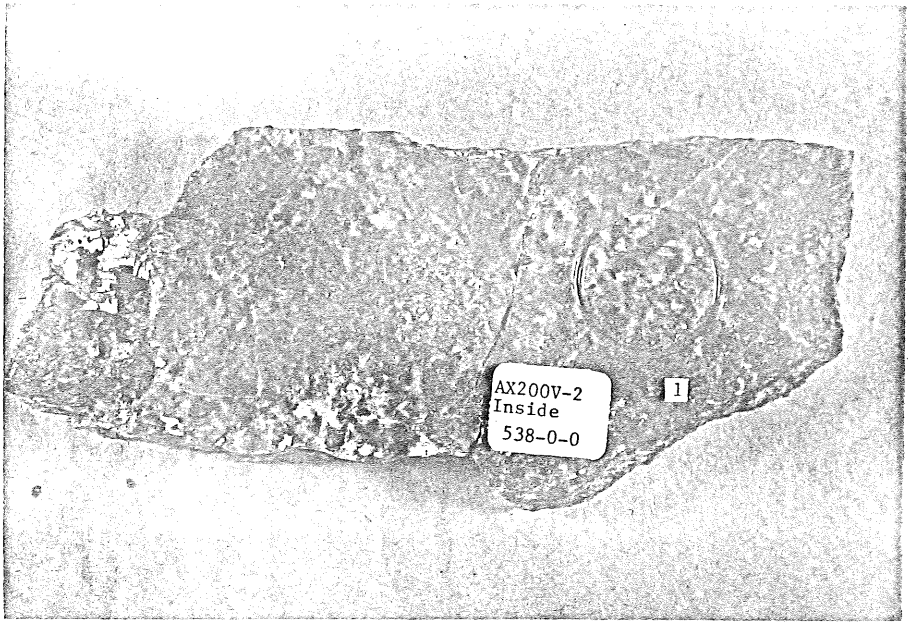
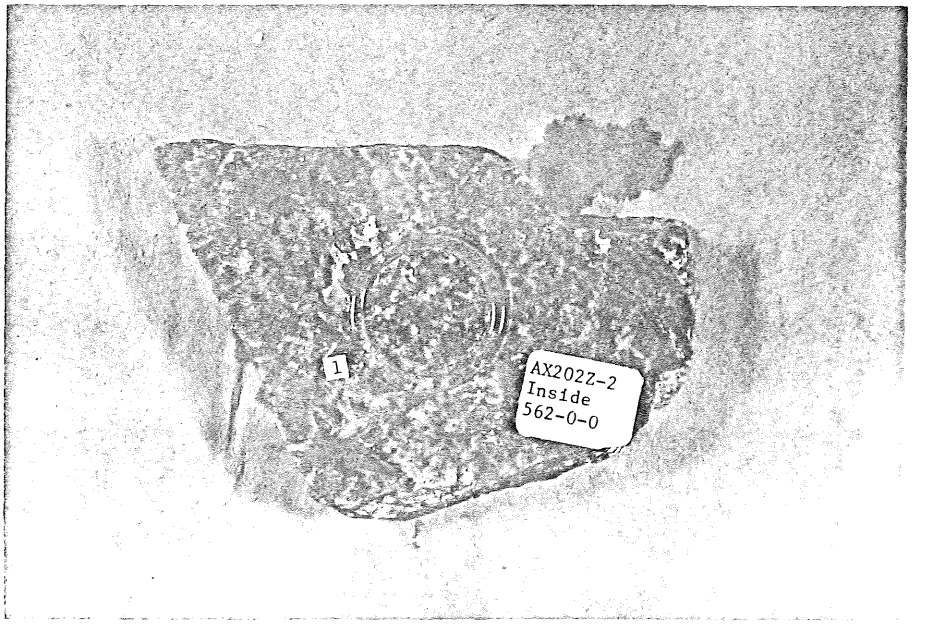


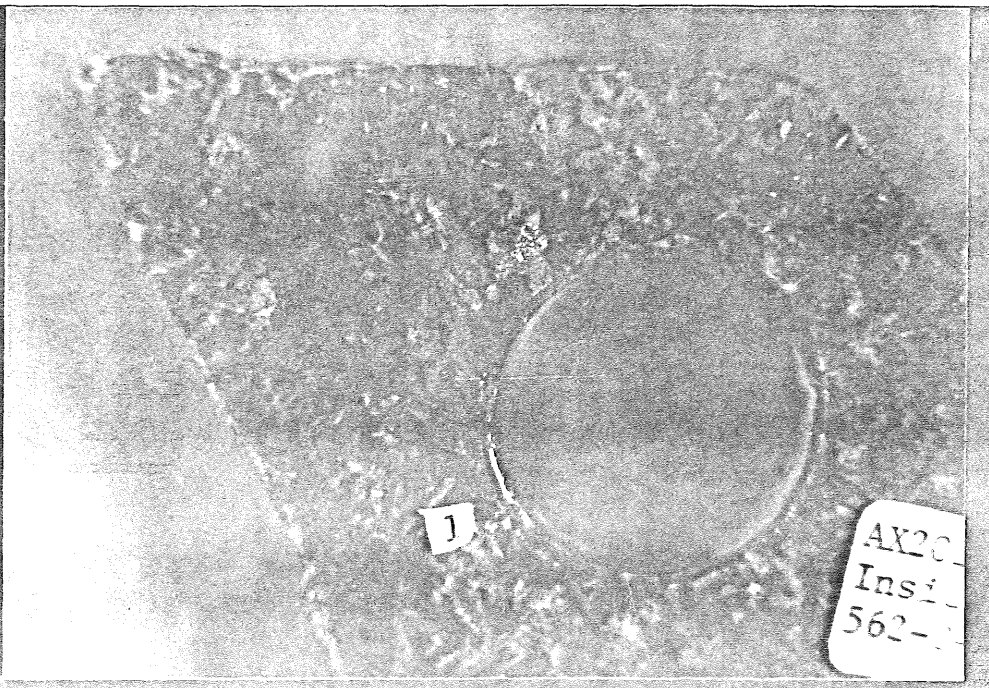
Fig 6
AX-5-3



A



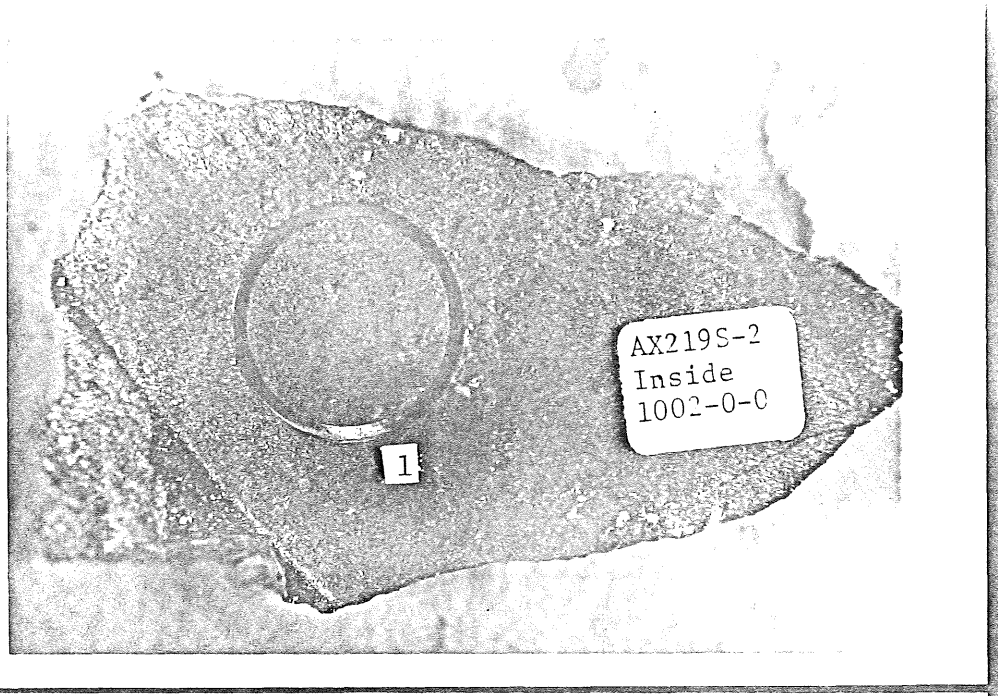
B



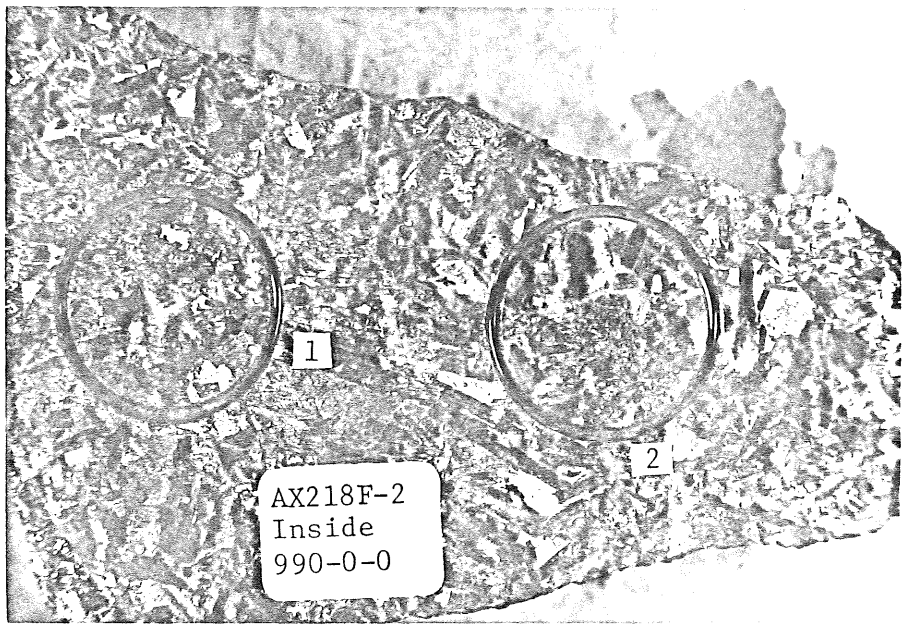
C

Fig 7

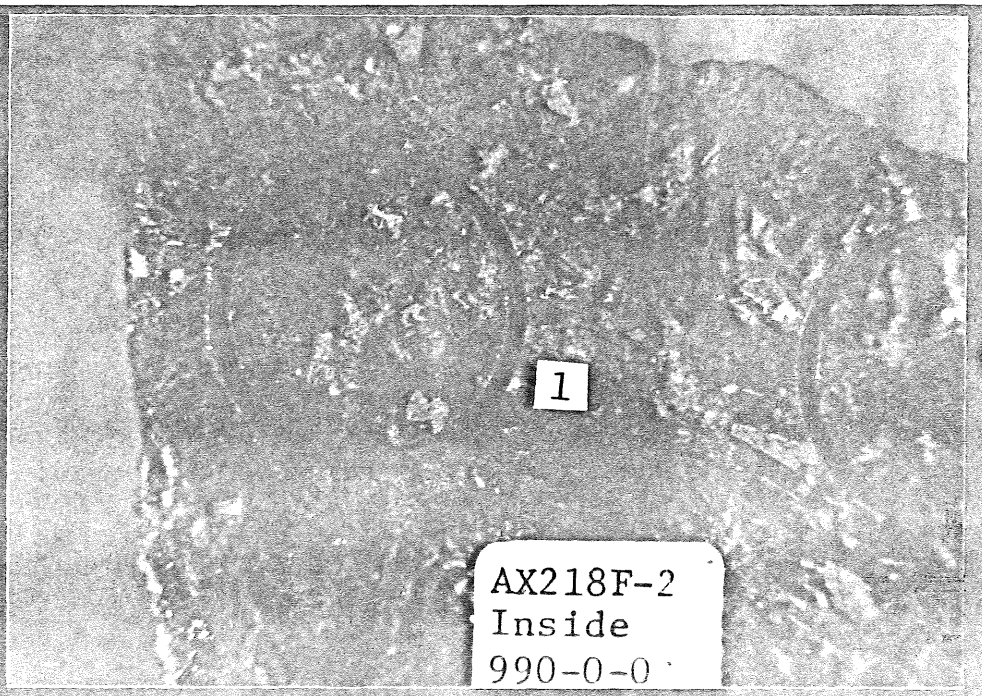
AX9005



A

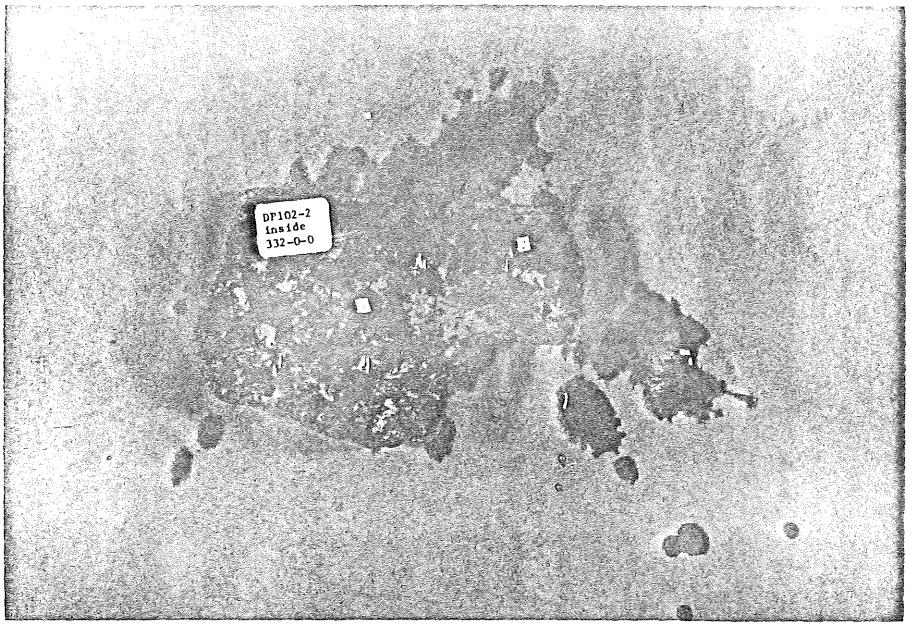


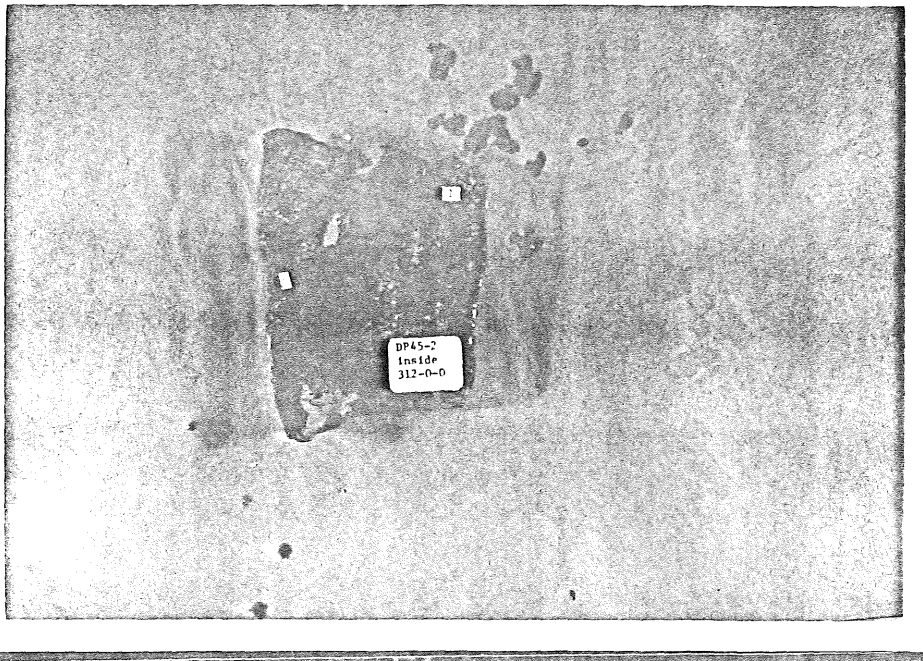
B



C

Fig 8


DP102-2
inside
332-0-0


DP45-2
inside
312-0-0

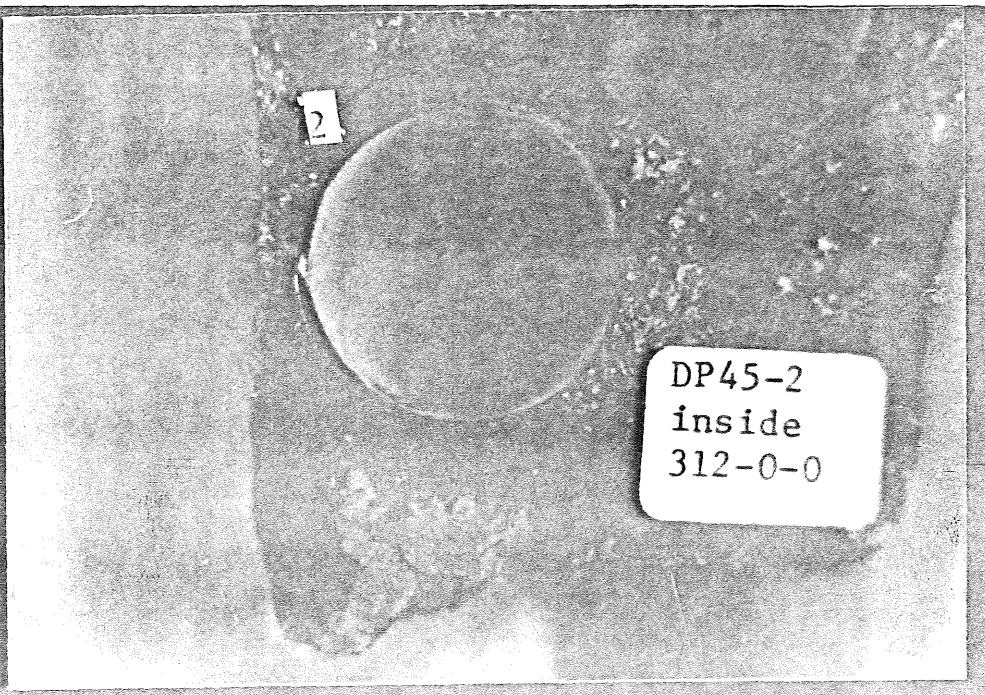

2
DP45-2
inside
312-0-0

Fig 9

IP9003

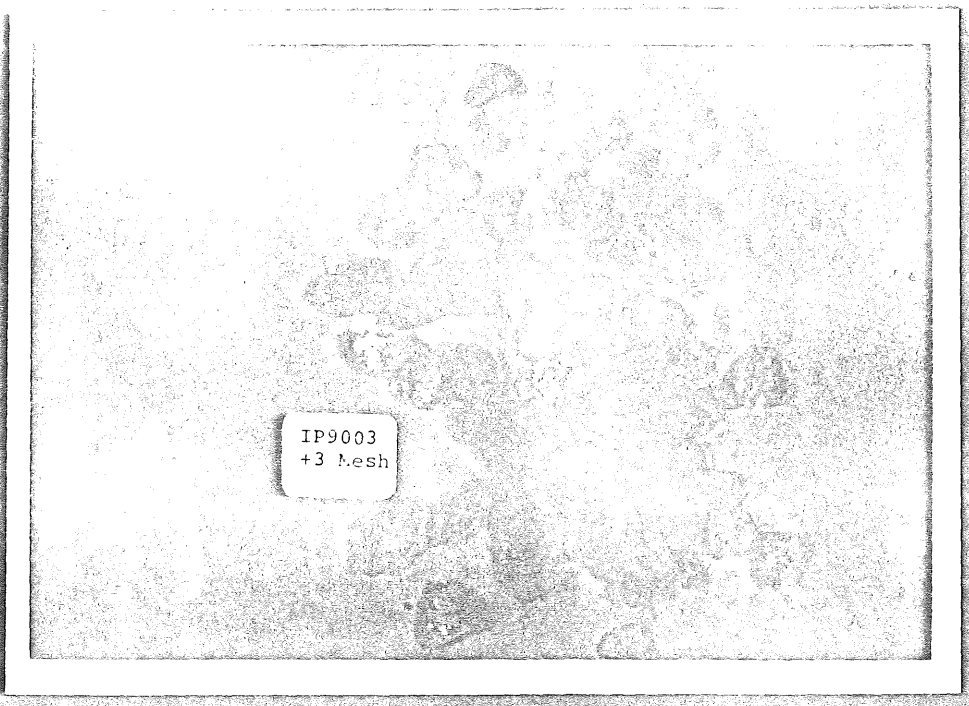


Fig. 2-7. Example of IP9003 disseminated ore from Maturi shaft.

Fig. 2-8. Examples of AX9004 semi-massive ore from A drift.

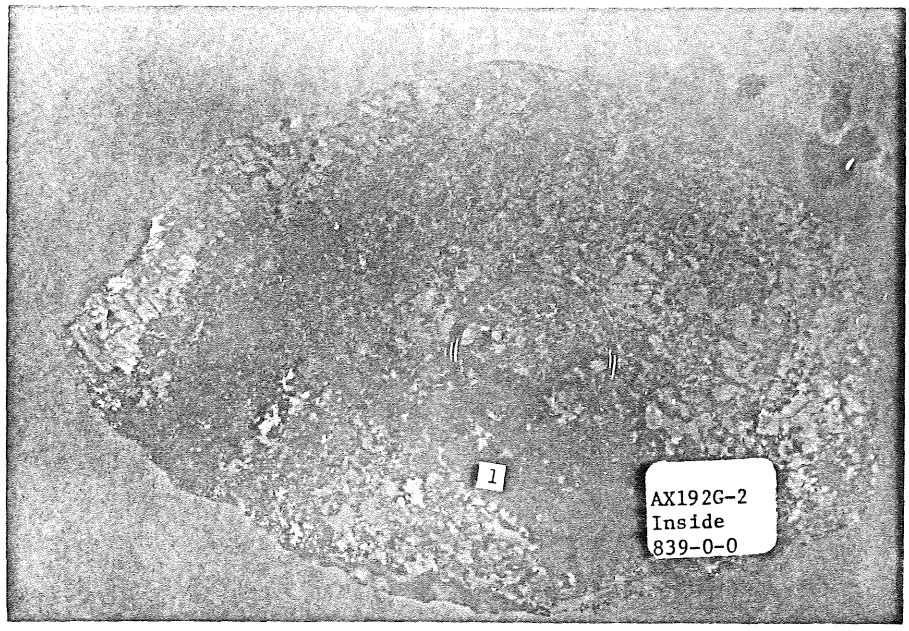
A. Slab photograph of average ore.

B. Slab photograph of high sulfide gabbro.

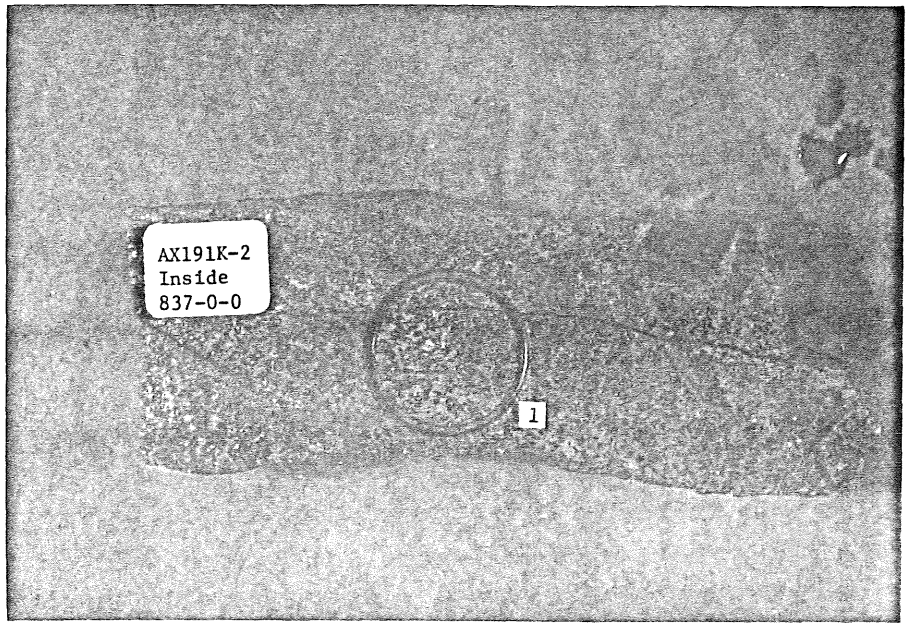
C. Slab photograph of mineralized hornfels.

Fig 10

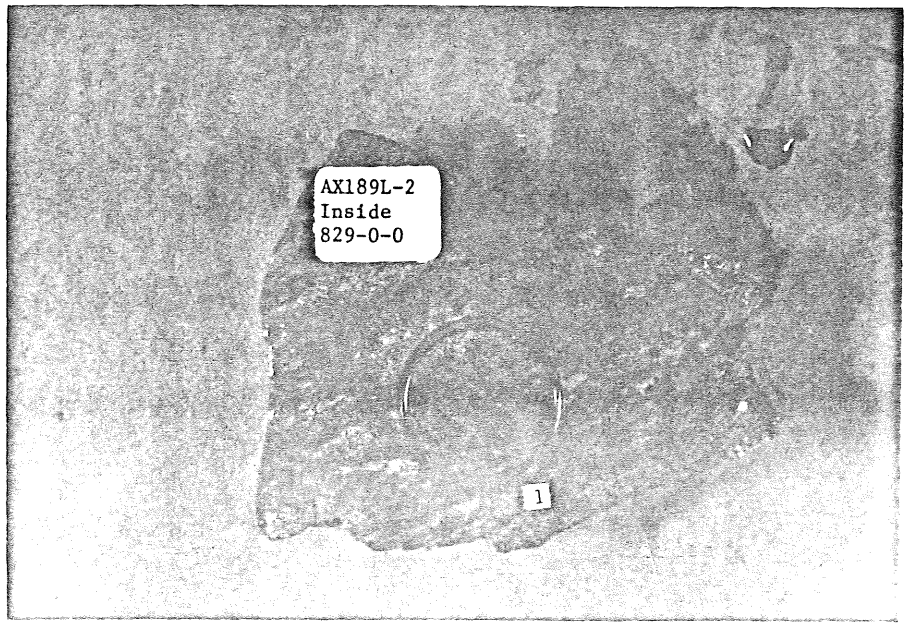
AX9J04



A



B



C

Product

The 1300 color and black and white photographs of rock slabs along with notes on visual mineralogic identification and textural classification referred to in the previous section will be outlined with the permanent rock sample collection in MRRC. Examples of typical textures from eight sample sets are illustrated in Fig. 2-1,8.

A sample computer printout of cross-referenced listings of rock slab, thin section, and Scanning Electron Microscope photographs is presented in Appendix 2. The cross-referenced catalogue of photographs and the associated computer file is listed in Appendix II.

3. Petrographic Examination of Polished Thin Sections.

Procedures

Preparation of polished thin sections for petrographic analysis consisted of surfacing 25-30 individual one inch cores at a time from the rock slabs on a vibratory lap down to 1000 mesh. Cores were cemented with epoxy on one inch diameter glass discs. Cores were then cut on a diamond saw and the sections were thinned to 40 micrometers. The sections were then thinned by hand to the standard 30 micrometer thin section thickness. The sections were then polished to a one micrometer surface on a rotary lap with one micrometer diamond paste on a Buehler micromet lapping material.

Optical examination of the polished thin sections was made on a Leitz petrographic microscope. Optical identification of transparent minerals was made using the optical properties of index of refraction, extinction, birefringence, optic axis angle for biaxial minerals, and optic sign. One hundred to a thousand point identifications (counts) of

minerals were made on 0.5 to 1.5 cm. square grids on each polished thin section. These data are presented and cross referenced in Appendix III. The point count data provides data on relative mineral proportions by area. Assuming that the minerals are uniformily and isotropically distributed, the data also give directly the volume (modal) proportions (modes) of the minerals. Because of the small scale variations of mineralogy and textures (Weiblen and Cooper, 1977) associated with the processes of melt/crystal segregation discussed in section 6 below this assumption is not very good for gabbroic rocks. However initial selection of thin section cores was made to obtain representative sections of the rock slabs in each set of sections from the rock slabs.

Results

Optical determinations from the point counting as well as reconnaissance examination of the 450 polished thin sections resulted in the identification of the following hydrous minerals:

A) Sericite - a fine-grained (1-5 micrometer) intergrowth of muscovite in plagioclase. This type of hydrous alteration of plagioclase is ubiquitious in rocks containing plagioclase which have reacted with water or fluorine. A reaction of the following type may be involved:

$(CaAl_2Si_2O_8 - NaAlSi_3O_8)$ $(CaAl_2Si_2O_8 - NaAlSi_3O_8)$
Plagioclase + water = plagioclase + muscovite + quartz + ions
(K bearing) (K free)

$3KAlSi_3O_8 + H_2O \rightleftharpoons KAl_3Si_3O_{10}(OH)_2 + 2K^+ + OH^- + 6SiO_2$

B) Mafic Amphibole - Hornblende is the most common variety of this mineral group in the Duluth Complex rocks. It occurs intergrown with plagioclase, clinopryoxene, sulfides and oxides. It is

possible to form hornblende from olivine, orthopyroxene, or plagioclase and clinopyroxene (plus or minus iron-titanium oxides) and water at temperatures in the range of 200° C up to magmatic temperatures of about 1000°C. The hornblende may have formed therefore by direct crystallization from the magma or by sub solidus reaction. An illustrative sub solidus reaction may be written as follows:

Magnetite+Ca-plagioclase + clinopyroxene + water =

hornblende + Na-plagioclase

$$Fe_3O_4 + NaAlSi_3O_8 + 2Ca(Fe,Mg)Si_2O_6 + H_2O \rightleftharpoons NaCa_2(Fe,Mg)_5AlSi_7O_{22}(OH)_2 + \tfrac{1}{2}O_2$$

Actinolite-This amphibole is associated with clinopyroxene and hornblende in altered rocks and may have formed by the following reaction:

Clinopyroxene + water + CO = Actinolite + calcite + quartz

$$5\,Ca(Fe,Mg)Si_2O_6 + H_2O + 3CO_2 \rightleftharpoons Ca_2(Fe,Mg)_5Si_8O_{22}(OH)_2 + 3\,CaCO_3 + 2SiO_2$$

Cummingtonite-Similar to the clinopyoxene-actinolite association, cummingtonite is found with olivine in altered rocks, which suggests the following reaction:

Olivine + Quartz + water = cummingtonite

$$7(Fe,Mg)_2SiO_4 + 9SiO_2 + 2H_2O \rightleftharpoons 2Fe_7Si_8O_{22}(OH)_2$$

It is interesting to note that in the last two reactions postulated above, formation of actinolite releases silica, whereas formation of cummingtonite requires additional silica. Actinolite is more common than cummingtonite (Appendix 3) which suggests that hydrous alteration of the mineralized rocks may have occurred with only the addition of water and did not involve any significant addition or loss of silica.

The three varieties of mafic amphibole described above have not been distinguished in the modal tabulation in Appenix 3, but the relative proportions are recorded in the original archived data.

C) Fibrous Amphibole - This occurrence of actinolite is described separately in Section A of this report.

D) Chlorite - This hydrous sheet silicate is found in reation relation

with olivine and plagioclase and other hydrous minerals. The former occurrence suggests the reaction:

CO_2 + H20 + Plagioclase + Olivine = Chlorite + calcite + quartz

$2CO_2 + 4H_2O + 2CaAl_2Si_2O_8 + 2(Fe,Mg)_2SiO_4 \rightleftharpoons (Fe,Mg)_4Al_4Si_2O_{10}(OH)_8 + 2CaCO_3 + 4SiO_2$

The actual chloritic material analyzed thus far is intermediate in composition between serpentine and chlorite (Appendix 4).

E) Serpentine - The occurrence of the high-magnesium variety of this hydrous silicate has not been confirmed thus far by electron microprobe analyses (Appendix 4). The occurrences listed in the modal data (Appendix 3), identified on the basis of optical properties may all be septachlorite (This identification problem is being pursued by Stevenson). Prior to this study, serpentine was considered a likely common hydrous mineral based on the possible reaction:

Olivine + water = Serpentine + iron oxides

$O_2 + 6(Mg,Fe)_2SiO_4 + 4H_2O \rightleftharpoons Mg_6Si_4O_{10}(OH)_8 + 2Fe_3O_4 + 2SiO_2$

F) Idingsite - This general term has been used for optically indeterminate hydrous alteration of olivine. Some refinement of this identification will be come from Stevenson's studies.

G) Talc - The occurrence of this hydrous silicate with olivine and serpentine may be related to introduction of CO_2 along with water in mineralized rocks or the specific temperature and pressure at which water reacted with olivine or orthopyroxene (Deer, Howie, and Zussman, 1966, p. 229). Introduction of CO_2 after formation of serpentine could form talc by the reaction:

CO_2 + Serpentine = talc + carbonate + water

$3CO_2 + Mg_6Si_4O_{10}(OH)_8 \rightleftharpoons Mg_3Si_4O_{10}(OH)_2 + 3MgCO_3 + 3H_2O$

H) Epidote - At least two varieties of this mineral group, common epidote and allanite (Appendix 3) occur along fractures in association with plagioclase. They could form by the hydration

and oxidation of plagioclase containing a small amount of iron in substitution for calcium (Appendix 4):

Oxygen + Fe bearing Ca-plagioclase + water = epidote

$$2\tfrac{1}{2}O_2 + 2(Ca,Fe)Al_2Si_2O_8 + H_2O \rightleftharpoons 2(Ca,Fe)(Al_2O)(Si_2O_7)(SiO_4)(OH)$$

In addition to the hydrous minerals listed above calcite, quartz, and cordierite were also indentified in the optical examination and point count studies of the polished thin sections. It will be noted from the reactions postulated above, that the amount of calcite and quartz may reflect the extent to which CO_2 and silica were introduced into contact zone rocks when hydration occurred. Cordierite is a common constituent of contact zone hornfels and occurs in association with hyperstene and plagioclase in rocks which were probably derived from Virginia Formation argillites (Renner, 1969). The cordierite may contain some water in its structure (Beltrame, 1977).

4. Electron Microprobe Analyses of Selected Minerals.

Procedures

Subsequent to the optical examination and point counting of individual polished thin sections, selected examples of typical textural occurrences of the major anhyrous silicate minerals, the different hydrous minerals, and sulfides were photographed in each polished thin section in preparation for electron microprobe analyses. Photomicrographs of the entire thin sections were also made for location purposes. These photographs are currently on file in the Electron Microscopy Center in the Space Science Center at the University of Minnesota. They will be made a part of the permanently archived data with the electron microprobe analyses and polished thin sections.

Electron microprobe analyses were made on an automated Model 400 Materials Analysis Company electron microprobe with operating conditions of 20 kilovolts electron beam voltage, .015 microamperes of beam current, and 20 second counting intervals on the peak of K alpha x-ray lines and 10 second counting intervals below and above the peak for background corrections. X-ray intensities corrected for background were reduced to chemical composition using mineral standards similar in composition to the material being analyzed..The procedure is described by Grant and Weiblen (1971). The specific standards used are listed in the archived data with the original intensity data.

Results

At the end of the Contract Period (January 31, 1978) 60

analyses for Si, Al, Fe, Mg, Ca, Na, K, Ti, P, Mn, and Cr were completed. Each analysis consists of at least three replicate analyses in the raw data for each element on each of the 60 mineral grains. The data are tabulated in Appendix 4. Analyses for olivine and plagioclase in the AMAX samples indicates a narrow range in Fe and Mg in olivine as has been found in previous analyses of the INCO Pit samples and elsewhere in the contact zone of the Complex (Weiblen and Morey, 1976). A wider but still restricted range of Ca and Na in plagioclase was found. The significance of this restricted variation and the exceptions are discussed in Section 6 of this report. Analyses of amphibole and biotite show a range of compositions similar to that found in the INCO Pit samples also (Weiblen and Morey, 1976).

The initial analyses of presumed septechlorite and serpentine are puzzling (Appendix 1). Further analyses are underway as a part of Stevenson's study and the ongoing analytical program of the Minnesota Geological Survey on Duluth Complex rocks.

5. Systematic and Manipulable Computer Files of Numerical Data.

Procedures

A sample numbering system outlined in Appendix 5 was devised by Stevenson to provide complete cross-referencing of all the data in the four categories above. Programs to handle the cross-referencing make use of aocompatible file system. The files may be accessed by batch processing input/output or on time-sharing terminals. The original data is preserved on archived computer cards.

Product

A copy of the each of the computer programs to enter, record, and manipulate the various data is presented in Appendix 5.

6. First Order Analysis of the Mineralogic Data

Collection of the data presented in Appendices 2 - 4 on the different types of hydrous minerals and their distribution in different samples was the prime objective of this study. However it is now possible to calculate bulk compositions of a large number of individual rock samples (Appendix 3), and this makes it possible to estimate the overall range and construct preliminary petrogenetic models for the variation in the mineralogy of mineralized rocks in the Duluth Complex. Such an exercise must be an iterative one because the quality and quantity of data determine in part the validity of the results and the results in turn affect the methods used in subsequent data collection. Based on the data obtained in this study it is now possible to attempt for the first time to realistically estimate the overall range of variation in mineralogy and construct constrained petrogenetic models for formation of the mineralized rocks in the basal zone of the Duluth Complex. This attempt is currently underway and will be published in a Symposium volume on sulfide mineralization in mafic rocks edited by T. Naldrett and to be published by the Geological Society of Canada in August, 1978.

A. Occurrence of Asbestiform Amphibole

The asbestiform amphibole found in an AMAX shaft sample (Round #144, 919 ft.) occurs in and adjacent to cavities (Fig. A1A). Calcite and prehnite are associated with the amphibole. Vermiculite, chlorite, biotite, plagiclase, and apatite are also present in the sample.

The asbestiform amphibole occurs as an epitaxial growth on bladed amphibole and both varieties are seen to be overgrown by and adjacent to calcite (Fig. A-1-B).

In hand speciman and thin section the asbestiform amphibole is white while the bladed variety is green (Fig.A-1C). Compositionally, (Fig. A-2). the green variety has more Al_2O_3 (10%) than the white asbestiform variety and thus it is a hornblende, while the other has a low (5%) Al_2O_3 content and it is an actinolite. MnO is also different between the two varieties, being higher in the white actinolite

The occurrence in cavities and association with calcite, provides explicit criteria for monitoring the occurrence of asbestiform amphibole in field, shaft, and any eventual mine wall exposure.

Fig. A-1.

A. Handsample AX42K showing amphibole association with calcite.

B. SEM view of calcite with asbestiform and nonasbestiform amphibole.

C. Transmitted light photograph of the epitaxial relations between green hornblende and white actinolite.

Fig. A-2.

A. Energy dispersive trace of white actinolite.

B. Energy dispersive trace of green hornblende.

Fig. A-1-A.

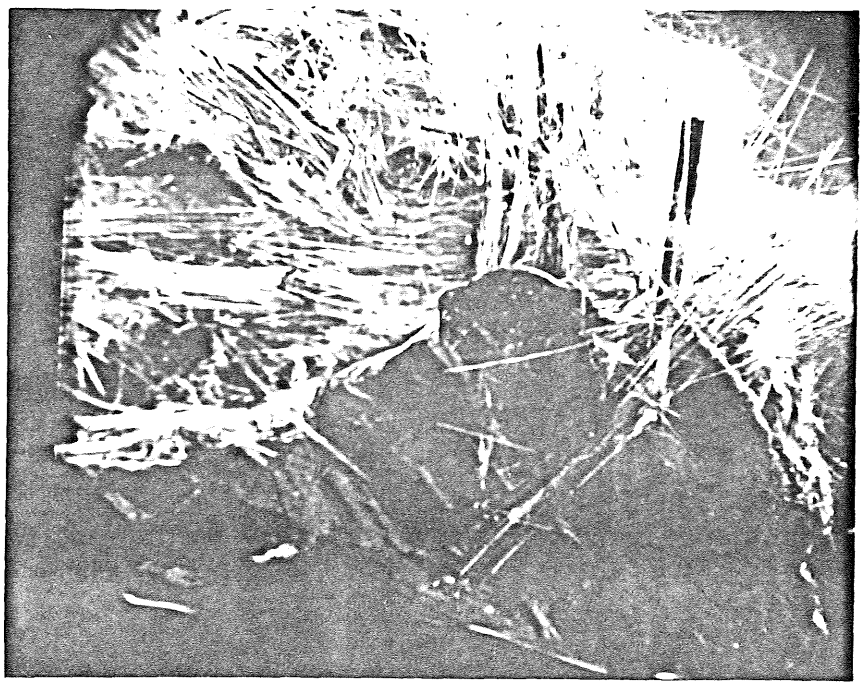


Fig. A-1-B

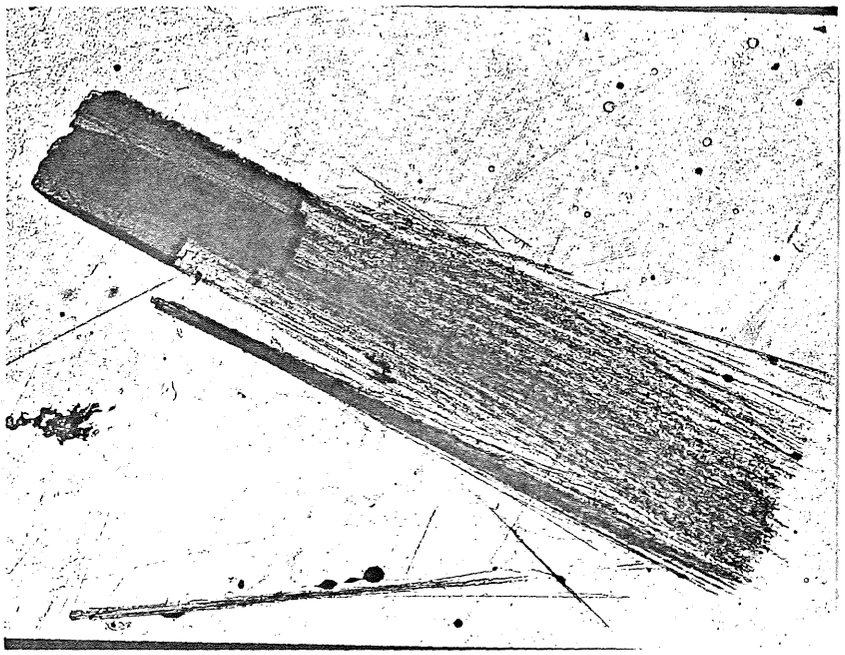
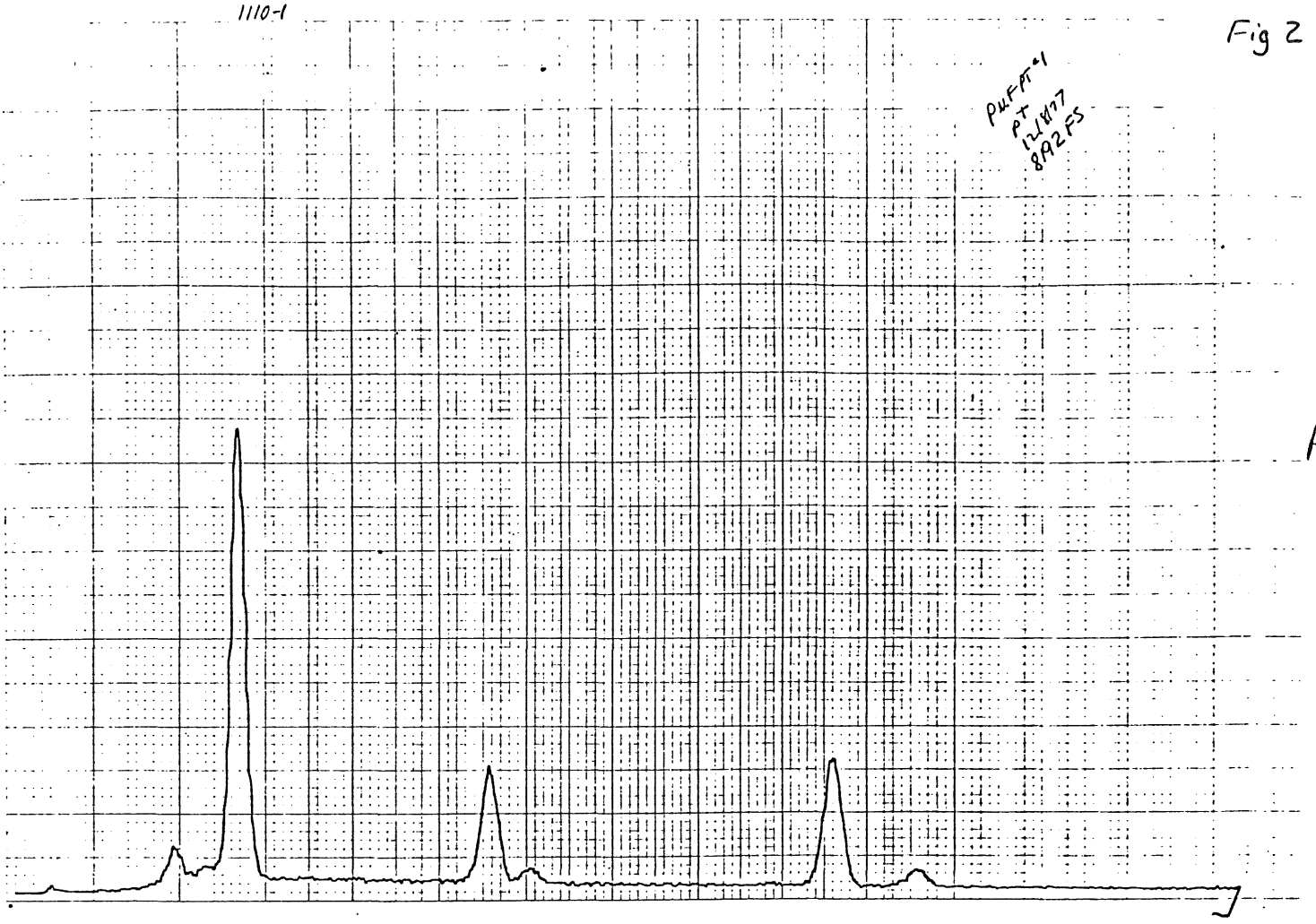
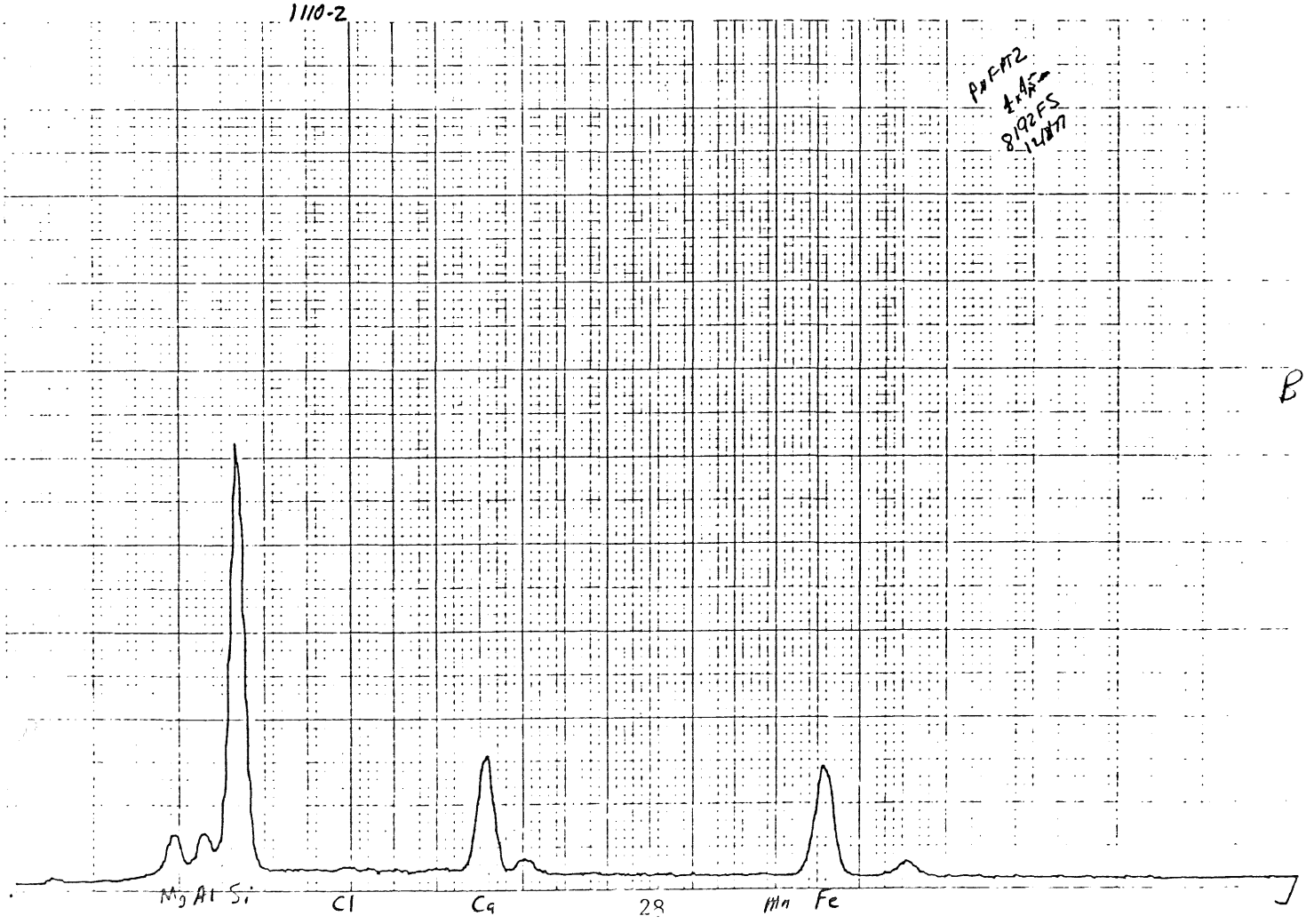


Fig. A-1-C.

Fig 2


1110-1
PWFPT-1
PT
14 MAY 77
8192 FS
A


1110-2
PWFPT2
8192 FS
14 MAY 77
B
Mg Al Si
Cl
Ca
28
Mn
Fe

B. Relationship between Structure and Copper-Nickel Mineralization.

A recently completed structural study of the Hoyt Lakes- Kawishiwi Area of the Duluth Complex by Cooper (1978),provides a basis for examining in detail the effect of faulting on mineralization. The modal data obtained in this study on hydrous mineralsabundance provides a data base for comparative studies of the relative abundance of hydrous minerals in rocks exposed in the vicinity of faults mapped or inferred by Cooper. Such studies will be needed to monitor the sources of amphibole in air and water samples and they will also add to our understanding of the relationship between hydrous alteration and copper-nickel mineralization.

C. The Emplacement and Cooling History of Individual Intrusions

As experimental calibration of the reactions postulated in Section 3 improves and the specific reactions can be better estimated from analyzed data and improved textural interpretations, it will be possible to estimate the temperatures and pressures at which the hydrous alteration occurred. This will help to answer the question whether the sulfide mineralization occurred independently of the hydrous alteration.

D. The nature and Extent of Reaction Between the Contact (and Included) Rocks and the Duluth Complex Magmas

The data obtained in this study is being used in part in a Masters Thesis study (Churchill, 1978) of the extent of equilibration of Duluth Complex rocks with an external source of oxygen.

CALCULATED BULK COMPOSITIONS BASED ON MODAL DATA
NORMALIZED TO THE SKAERGAARD CHILLED MARGIN COMPOSITION

Data from Appendices 3 and 4

760218

ALL OXIDES NORMALIZED TO THIS ANALYSIS

COPY OF INPUT CARD DATA TITLE/B(I)/Y(I)/X(I)

SAMPLE	SIO2	AL2O3	FEO	MGO	CAO	NA2O	K2O	TIO2	P2O5	MNO	CR2O3	CU	NI	FE	CO	S	C	H2O+	CO2	CL	F	TOTAL
SKIDROW-MAKAOPUH	48.08	17.22	9.63	8.62	11.38	2.37	.25	1.17	.10	.16	.02	.06	.10	.50	.03	.28	.01	.25	.01	.01	0	99.97
	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0	0

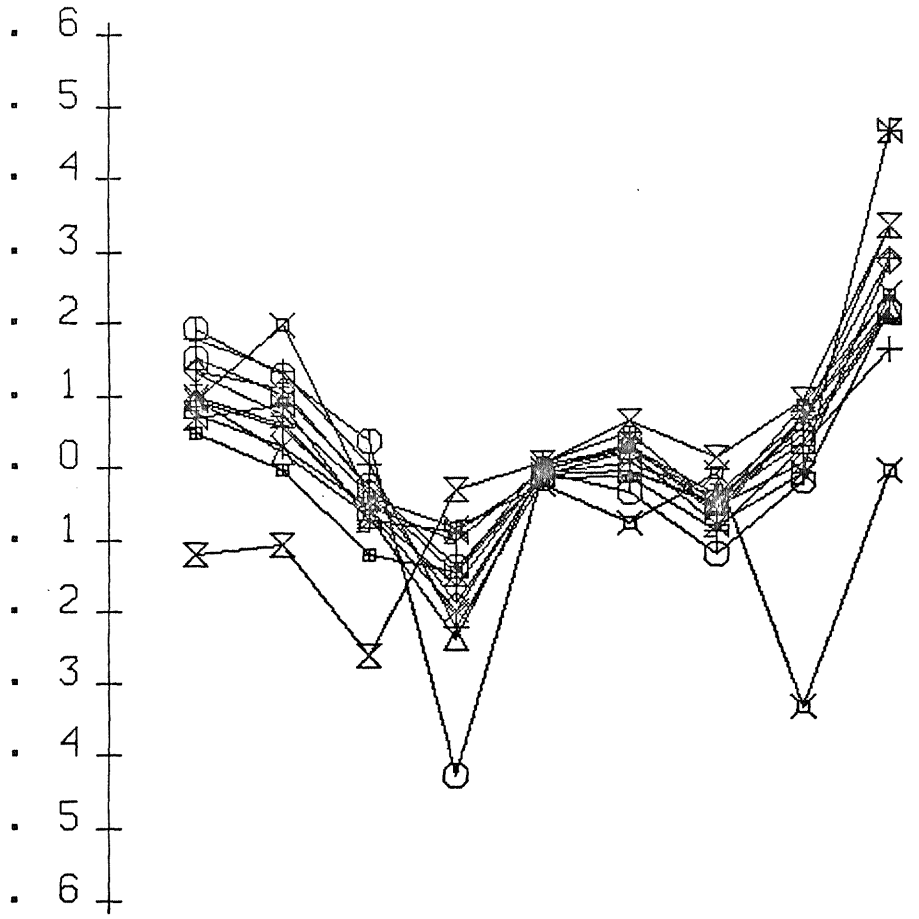
AMAX AVE. CAL. COMPOSISITONS

AX1AVE	44.99	17.11	14.05	6.12	9.78	2.63	.81	1.36	.04	.25	.03	.31	.04	1.18	0	.89	0	.39	.02	0	0	100.00
AX2AVE	44.44	18.08	13.82	6.36	8.52	2.73	.99	1.13	.06	.25	.02	.39	.03	1.52	0	1.12	.01	.46	.03	0	0	99.98
AX3AVE	42.03	15.06	18.32	7.60	8.04	2.03	.79	1.05	.07	.28	.02	.58	.09	1.77	.01	1.39	0	.87	.01	0	0	100.01
AX4AVE	37.48	13.76	9.92	5.95	5.71	1.97	.72	1.01	.05	.20	.02	1.23	.11	12.81	.04	8.55	.31	.15	0	0	0	99.99
AX5AVE	41.83	12.67	20.08	10.81	6.89	2.04	.57	1.08	.14	.35	.02	.54	.06	1.13	0	.95	0	.83	0	0	.01	100.00
DP1AVE	44.64	17.98	15.20	6.39	8.88	2.84	.92	1.55	.08	.25	.02	.05	.04	.46	0	.32	0	.36	.01	0	0	99.99
DP2AVE	43.18	13.00	13.63	7.84	10.70	2.15	.75	1.36	.03	.29	.06	.52	.20	3.53	.02	2.51	.02	.20	0	0	0	99.99
IP2AVE	44.91	18.95	12.63	6.01	8.61	2.90	.93	.53	.02	.23	.01	.58	.09	1.68	.01	1.33	0	.53	.04	0	0	99.99
IP3AVE	43.52	18.23	13.72	6.13	8.30	2.89	.69	.83	.01	.24	.01	.73	.04	2.38	.01	1.82	0	.42	.03	0	0	100.00
US1AVE	44.81	17.81	13.77	6.78	8.78	2.87	.84	.96	.03	.25	.02	.36	.08	1.32	.01	1.01	0	.30	0	0	0	100.00

RATIOS Z(I) =

SAMPLE	MN	FE	MG	TI	SI	AL	CA	NA	K	P	S	CU	NI	FM	CO	CR	OH	CO	CL	F	C	
AX1AVE	1.56	1.46	.71	1.16	.94	.99	.86	1.11	3.24	.40	3.24	4.92	.41	2.36	0	1.50	1.56	0	0	0	0	-0
AX2AVE	1.56	1.44	.74	.97	.92	1.05	.75	1.15	3.96	.60	4.08	6.19	.31	3.04	0	1.00	1.84	0	0	0	0	-0
AX3AVE	1.75	1.90	.88	.90	.87	.87	.71	.86	3.16	.70	5.05	9.21	.93	3.54	.36	1.00	3.48	.36	0	0	0	-0
AX4AVE	1.25	1.03	.69	.87	.78	.80	.50	.83	2.89	.50	31.19	19.59	1.14	25.70	1.43	1.00	.60	1.43	0	0	0	-0
AX5AVE	2.19	2.09	1.25	.92	.87	.74	.61	.86	2.28	1.40	3.45	8.57	.62	2.26	0	1.00	3.32	0	0	0	0	-0
DP1AVE	1.56	1.58	.74	1.33	.93	1.04	.78	1.20	3.68	.80	1.16	.79	.41	.92	0	1.00	1.44	0	0	0	0	-0
DP2AVE	1.81	1.42	.91	1.16	.90	.76	.94	.91	3.00	.30	9.13	8.26	2.07	7.06	.71	3.00	.80	.71	0	0	0	-0
IP2AVE	1.44	1.31	.70	.45	.93	1.10	.76	1.22	3.72	.20	4.84	9.21	.93	3.36	.36	.50	2.12	.36	0	0	0	-0
IP3AVE	1.50	1.43	.71	.71	.91	1.06	.73	1.22	2.76	.10	6.62	11.59	.41	4.76	.36	.50	1.68	.36	0	0	0	-0
US1AVE	1.56	1.43	.79	.82	.93	1.03	.77	1.21	3.36	.30	3.67	5.71	.83	2.64	.36	1.00	1.20	.36	0	0	0	-0

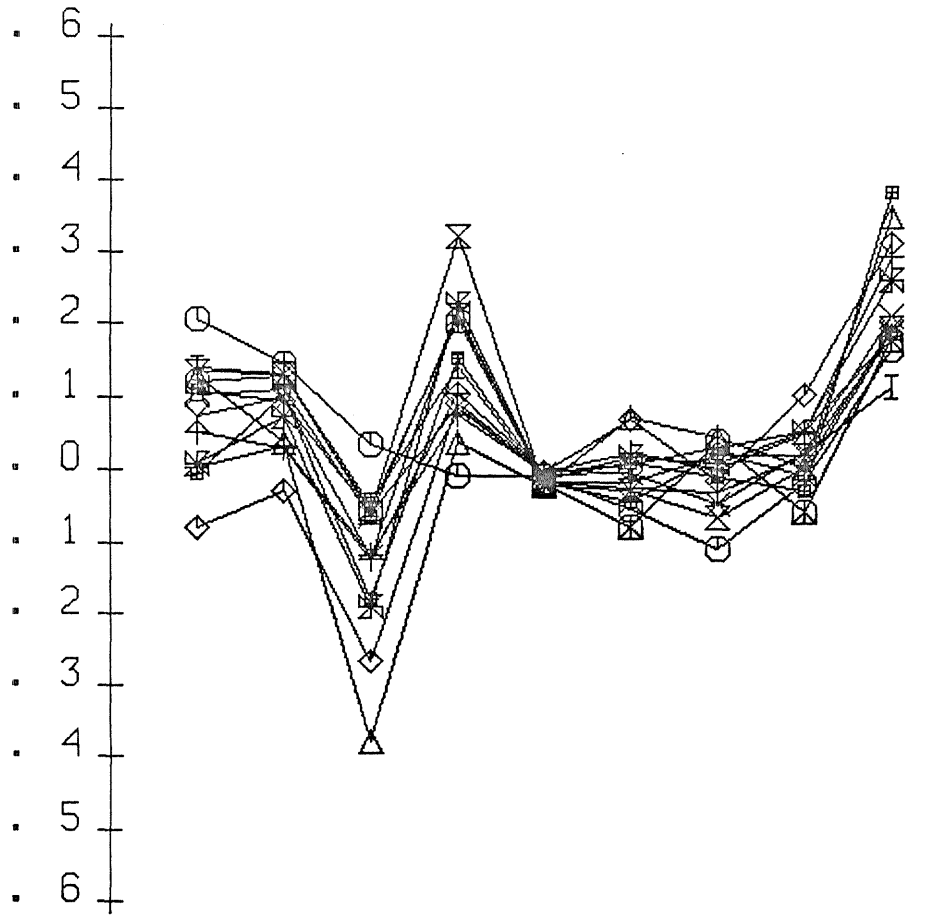
AMAX AX1 LEAN ORE CAL.



MN FE MG TI SI AL CA NA K

636 1
650 1
638 1
644 1
602 1
614 1
630 1
624 1
604 1
612 1
616 1
620 1
646 1

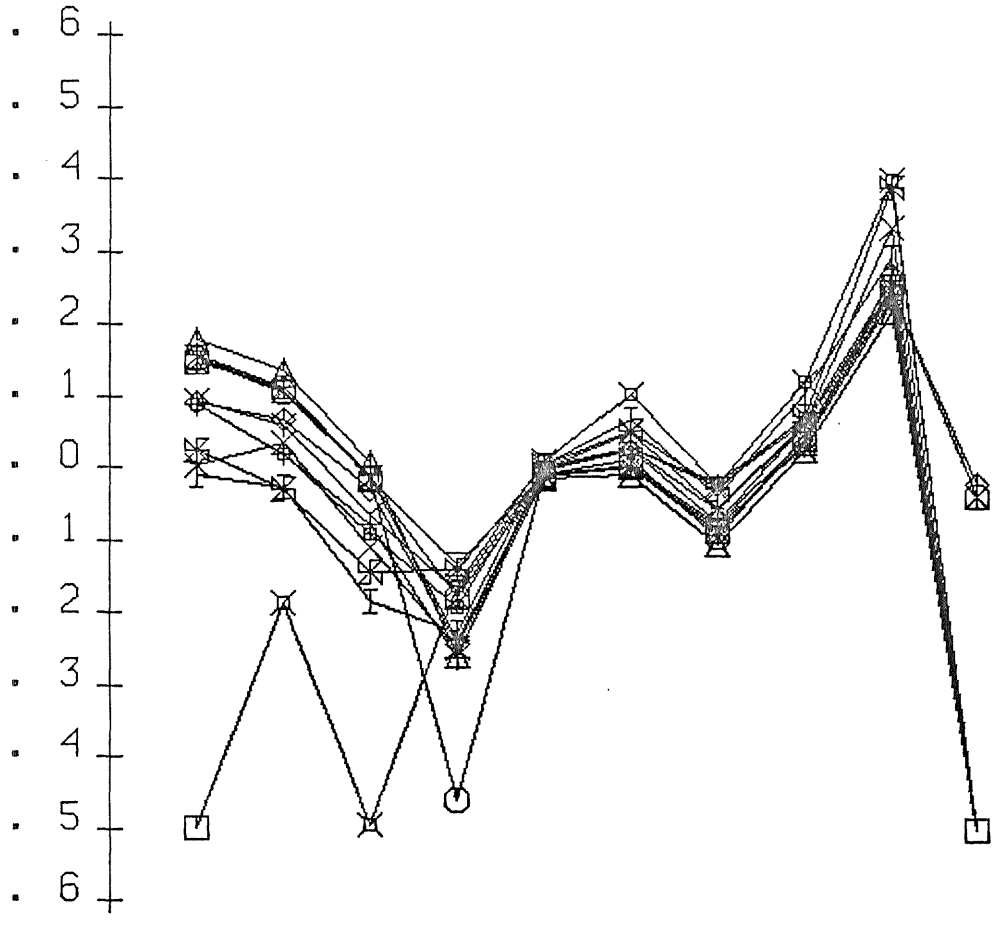
AMAX AX1 LEAN ORE CAL.



MN FE MG TI SI AL CA NA K

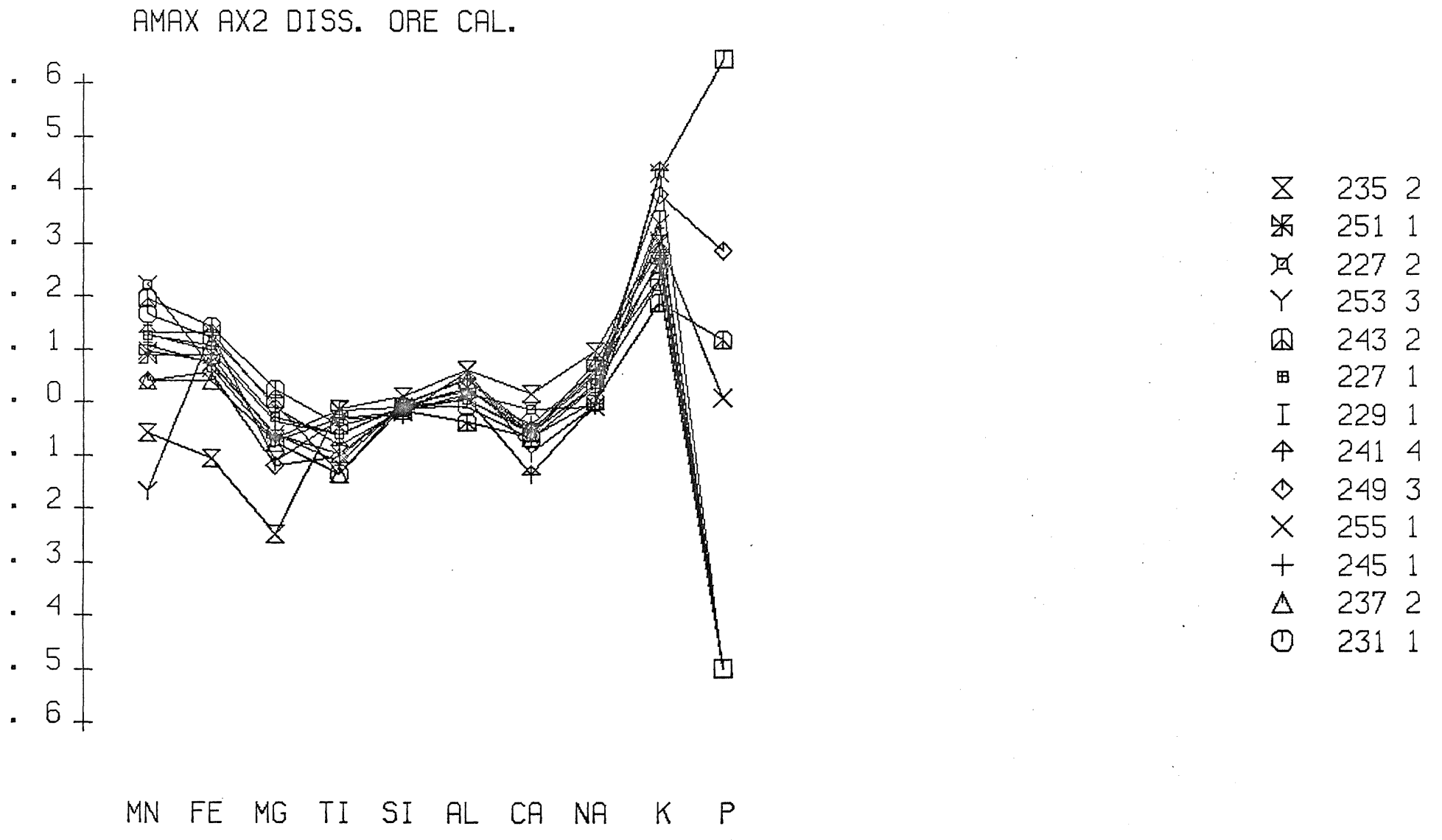
608 1
626 1
622 1
632 1
626 2
618 1
648 1
606 1
610 1
606 2
620 2
634 1
642 1

AMAX AX2 DISS. ORE CAL.

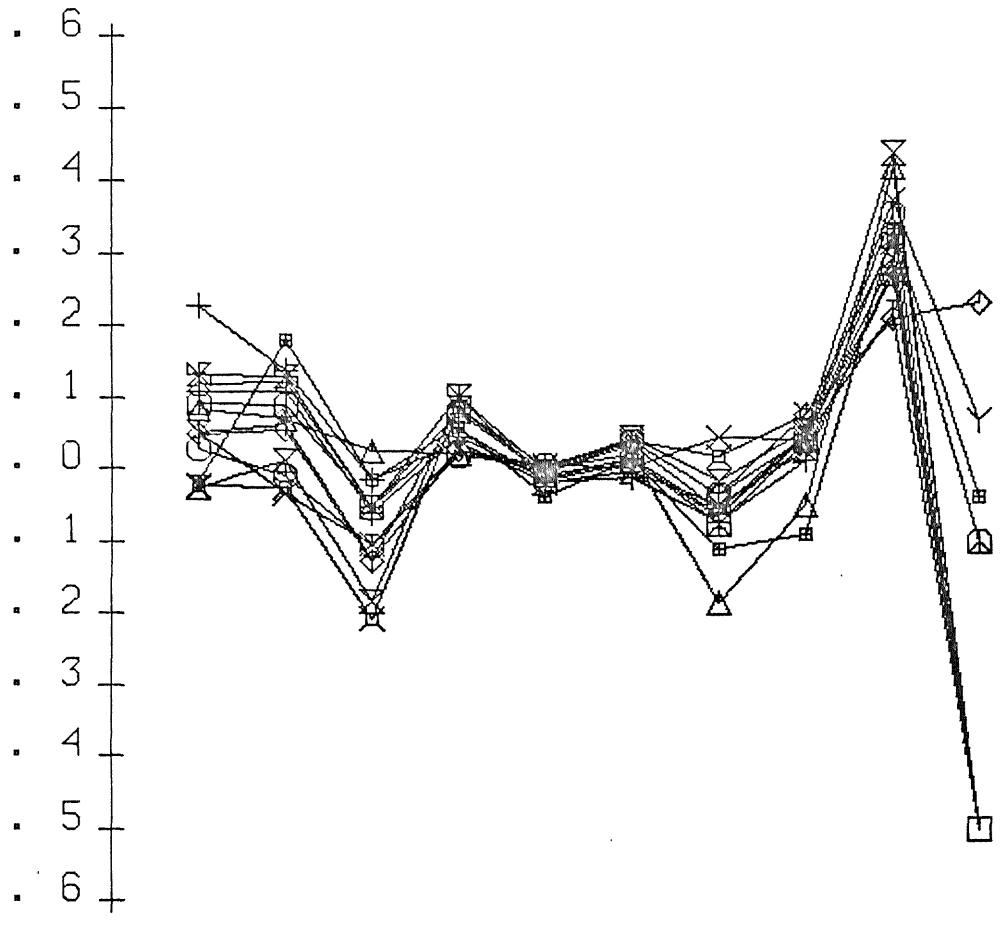


MN FE MG TI SI AL CA NA K P

⧖	255	2
⋇	217	1
⌑	241	5
Y	213	2
☮	245	2
⊞	241	1
I	239	2
⍏	243	1
◈	237	3
X	237	1
+	249	1
△	235	1
⏲	223	2

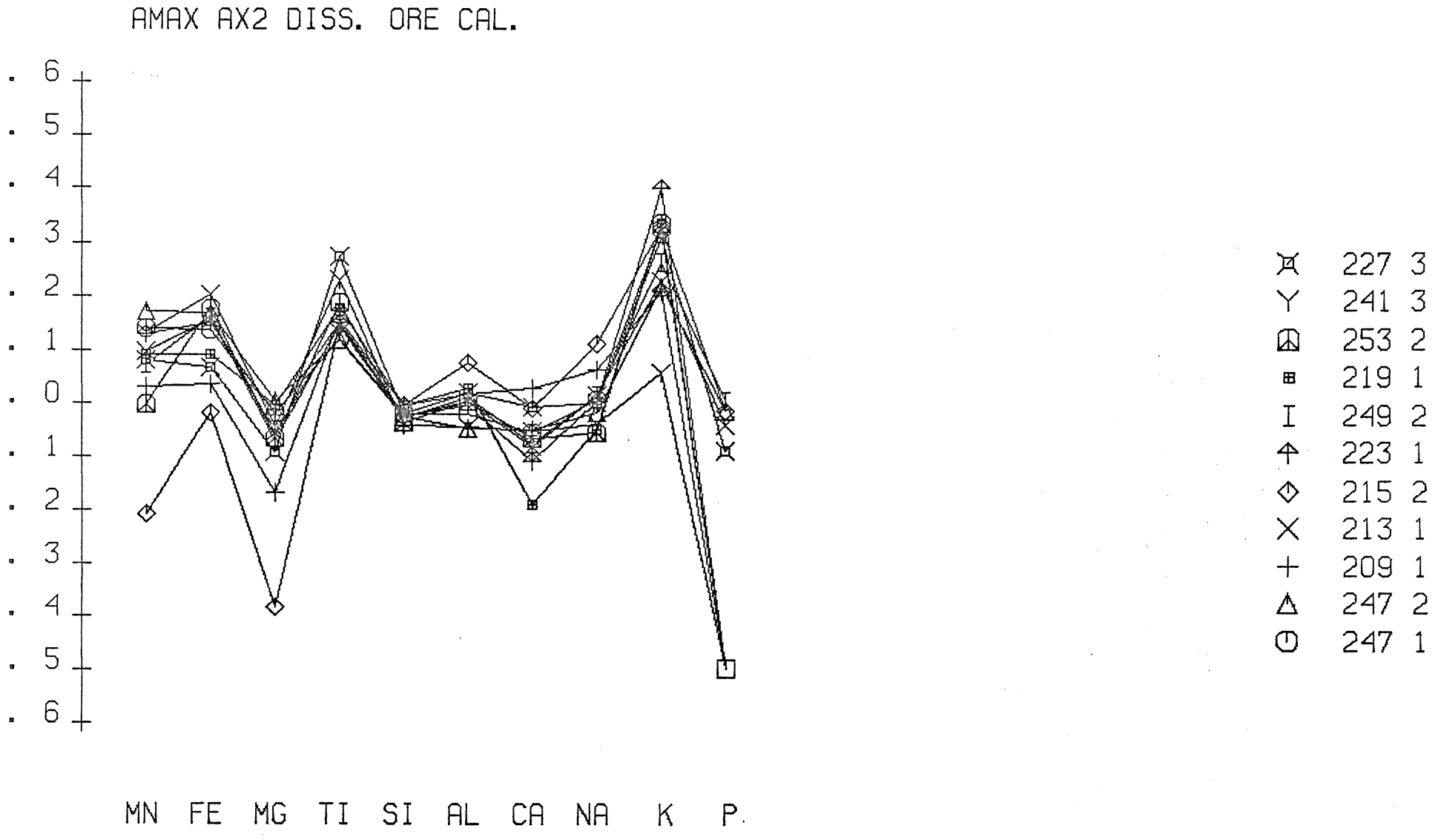

AMAX AX2 DISS. ORE CAL.
6
5
4
3
2
1
0
1
2
3
4
5
6
MN FE MG TI SI AL CA NA K P
235 2
251 1
227 2
253 3
243 2
227 1
229 1
241 4
249 3
255 1
245 1
237 2
231 1

AMAX AX2 DISS. ORE CAL.

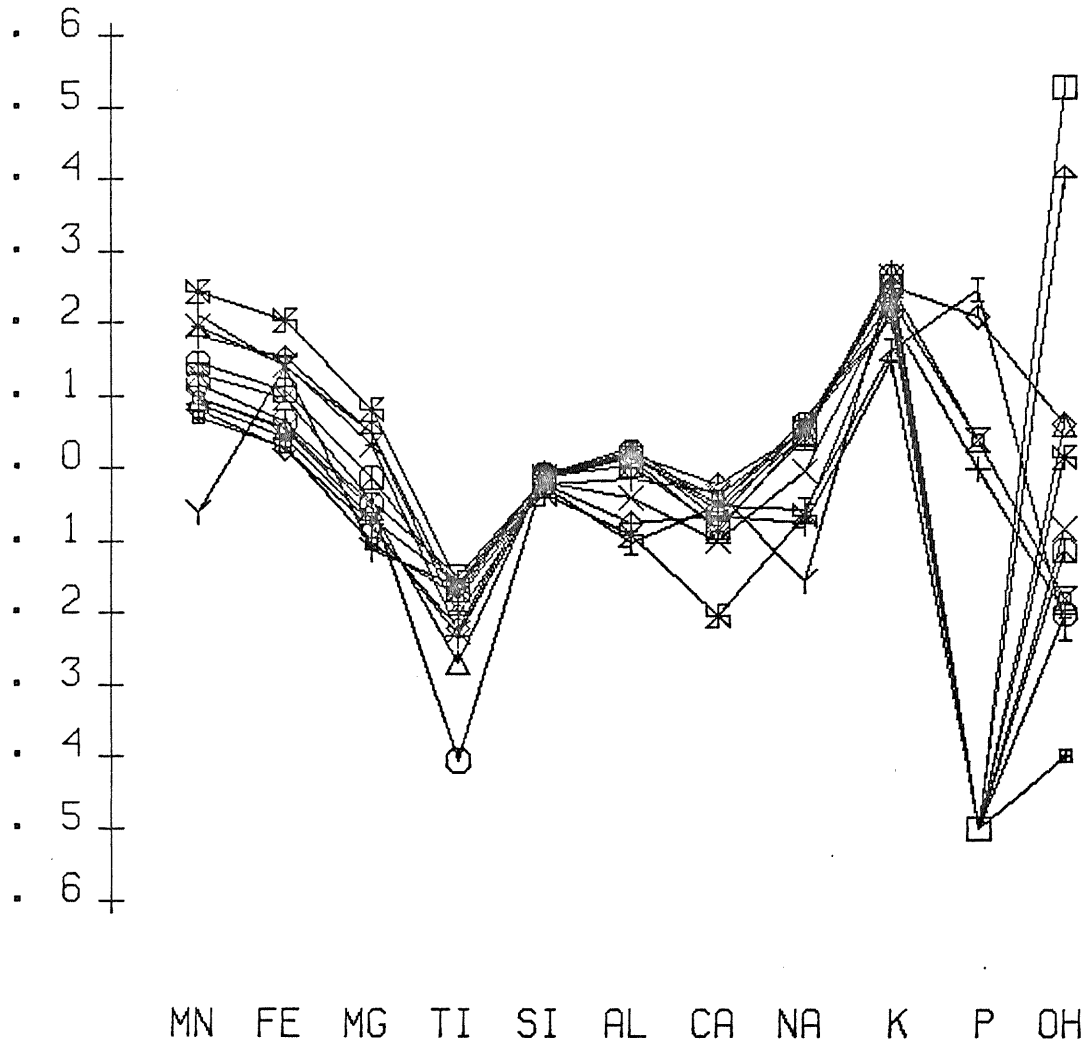


MN FE MG TI SI AL CA NA K P

253 1
221 1
209 2
211 1
211 2
231 2
233 1
241 2
239 1
215 1
257 1
225 2
225 1

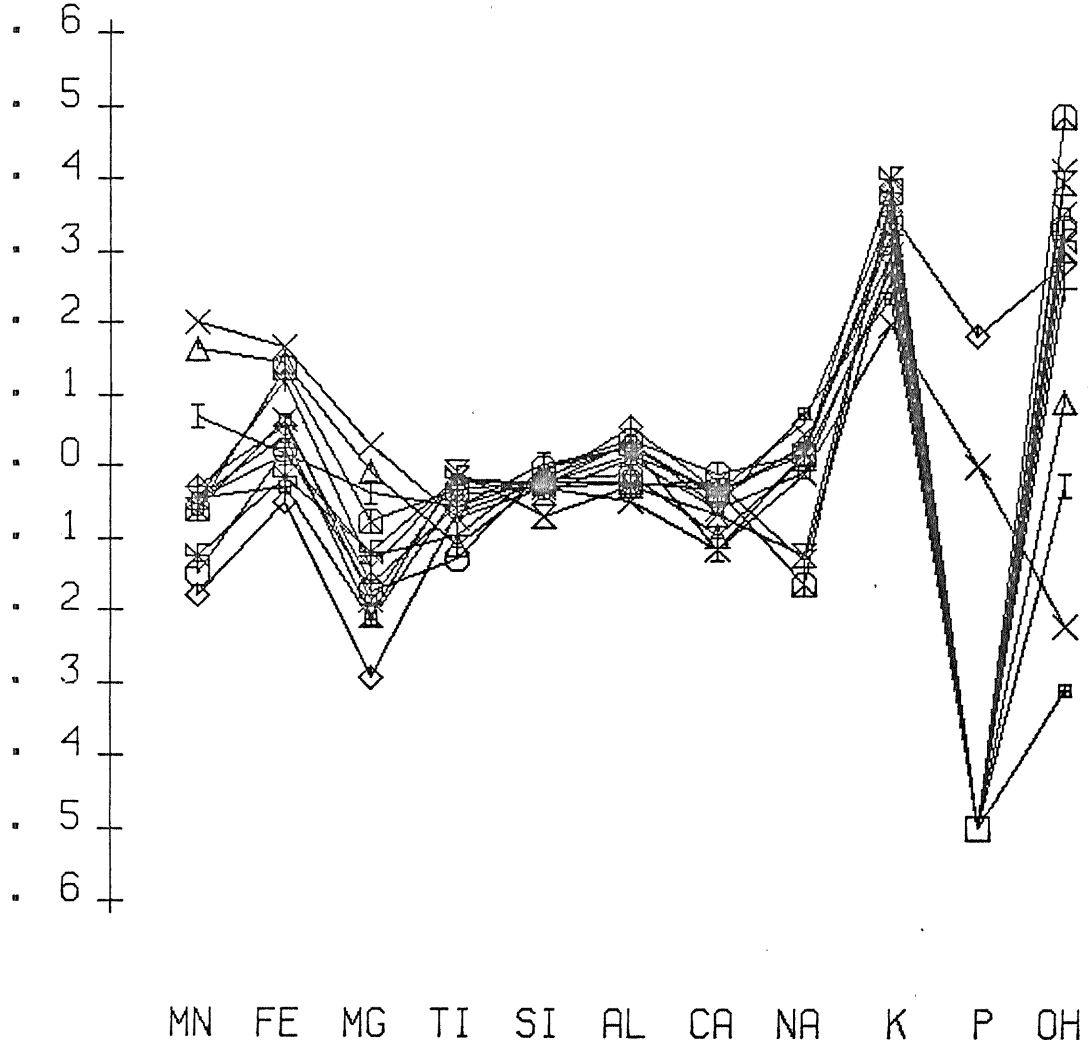

AMAX AX2 DISS. ORE CAL.
6
5
4
3
2
1
0
1
2
3
4
5
6
MN FE MG TI SI AL CA NA K P.
227 3
241 3
253 2
219 1
249 2
223 1
215 2
213 1
209 1
247 2
247 1

AMAX AX3 DISS. ORE CAL.

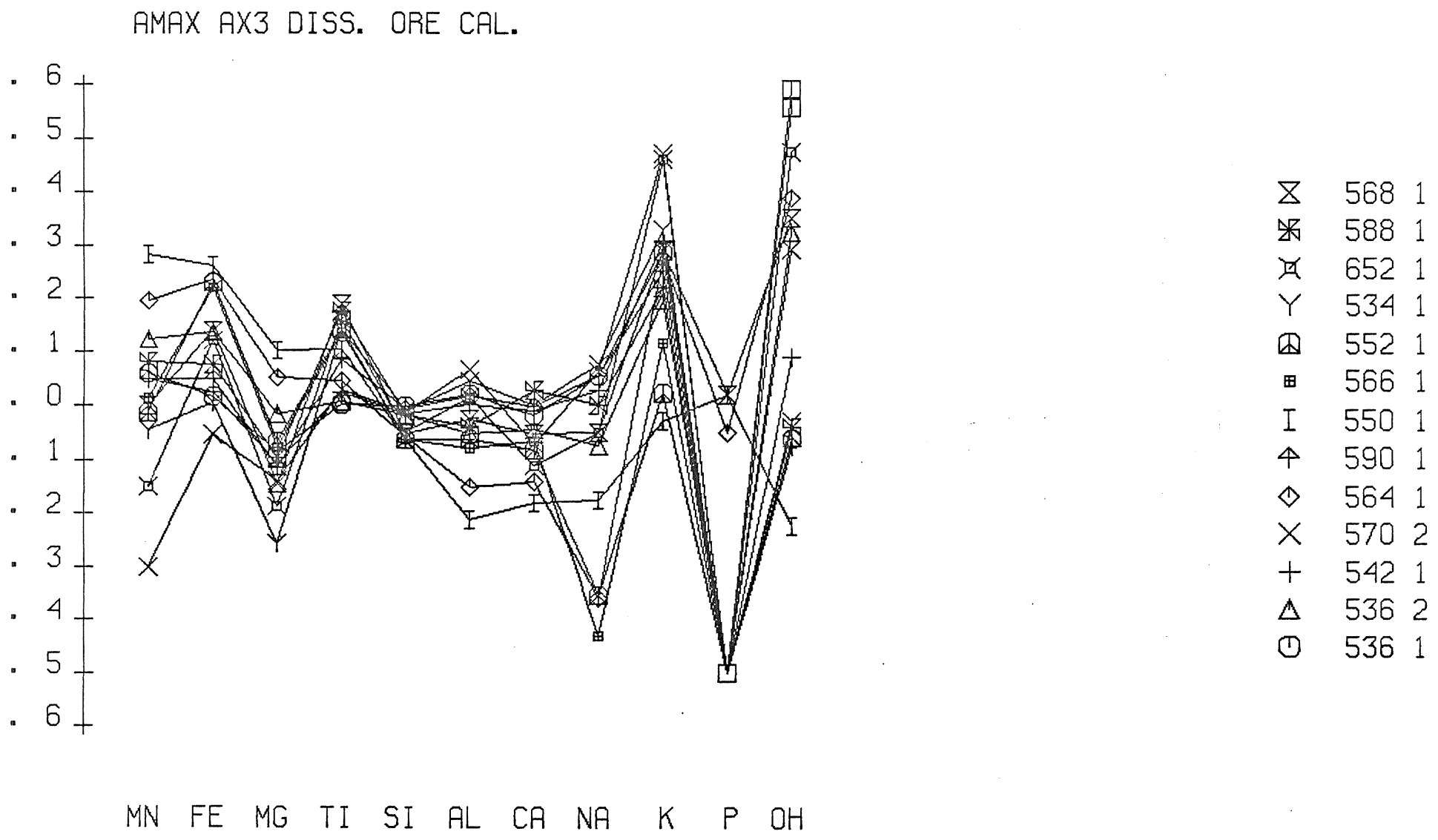


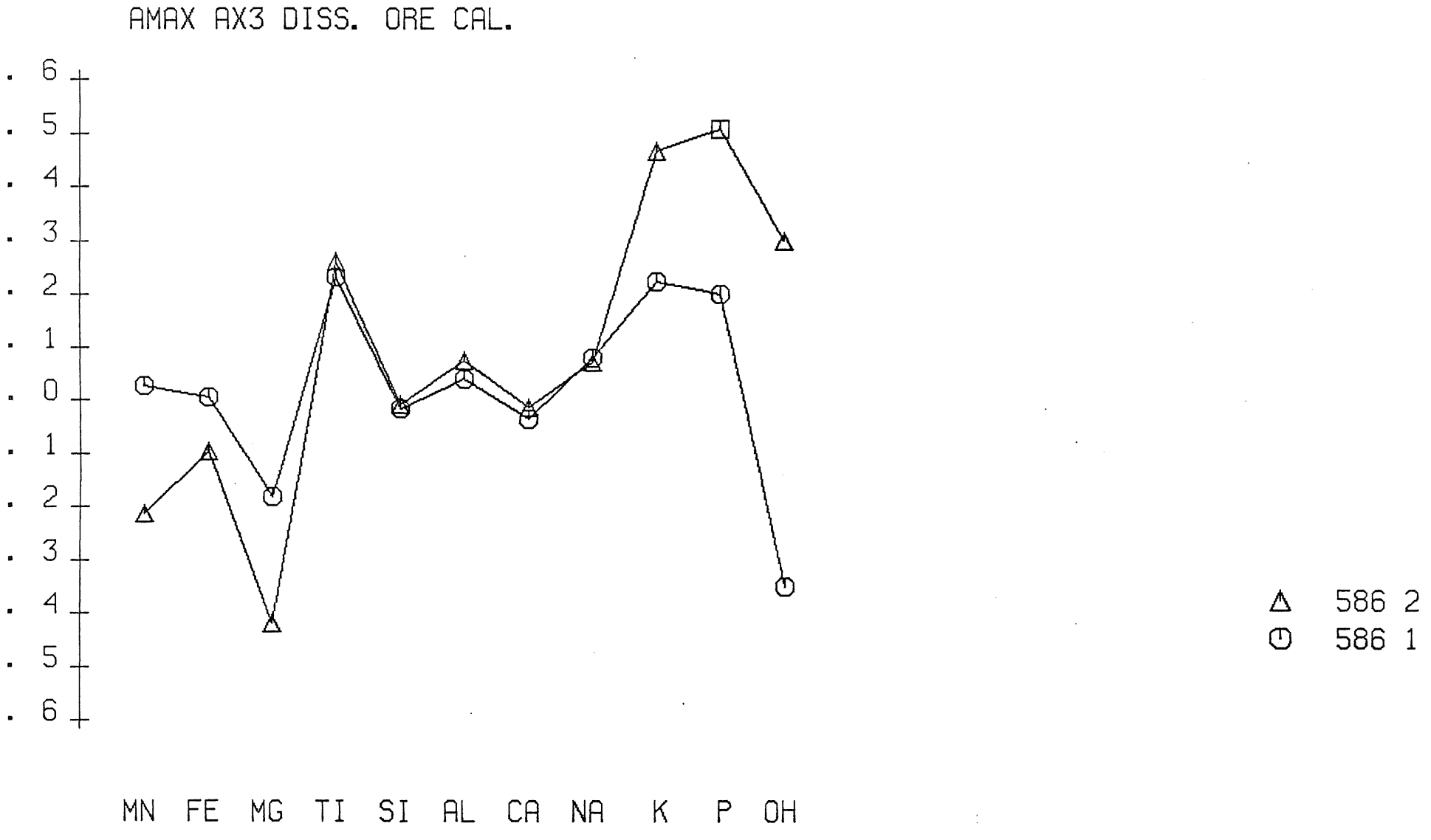
538	1
558	1
584	1
574	1
556	1
584	2
598	1
582	1
546	1
576	1
578	1
562	1
596	1

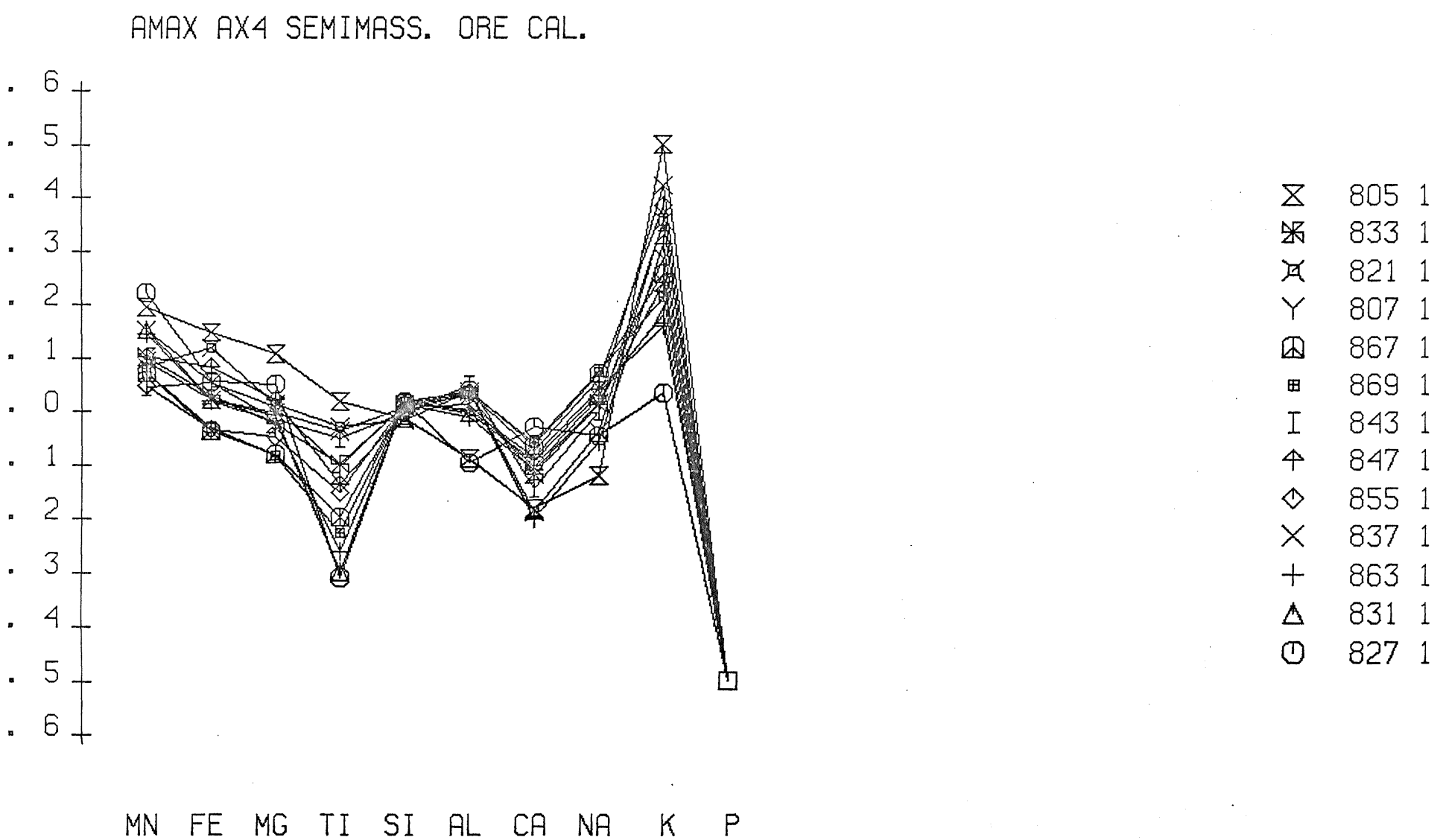
AMAX AX3 DISS. ORE CAL.



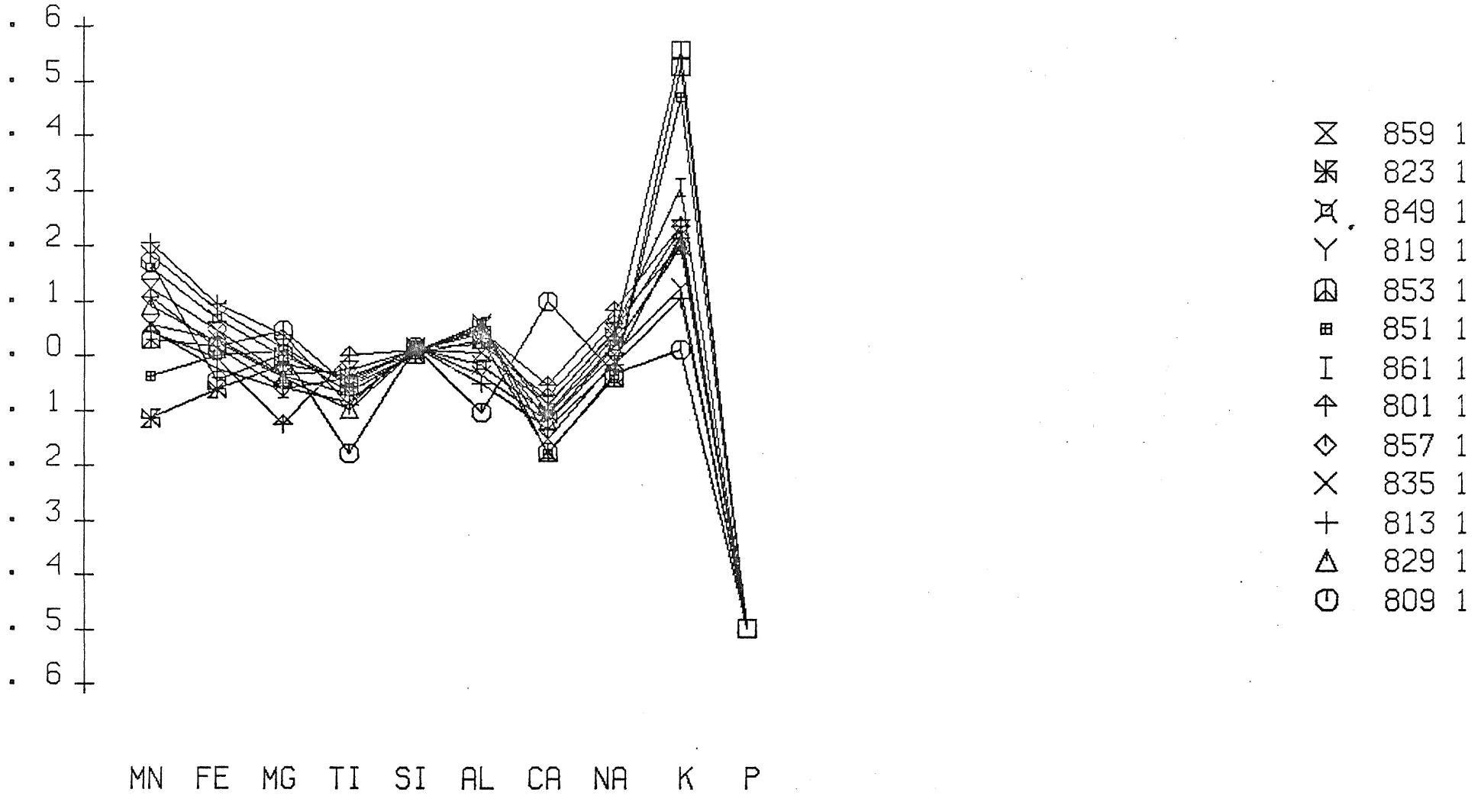
600 1
546 2
580 1
572 1
548 1
544 1
570 1
568 2
560 1
532 1
540 2
554 1
540 1


AMAX AX3 DISS. ORE CAL.
6
5
4
3
2
1
0
1
2
3
4
5
6
MN FE MG TI SI AL CA NA K P OH
568 1
588 1
652 1
534 1
552 1
566 1
550 1
590 1
564 1
570 2
542 1
536 2
536 1

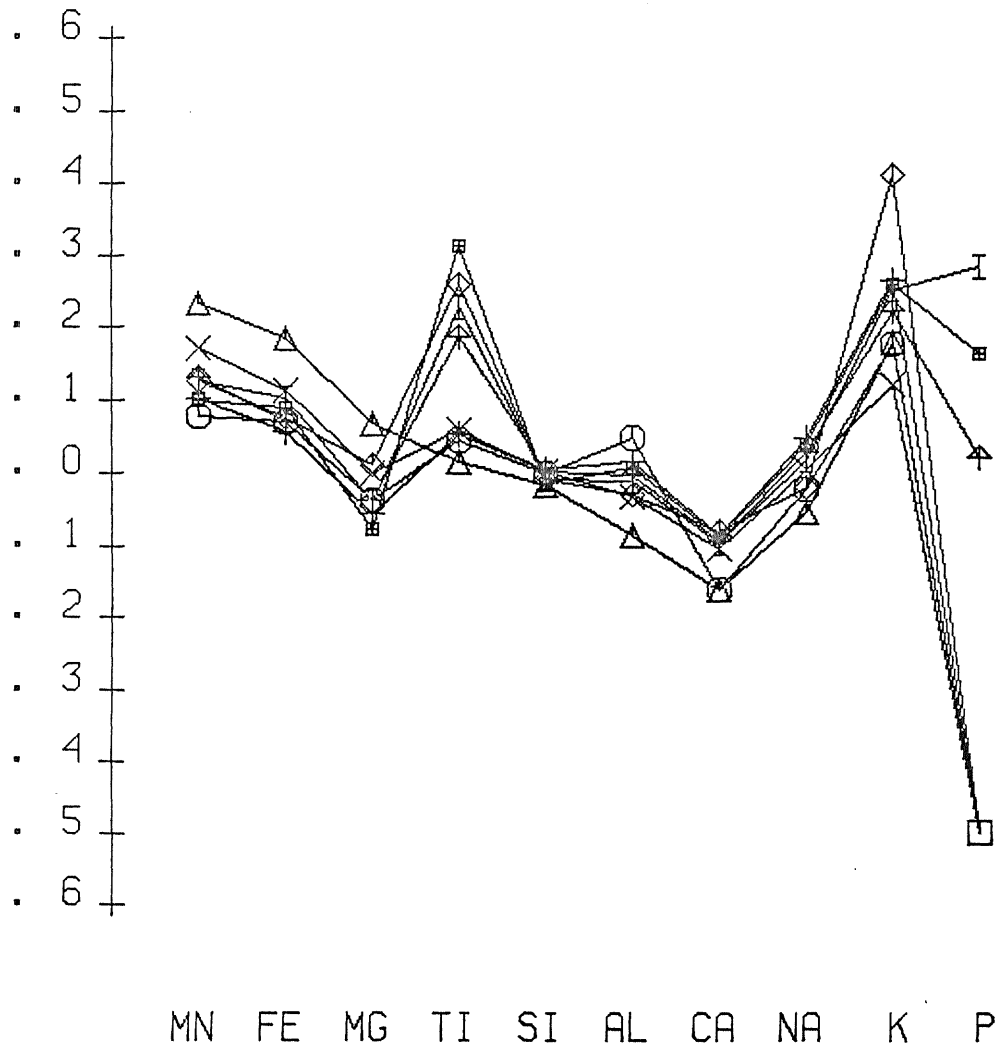

AMAX AX3 DISS. ORE CAL.
. 6
. 5
. 4
. 3
. 2
. 1
. 0
. 1
. 2
. 3
. 4
. 5
. 6
MN FE MG TI SI AL CA NA K P OH
586 2
586 1


AMAX AX4 SEMIMASS. ORE CAL.
6
5
4
3
2
1
0
1
2
3
4
5
6
MN FE MG TI SI AL CA NA K P
805 1
833 1
821 1
807 1
867 1
869 1
843 1
847 1
855 1
837 1
863 1
831 1
827 1

AMAX AX4 SEMIMASS. ORE CAL.

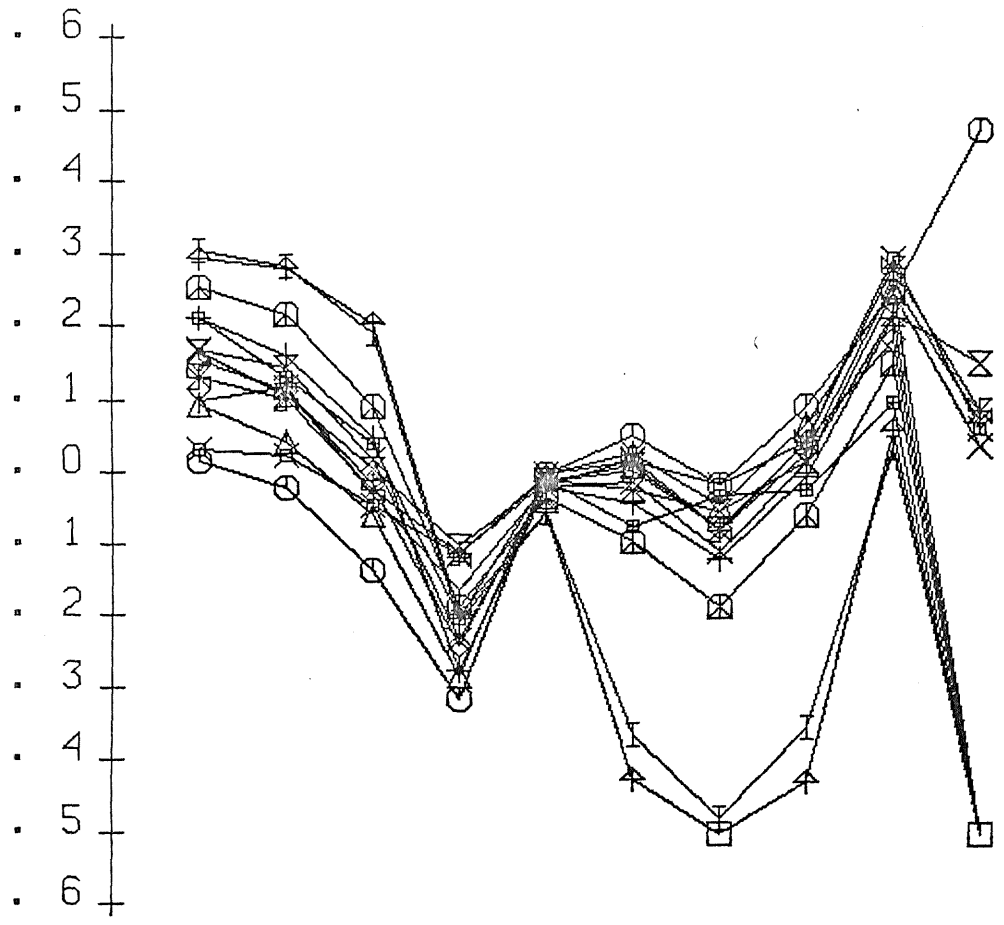


AMAX AX4 SEMIMASS. ORE CAL.



825 1
817 1
811 1
839-0
803 1
841 1
865 1
845 1

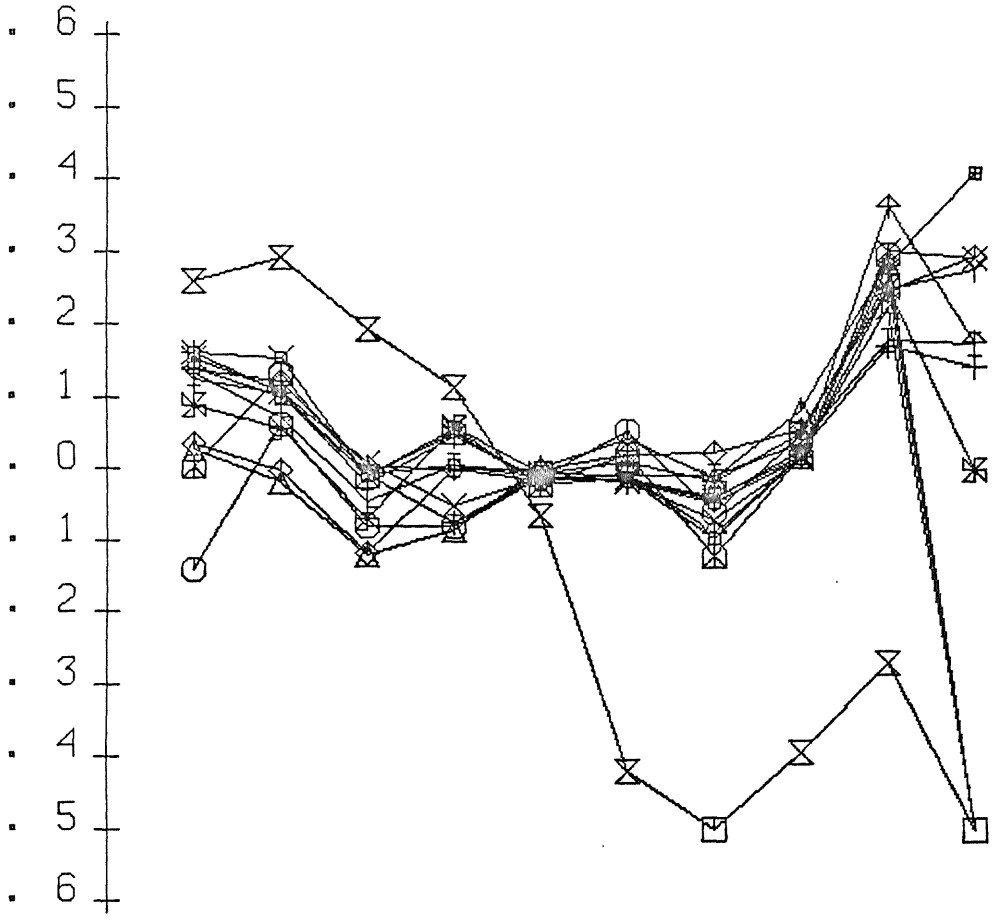
AMAX AX5 DISS. ORE CAL.



MN FE MG TI SI AL CA NA K P

984 1
988 2
1010 1
1018 2
1016 1
1008 1
1002 1
996 1
1004 1
994 1
988 1
1004 2
990 2

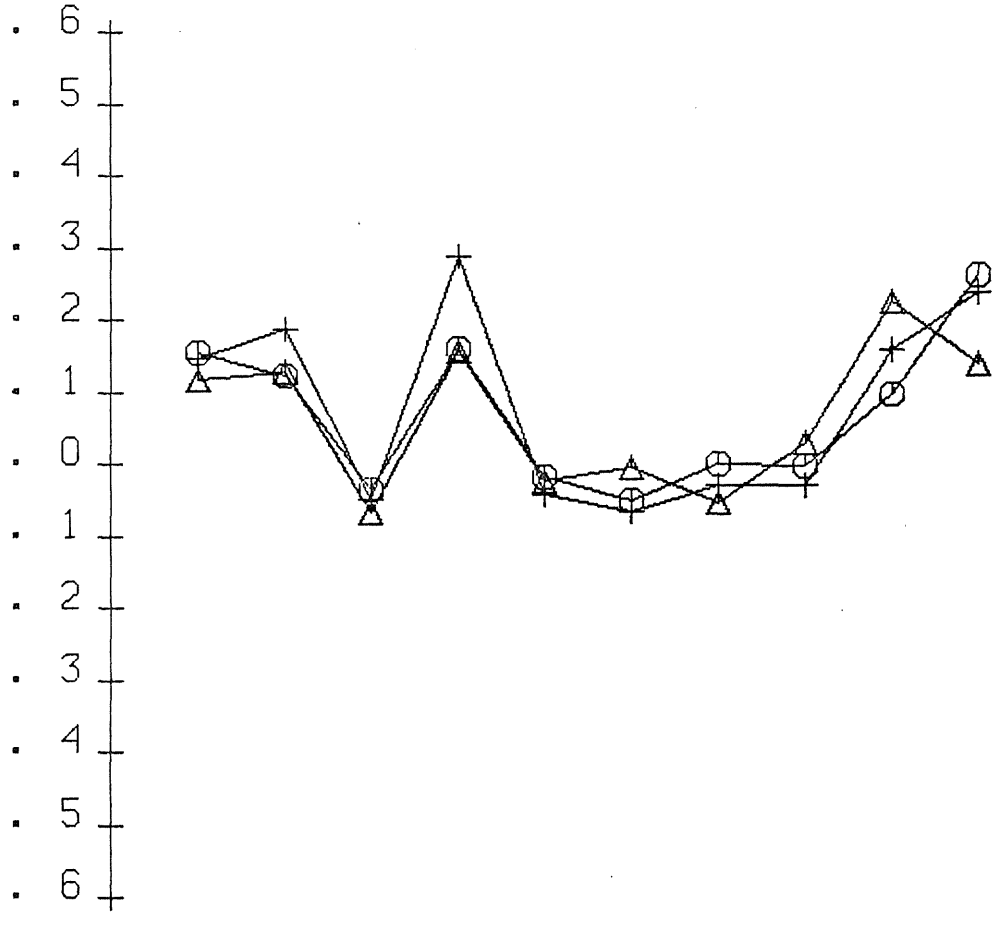
AMAX AX5 DISS. ORE CAL.



MN FE MG TI SI AL CA NA K P

992 1
1006 2
998 2
1010 2
1012 1
986 1
1006 1
998 1
1000 2
986 2
984 2
1000 1
1018 1

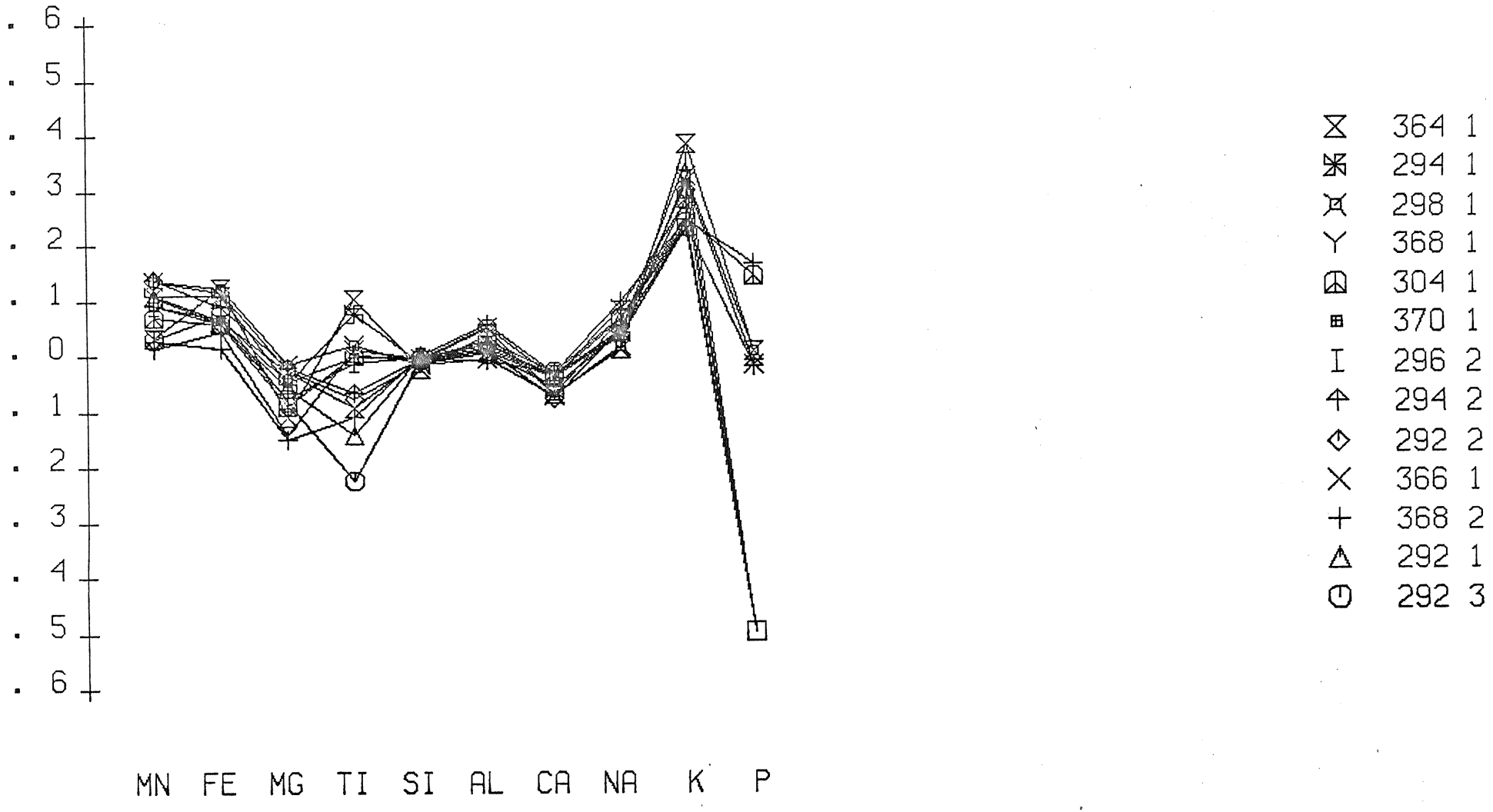
AMAX AX5 DISS. ORE CAL.



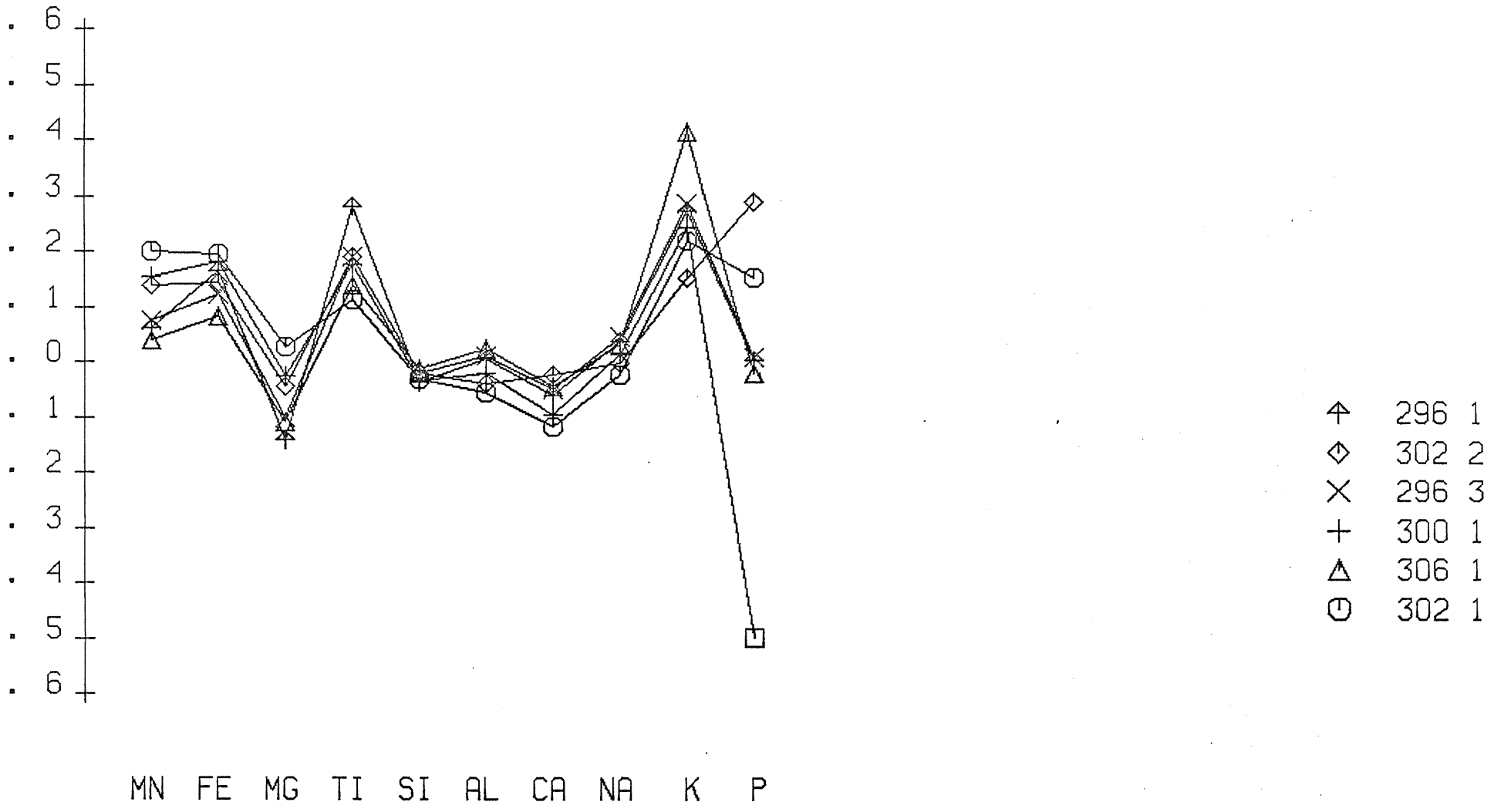
MN FE MG TI SI AL CA NA K P

+ 1014 2
△ 990 1
⏀ 1014 1

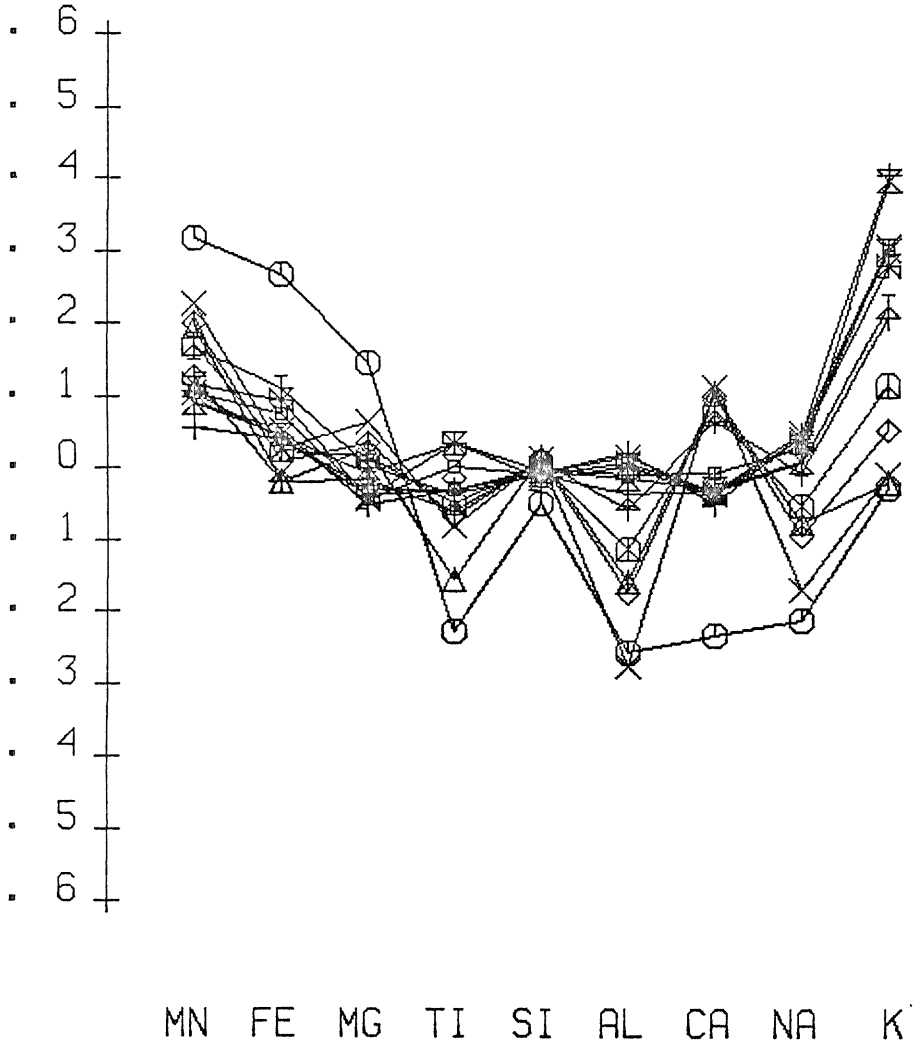
DP1 WASTE ROCK CAL.



DP1 WASTE ROCK CAL.

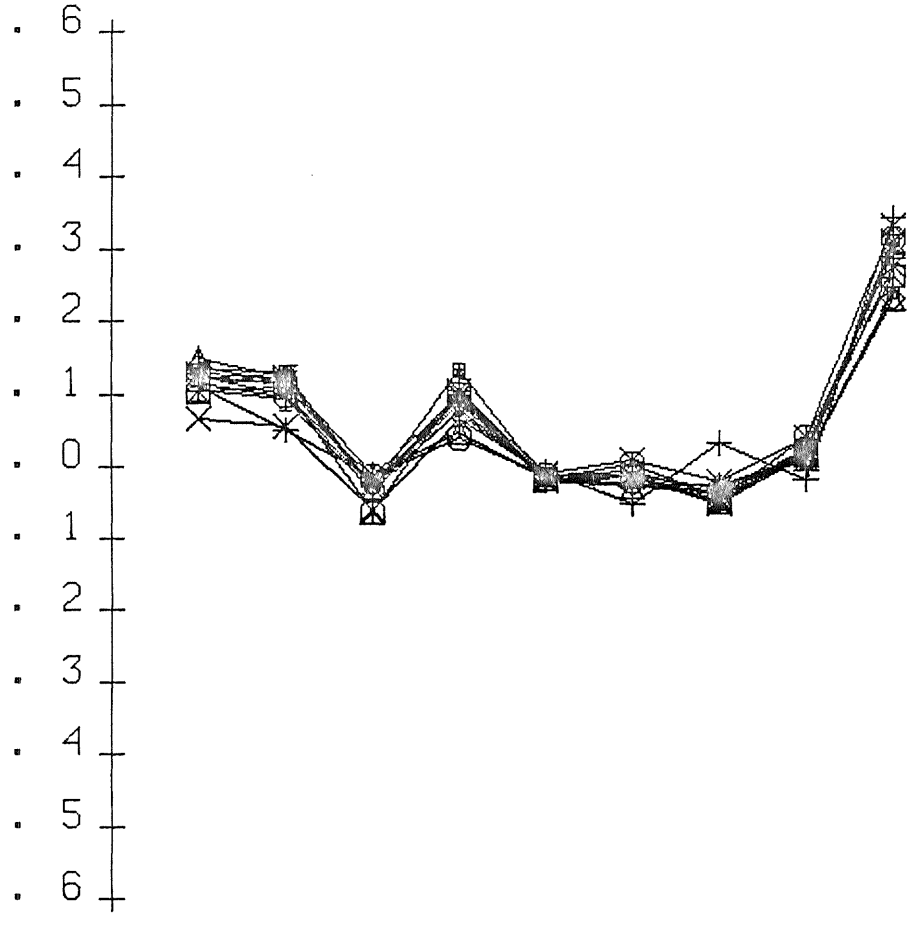


DP2 DISS. ORE CAL.



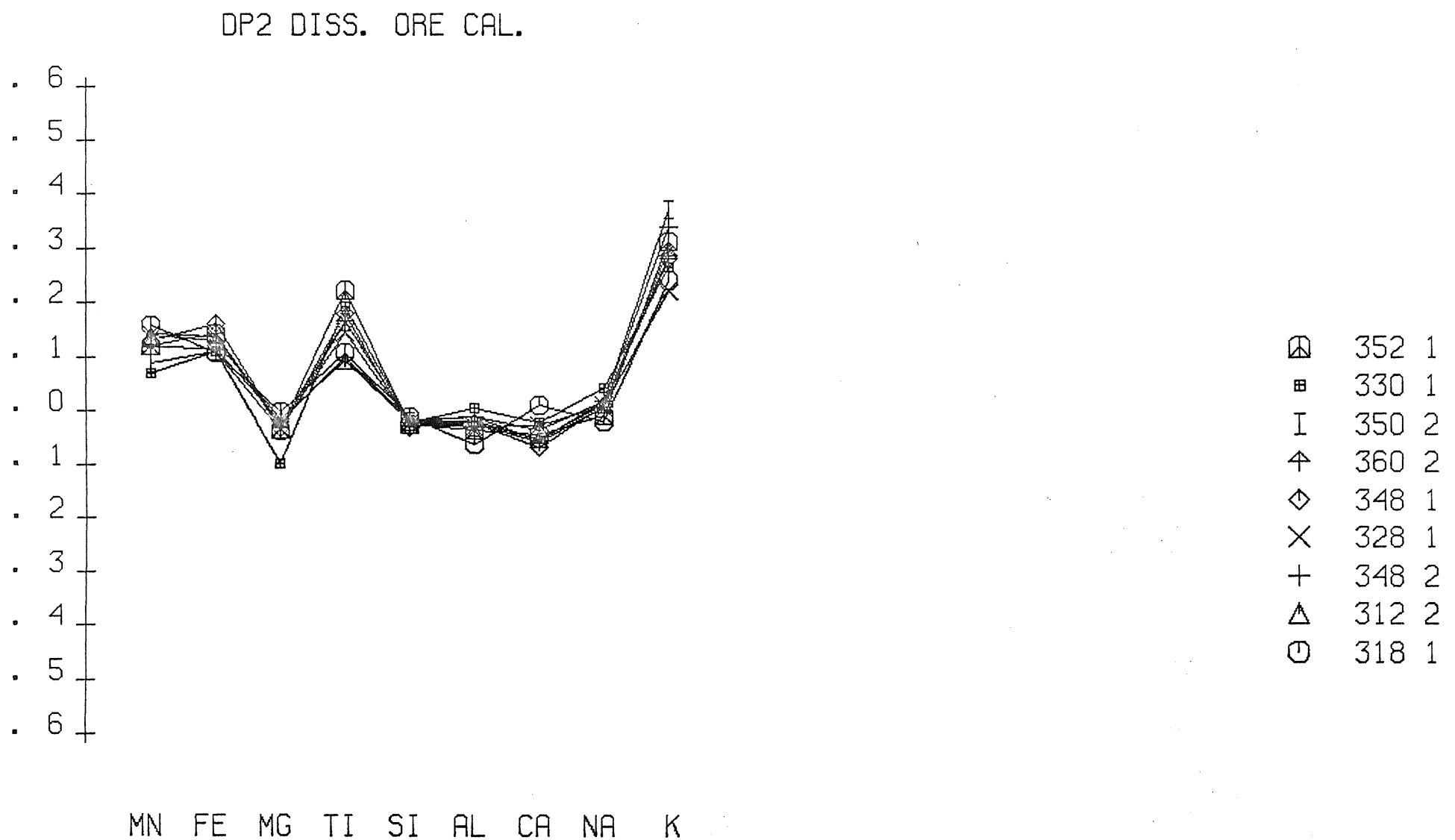
310	1
332	2
338	1
314	1
346	1
358	1
334	1
324	1
318	2
354	1
344	1
336	1
350	1

DP2 DISS. ORE CAL.

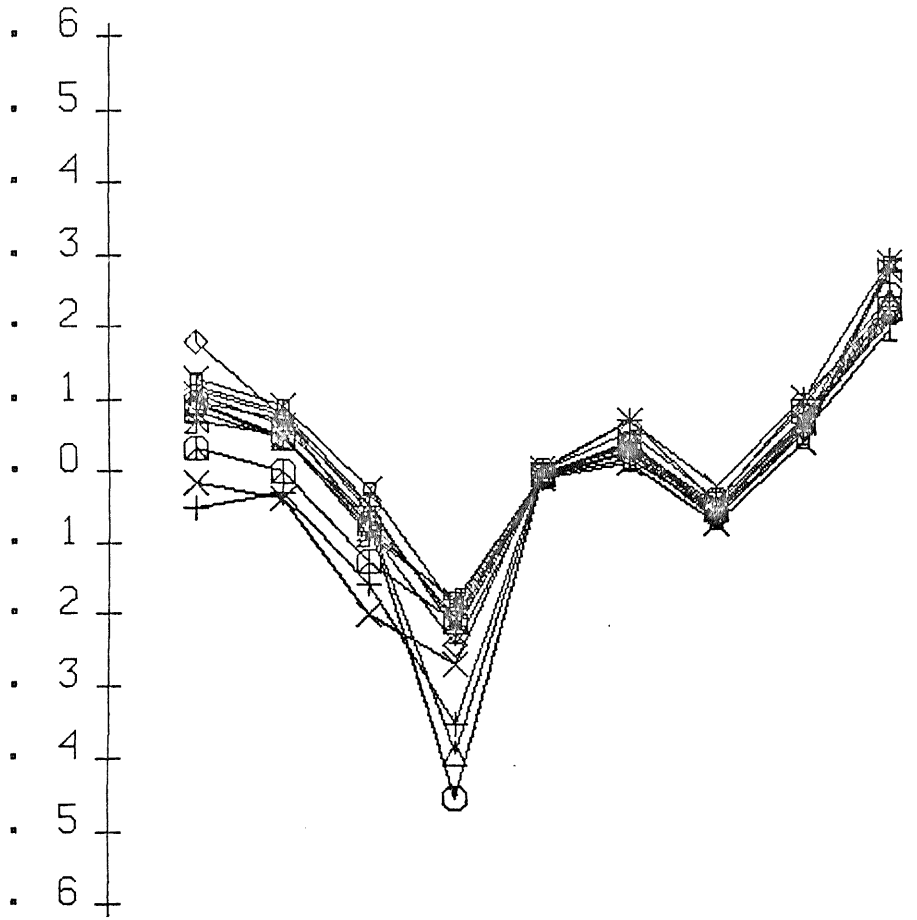


MN FE MG TI SI AL CA NA K

312 1
356 1
362 2
340 1
332 1
334 2
362 1
308 1
316 1
338 2
342 1
328 2
360 1


DP2 DISS. ORE CAL.
6
5
4
3
2
1
0
1
2
3
4
5
6
MN FE MG TI SI AL CA NA K
352 1
330 1
350 2
360 2
348 1
328 1
348 2
312 2
318 1

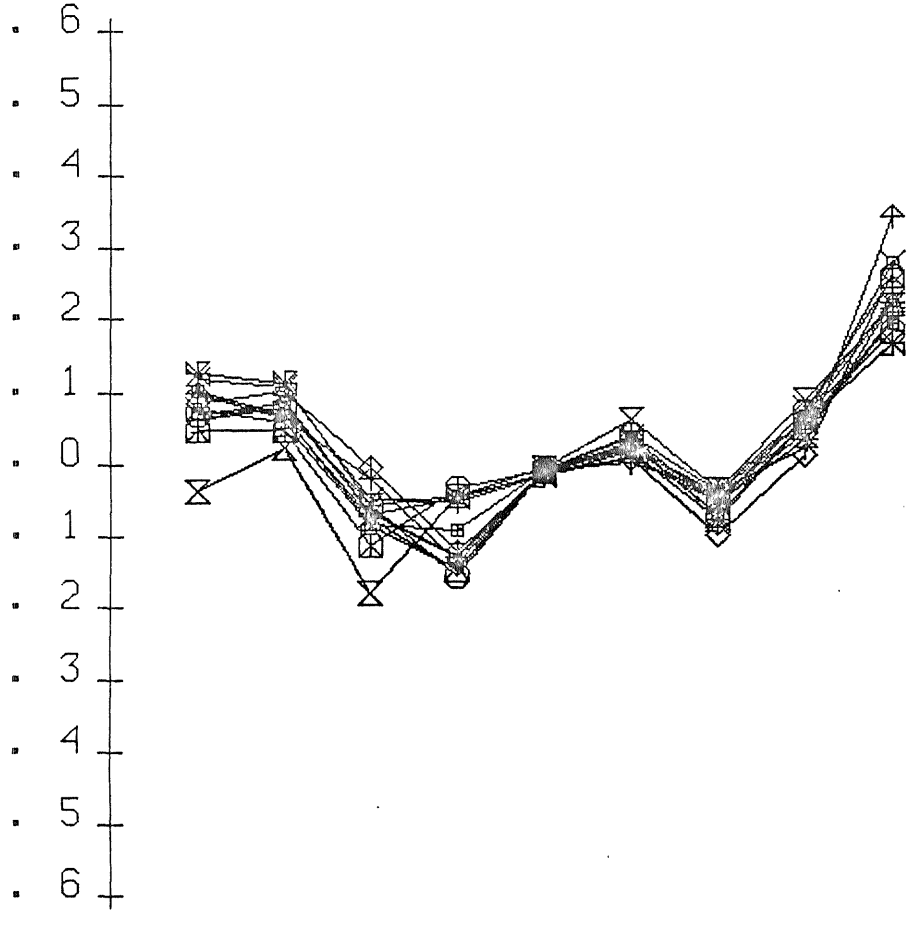
IP3 DISS. ORE CAL.



MN FE MG TI SI AL CA NA K

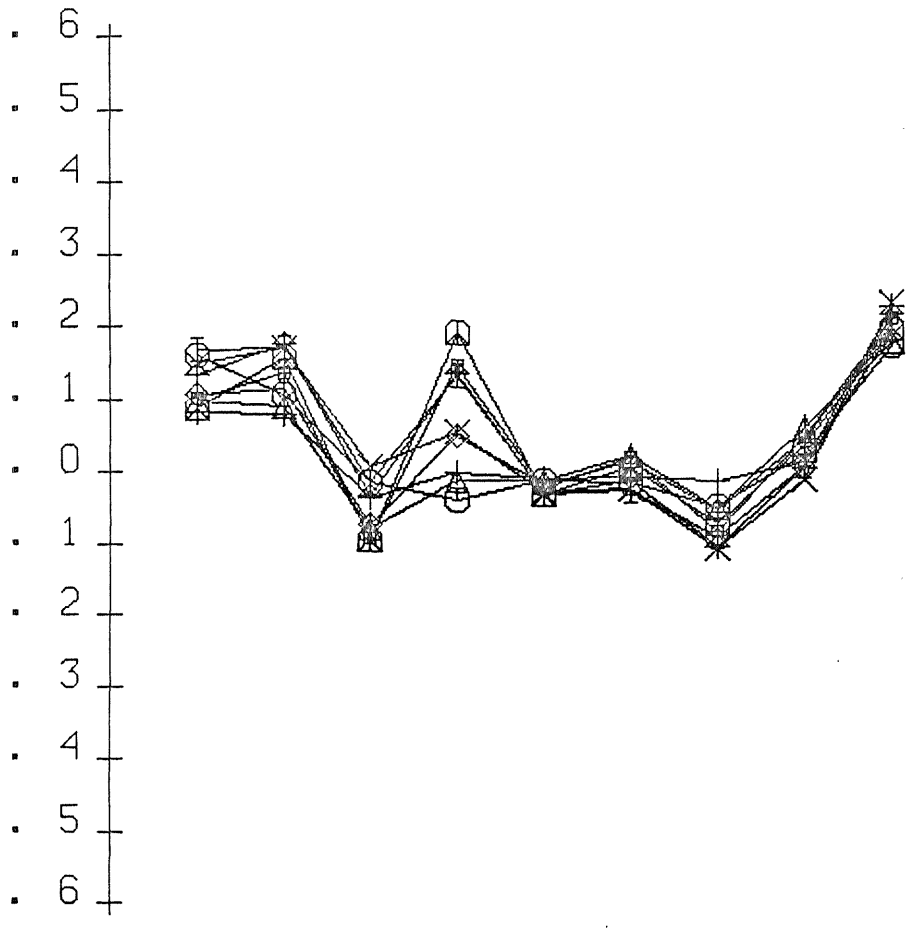
455 3
454 1
453 6
455 6
451 7
452 4
455 1
453 2
455 7
453 5
451 2
455 5
451 3

IP3 DISS. ORE CAL.



453 1
454 7
453 4
454 6
452 5
454 4
451 4
452 2
454 3
455 2
453 3
452 1
452 6

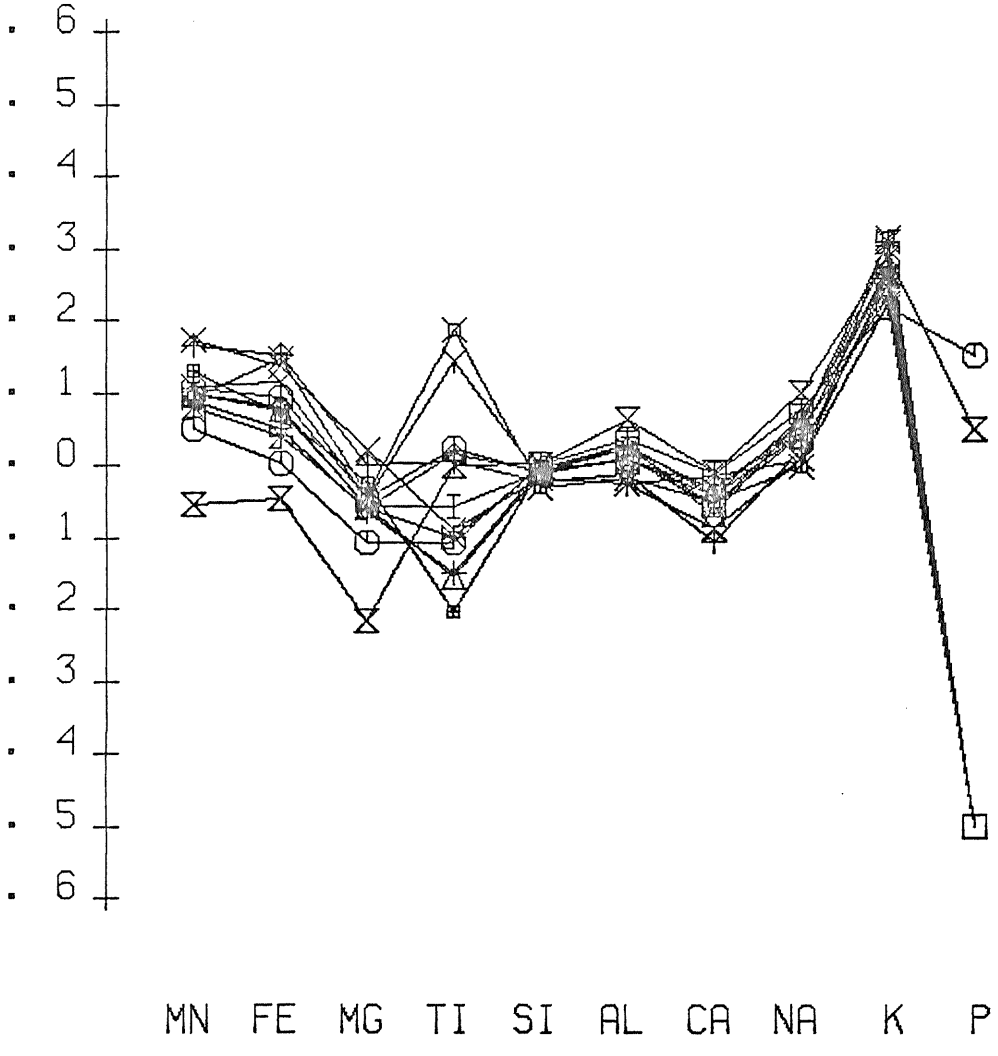
IP3 DISS. ORE CAL.



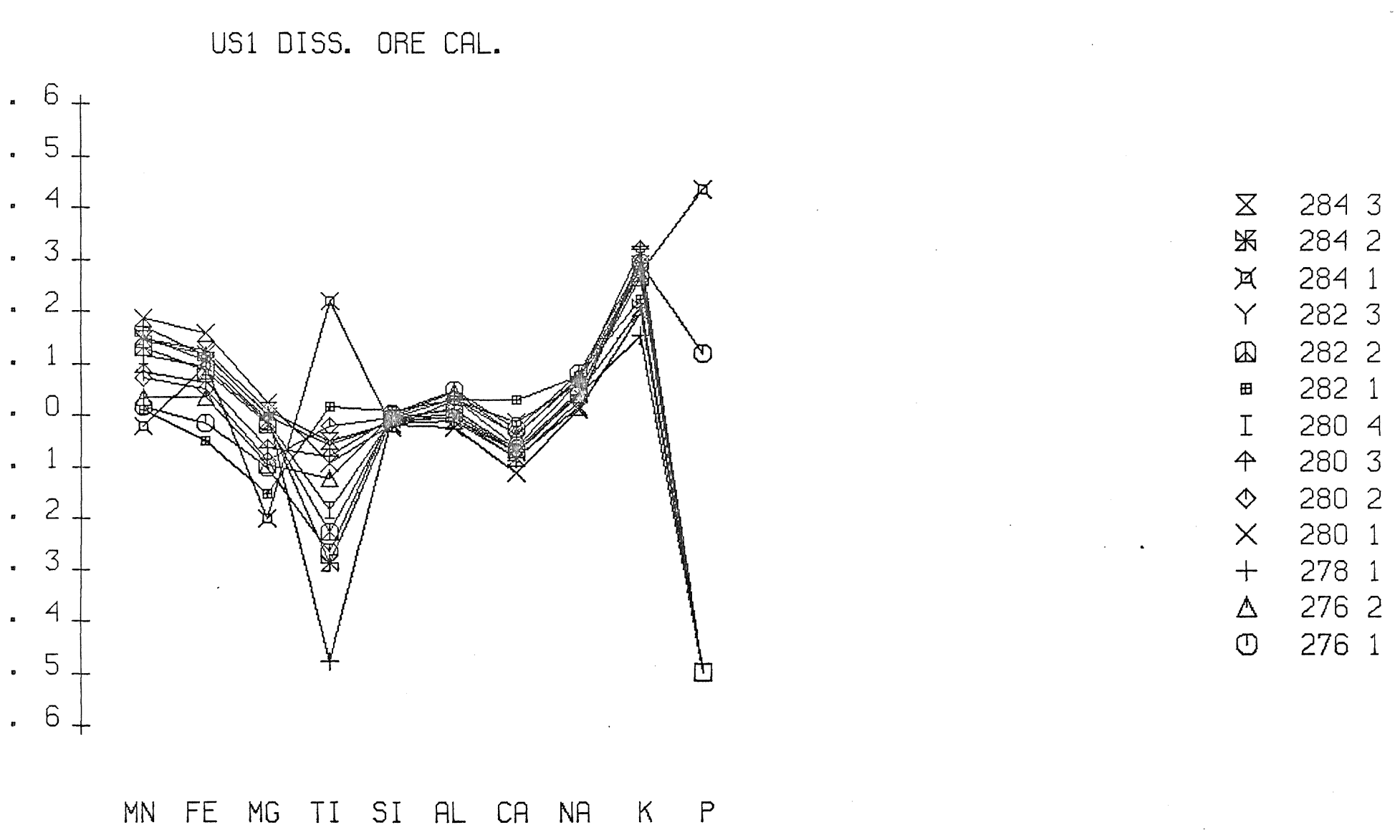
MN FE MG TI SI AL CA NA K

452 3
452 7
454 2
453 7
451 1
454 5
451 6
451 5
455 4

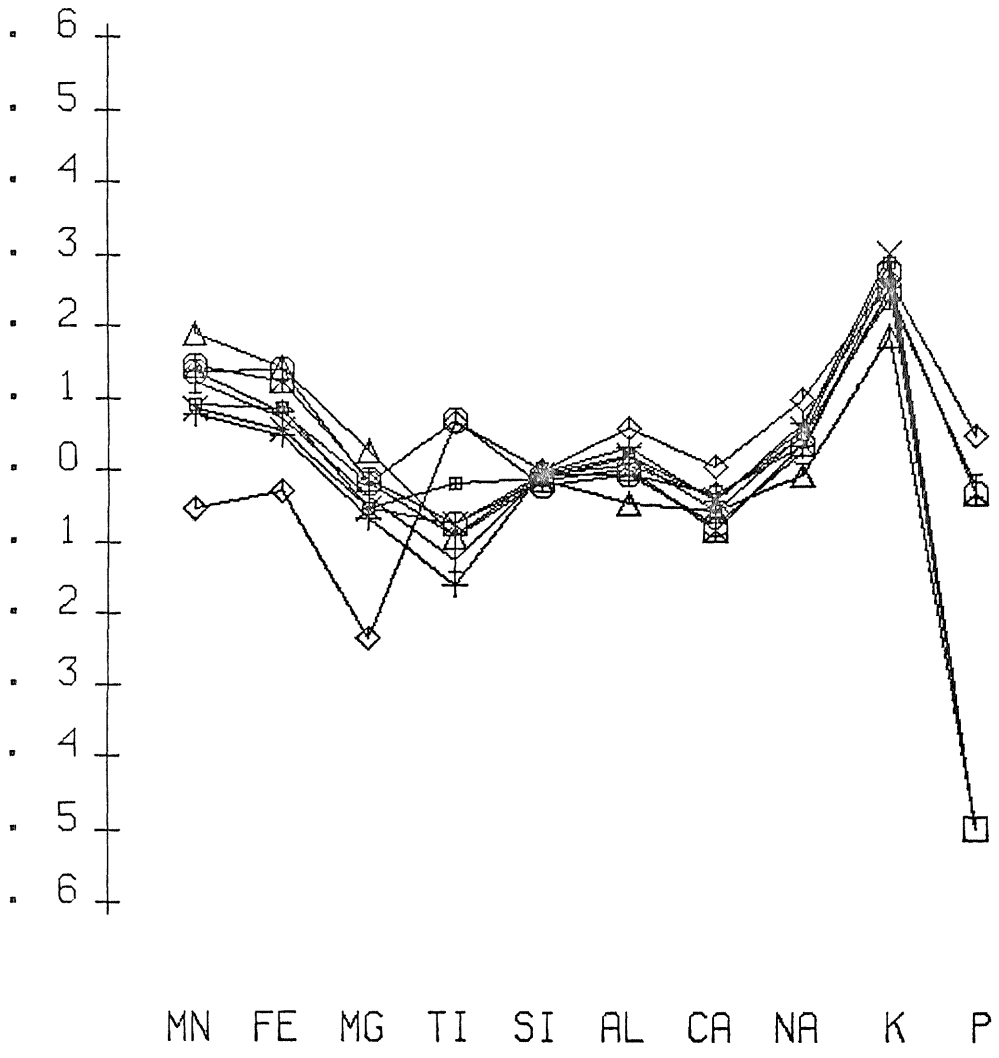
US1 DISS. ORE CAL.



274 1
272 4
272 3
272 2
272 1
270 2
270 1
268 2
268 1
266 3
266 2
266 1
264 1


US1 DISS. ORE CAL.
6
5
4
3
2
1
0
1
2
3
4
5
6
MN FE MG TI SI AL CA NA K P
284 3
284 2
284 1
282 3
282 2
282 1
280 4
280 3
280 2
280 1
278 1
276 2
276 1

US1 DISS. ORE CAL.



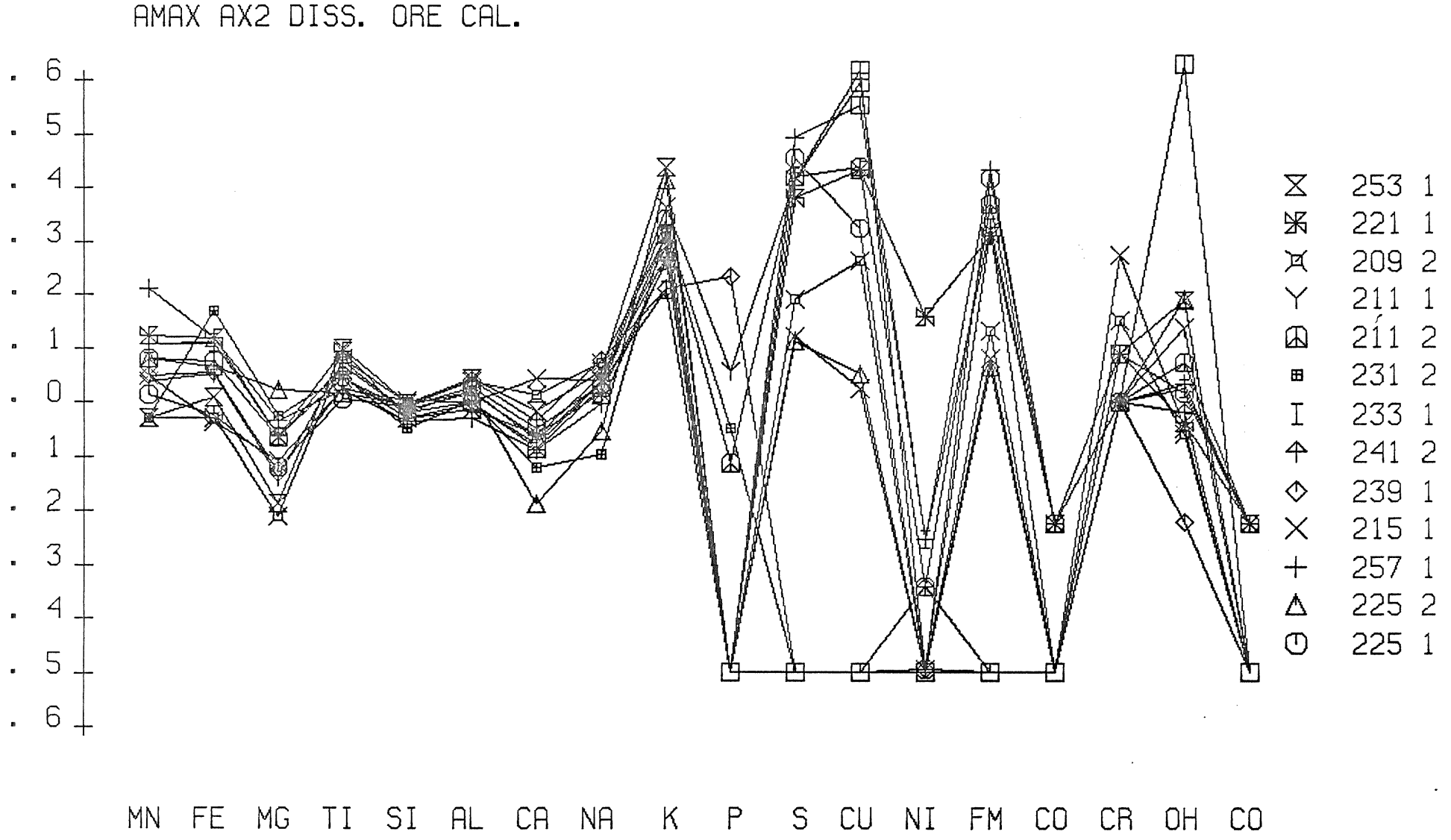
290 3
290 2
290 1
288 3
288 2
288 1
286 2
286 1
284 4

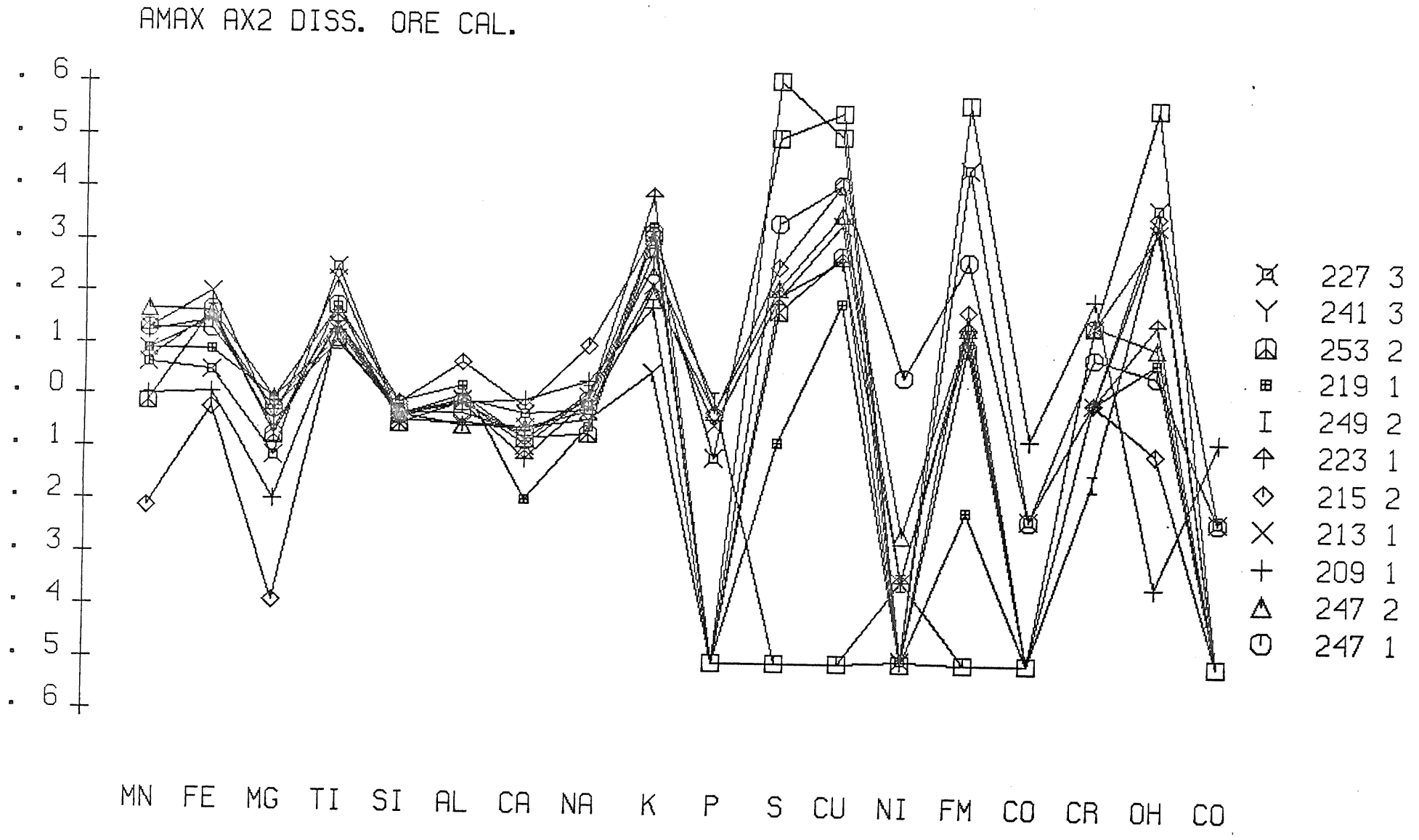
AMAX AX2 DISS. ORE CAL.

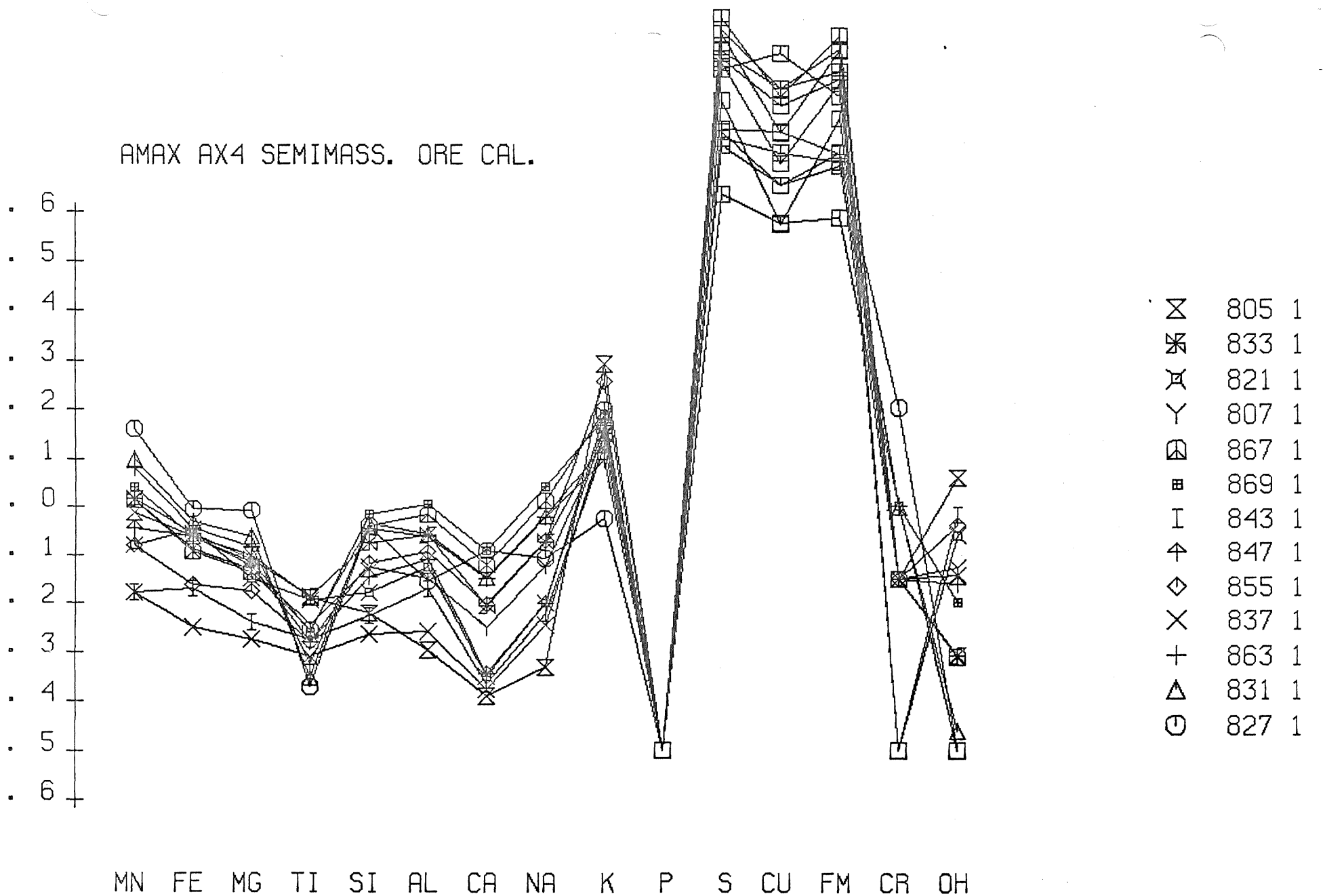
6
5
4
3
2
1
0
1
2
3
4
5
6

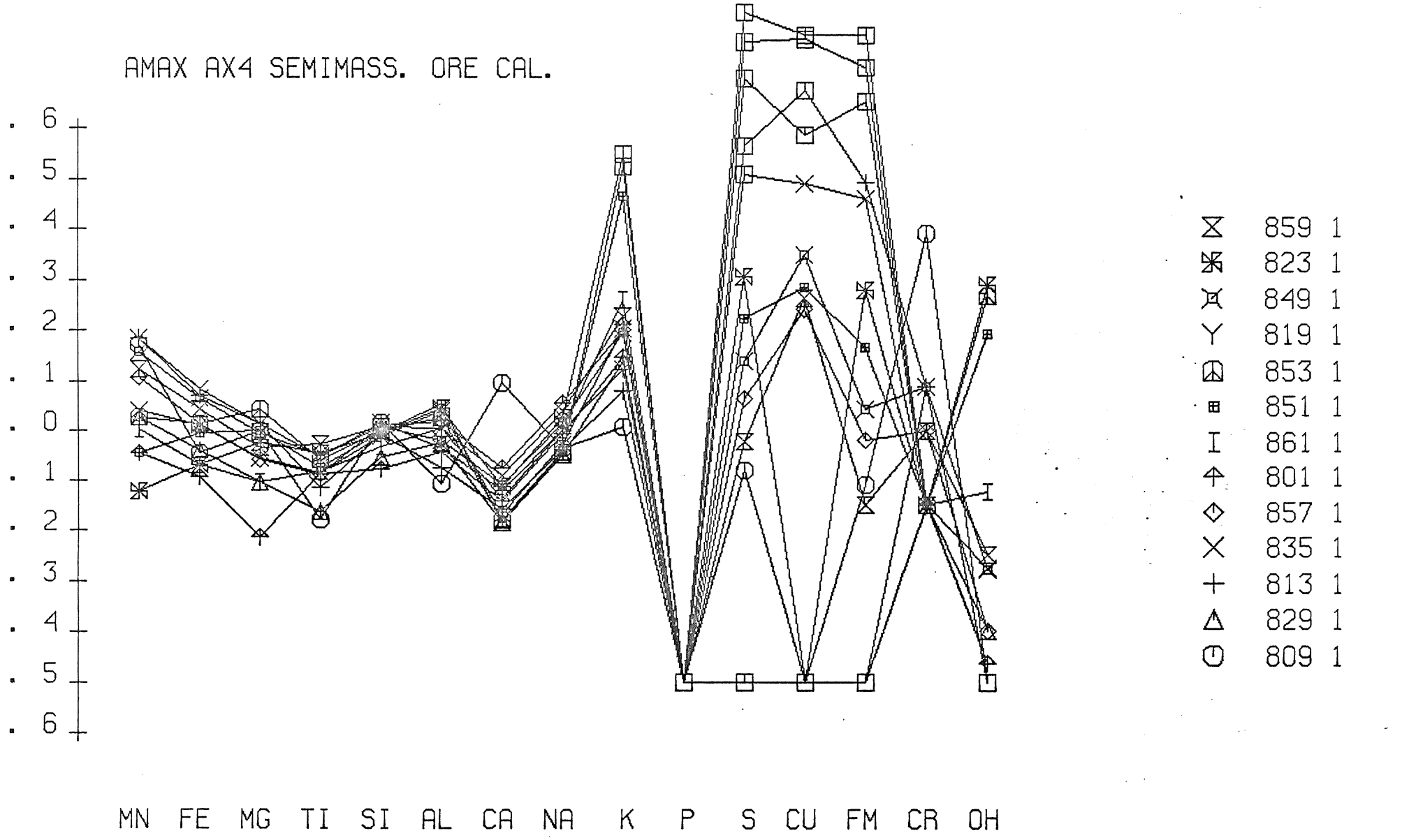
MN FE MG TI SI AL CA NA K P S CU NI FM CO CR OH CO

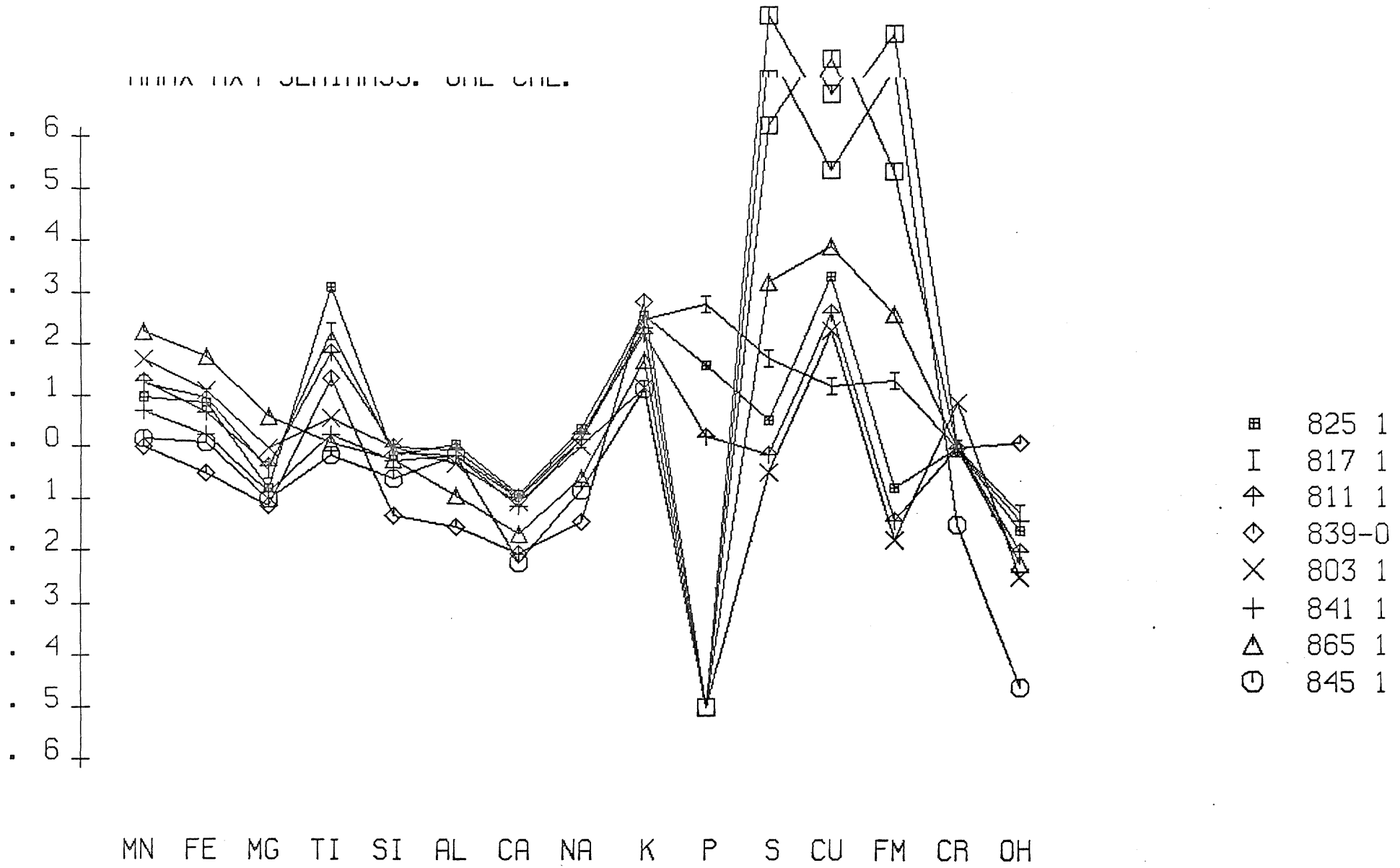
235 2
251 1
227 2
253 3
243 2
227 1
229 1
241 4
249 3
255 1
245 1
237 2
231 1

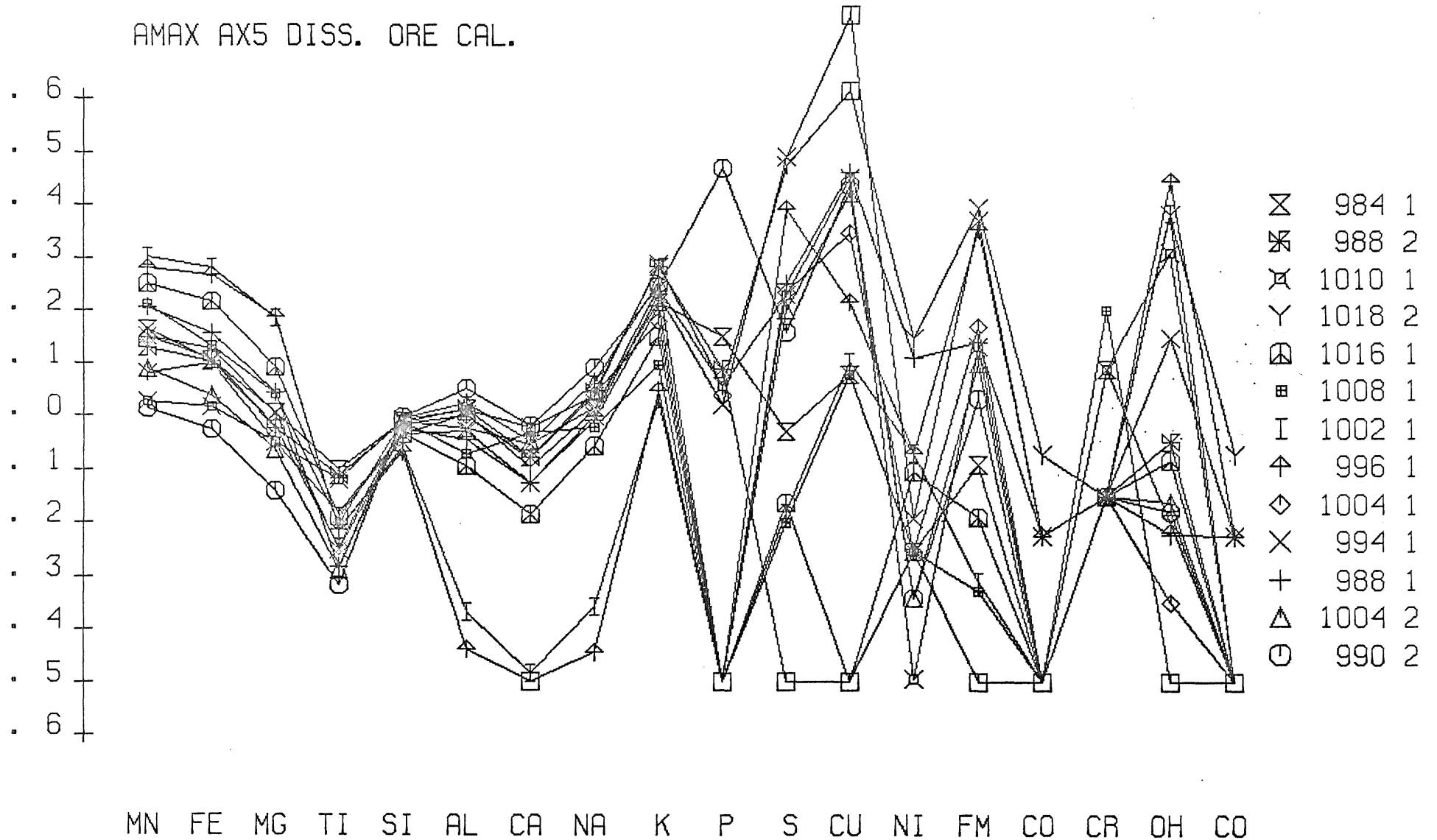

AMAX AX2 DISS. ORE CAL.
6
5
4
3
2
1
0
1
2
3
4
5
6
MN FE MG TI SI AL CA NA K P S CU NI FM CO CR OH CO
253 1
221 1
209 2
211 1
211 2
231 2
233 1
241 2
239 1
215 1
257 1
225 2
225 1

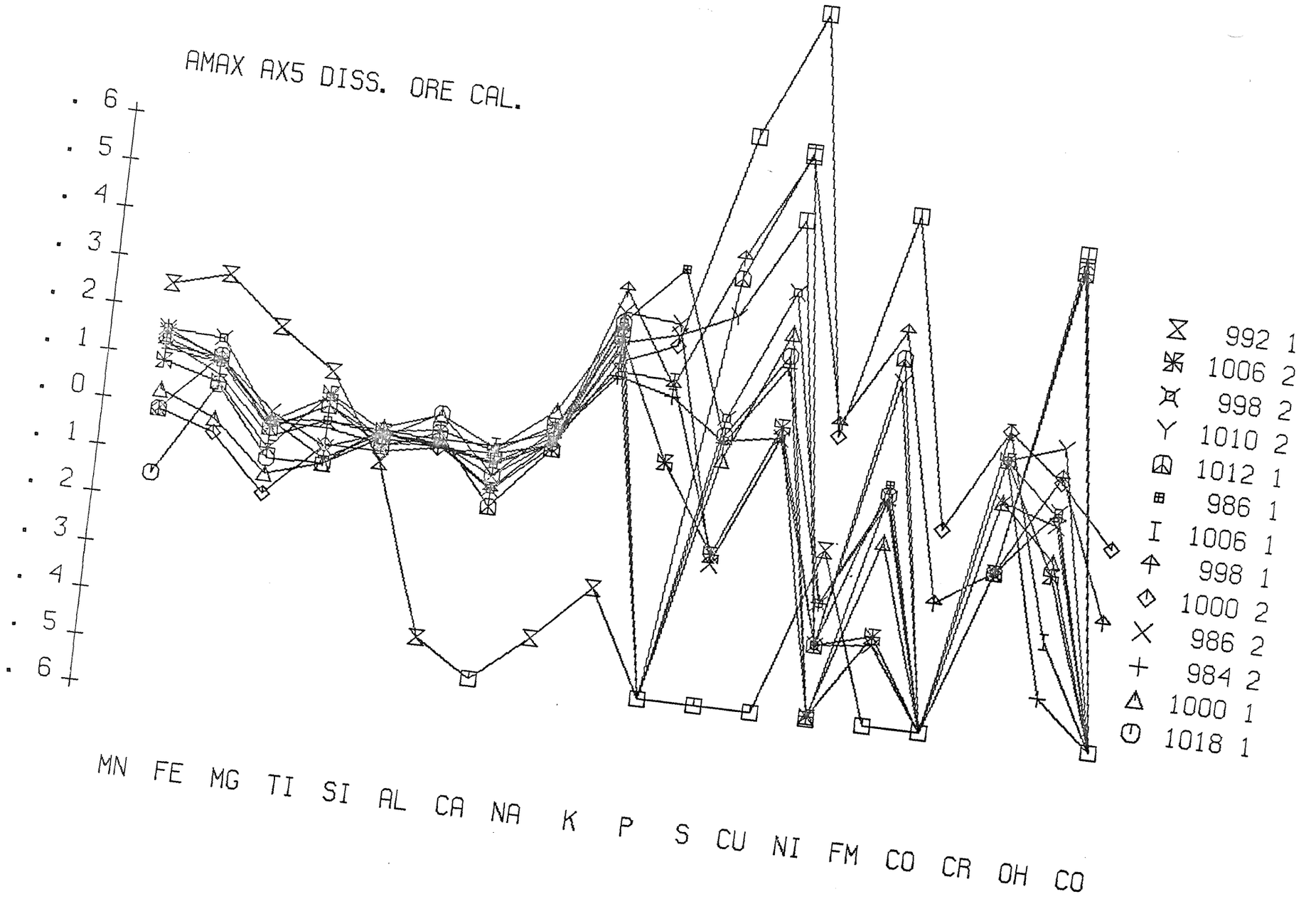

AMAX AX2 DISS. ORE CAL.
6
5
4
3
2
1
0
1
2
3
4
5
6
227 3
241 3
253 2
219 1
249 2
223 1
215 2
213 1
209 1
247 2
247 1
MN FE MG TI SI AL CA NA K P S CU NI FM CO CR OH CO

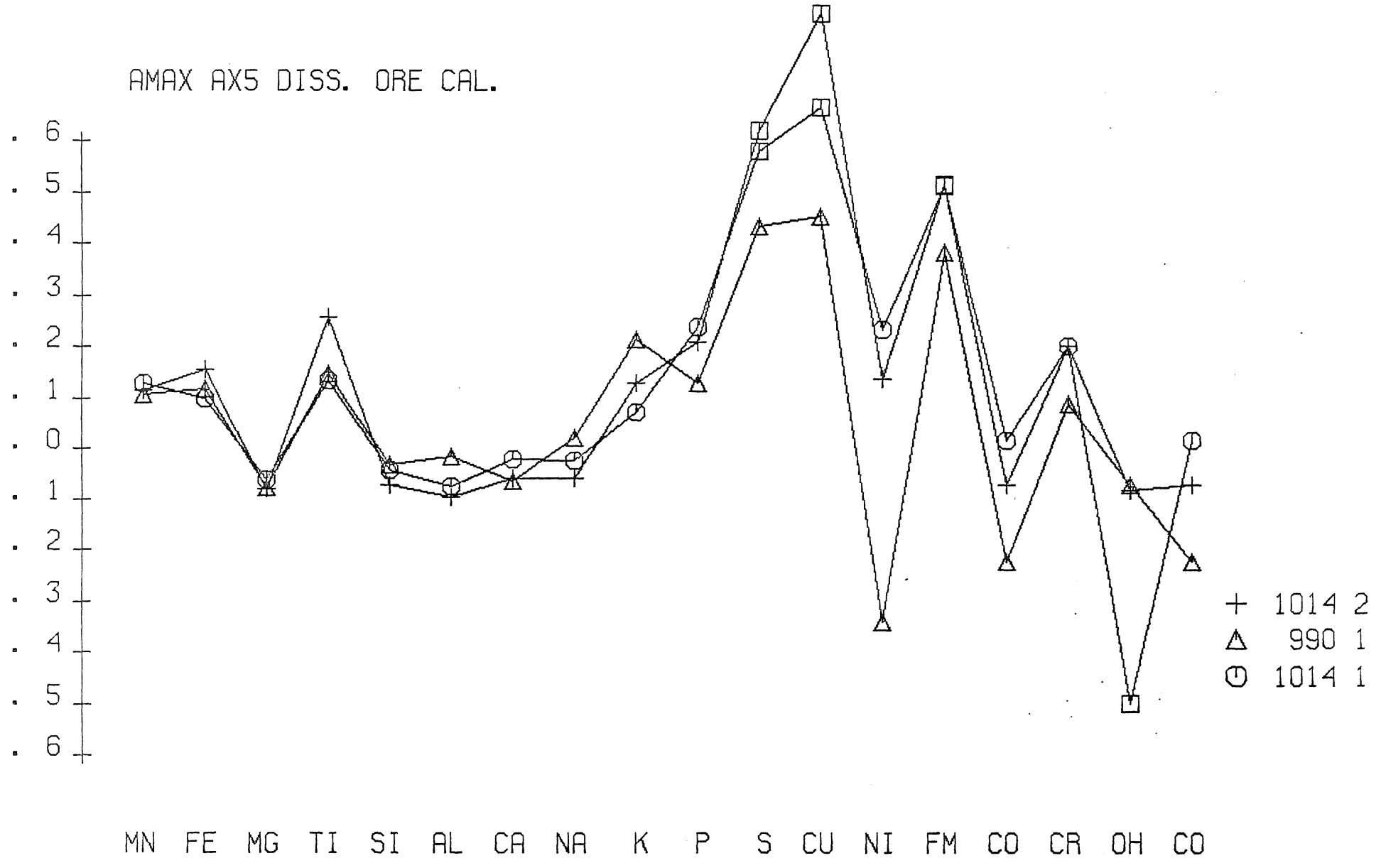

AMAX AX4 SEMIMASS. ORE CAL.
6
5
4
3
2
1
0
1
2
3
4
5
6
MN FE MG TI SI AL CA NA K P S CU FM CR OH
805 1
833 1
821 1
807 1
867 1
869 1
843 1
847 1
855 1
837 1
863 1
831 1
827 1

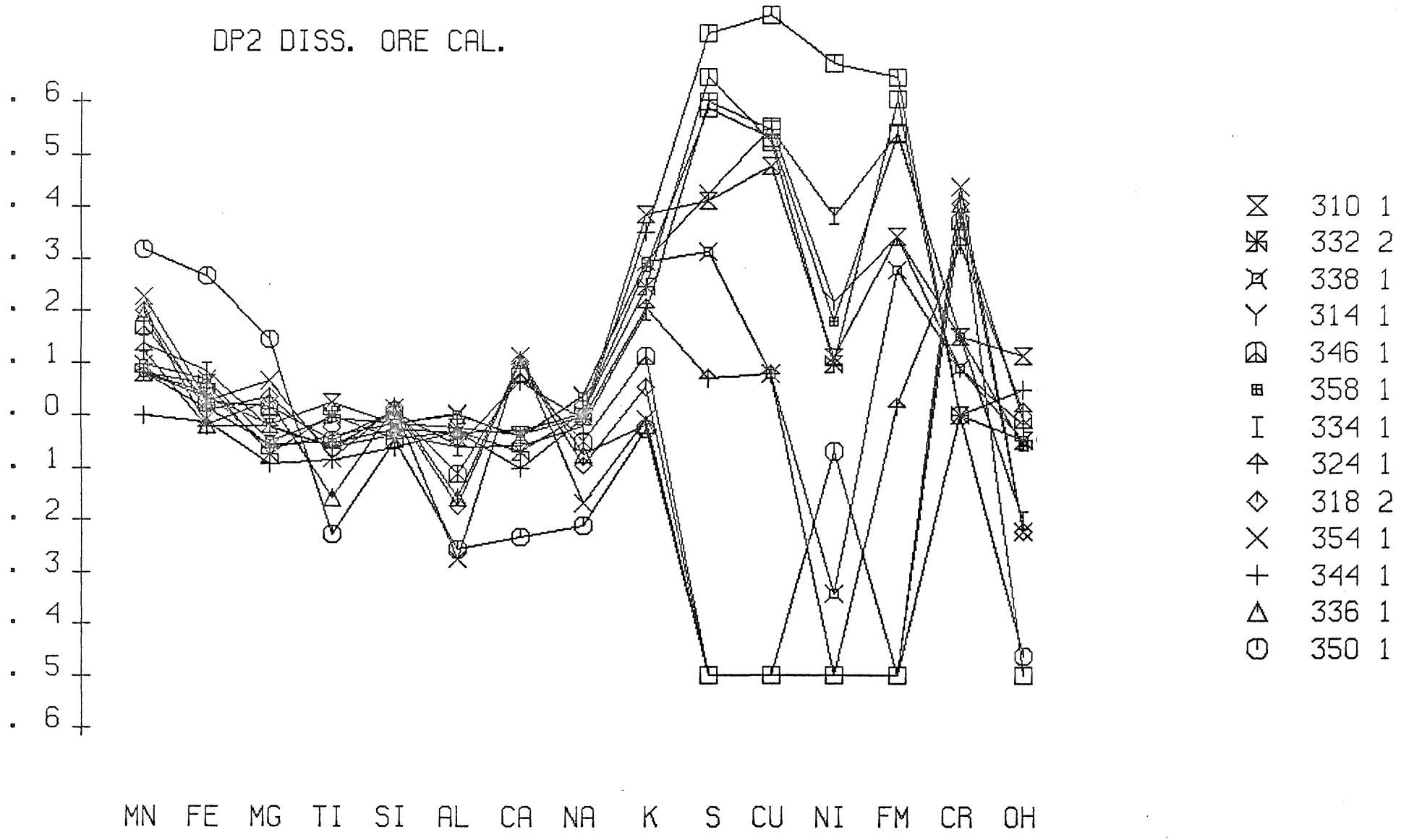

AMAX AX4 SEMIMASS. ORE CAL.
6
5
4
3
2
1
0
1
2
3
4
5
6
MN FE MG TI SI AL CA NA K P S CU FM CR OH
859 1
823 1
849 1
819 1
853 1
851 1
861 1
801 1
857 1
835 1
813 1
829 1
809 1

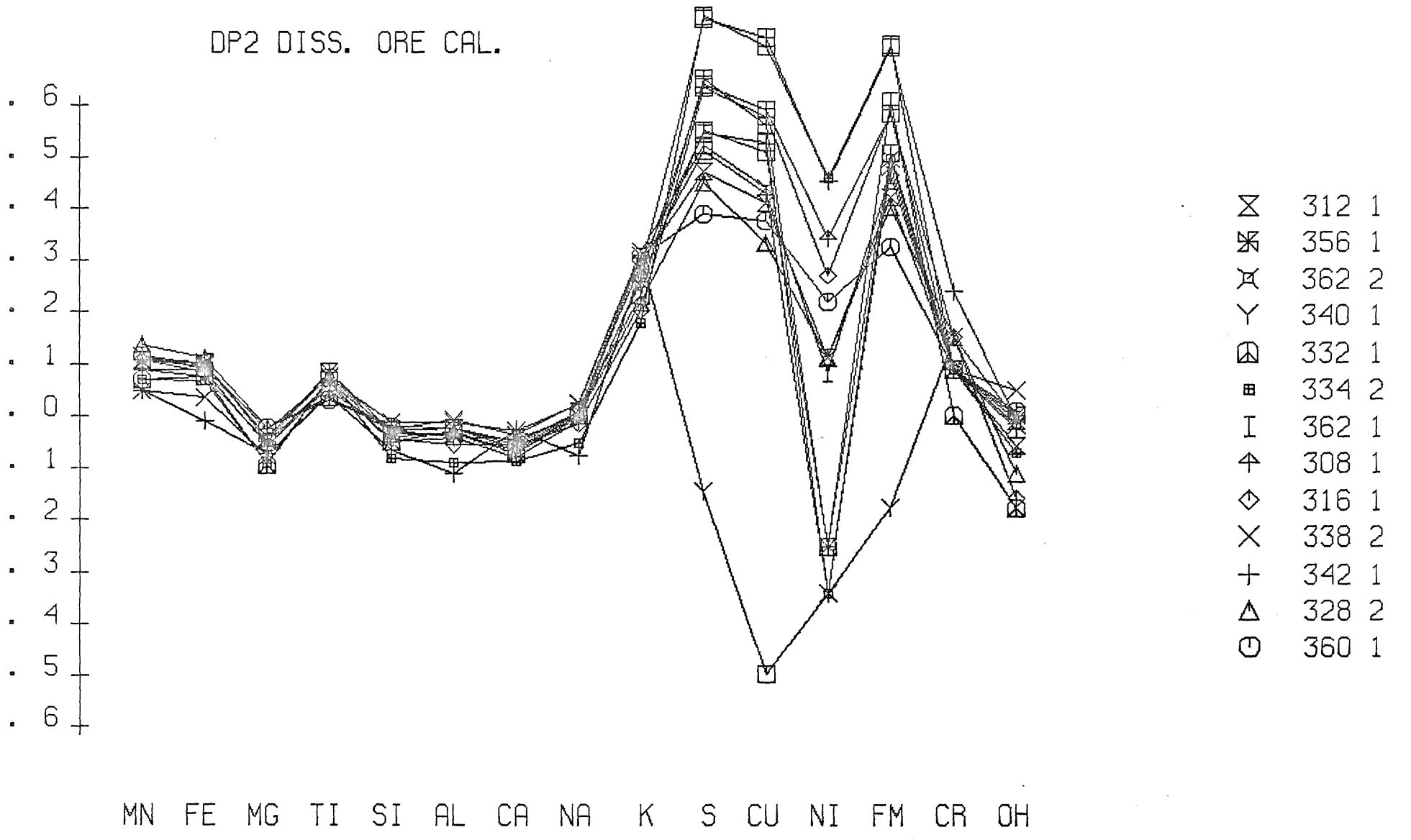

6
5
4
3
2
1
0
1
2
3
4
5
6
MN FE MG TI SI AL CA NA K P S CU FM CR OH
825 1
817 1
811 1
839-0
803 1
841 1
865 1
845 1

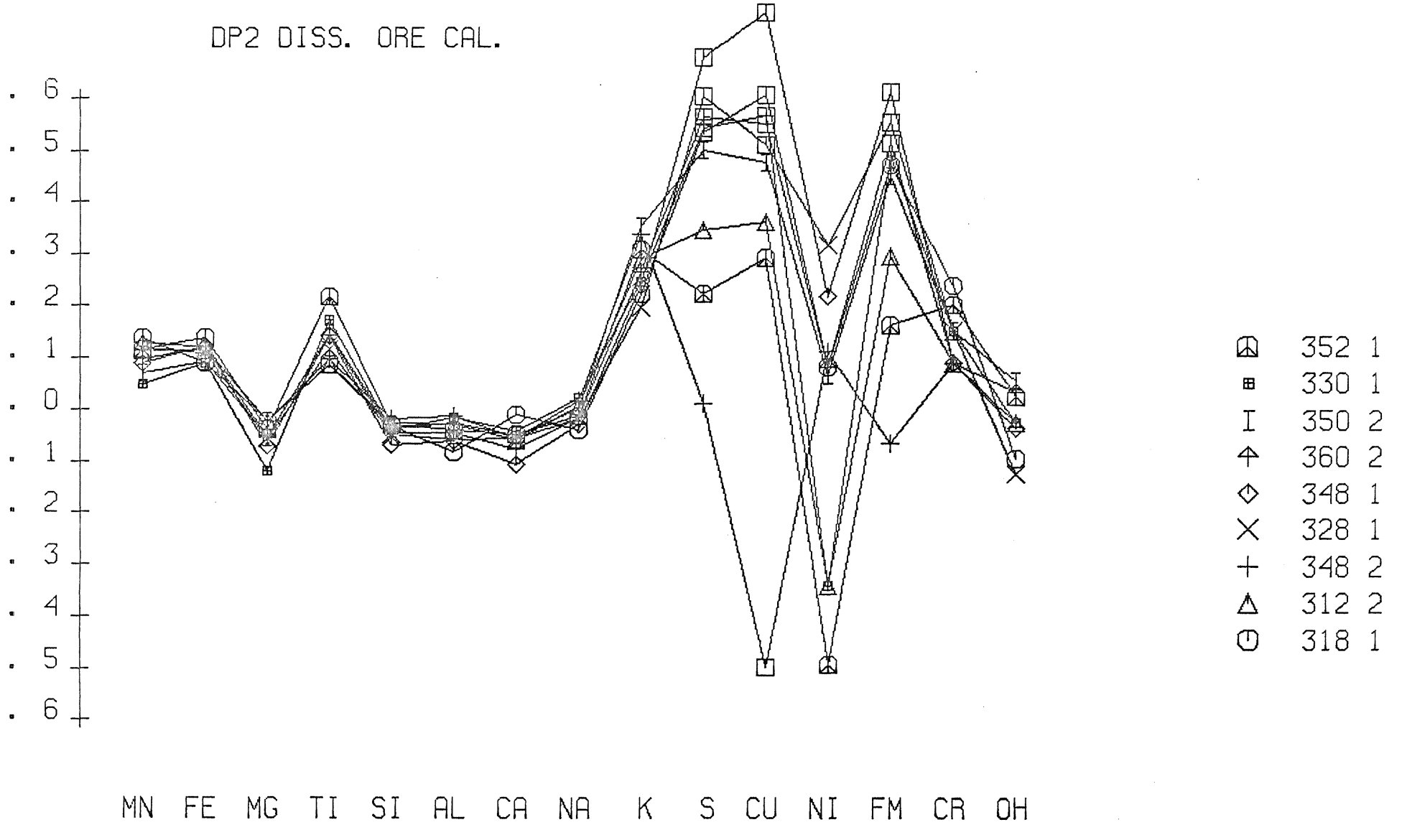

AMAX AX5 DISS. ORE CAL.
6
5
4
3
2
1
0
1
2
3
4
5
6
MN FE MG TI SI AL CA NA K P S CU NI FM CO CR OH CO
984 1
988 2
1010 1
1018 2
1016 1
1008 1
1002 1
996 1
1004 1
994 1
988 1
1004 2
990 2

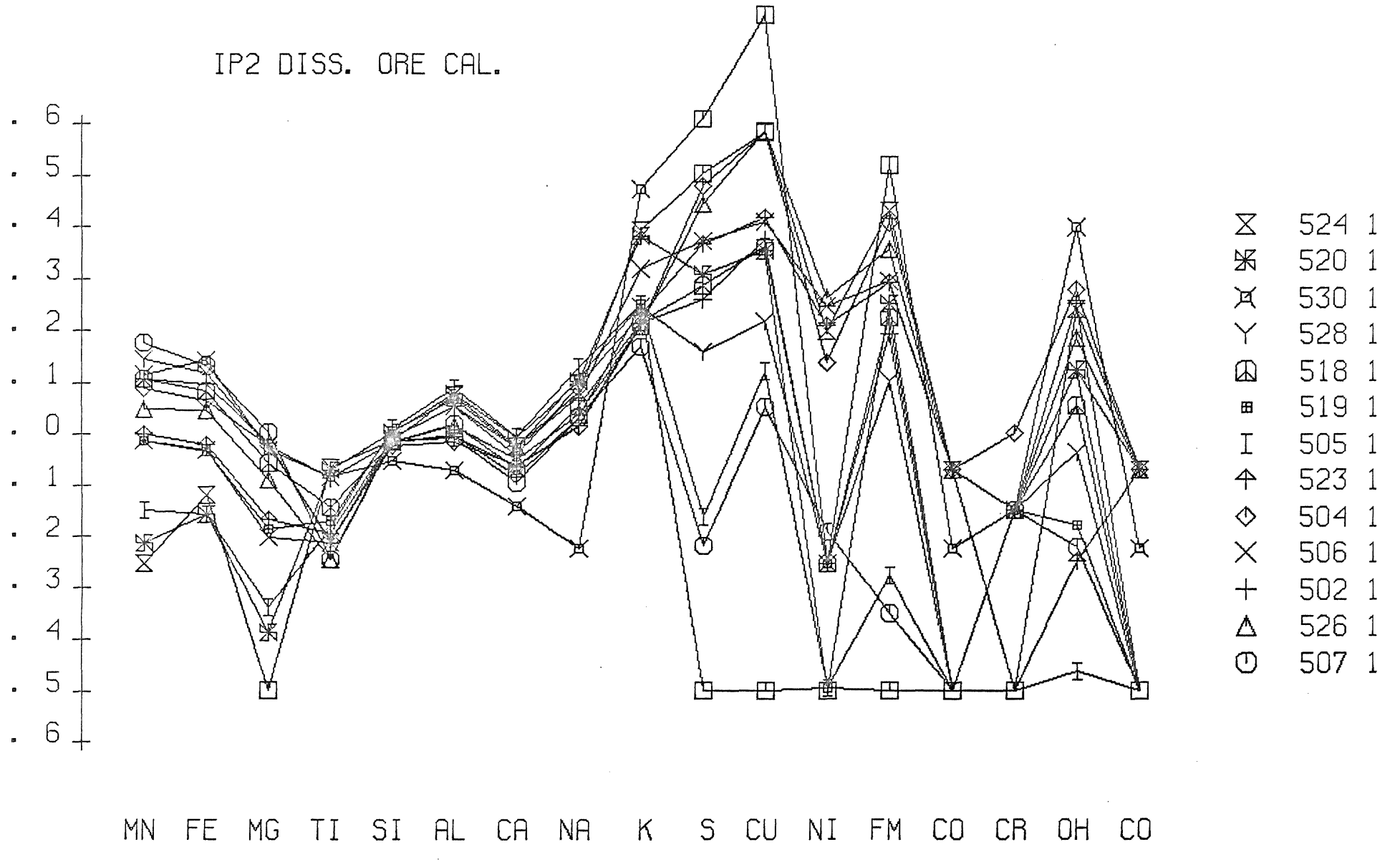

AMAX AX5 DISS. ORE CAL.
6
5
4
3
2
1
0
1
2
3
4
5
6
MN FE MG TI SI AL CA NA K P S CU NI FM CO CR OH CO
992 1
1006 2
998 2
1010 2
1012 1
986 1
1006 1
998 1
1000 2
986 2
984 2
1000 1
1018 1

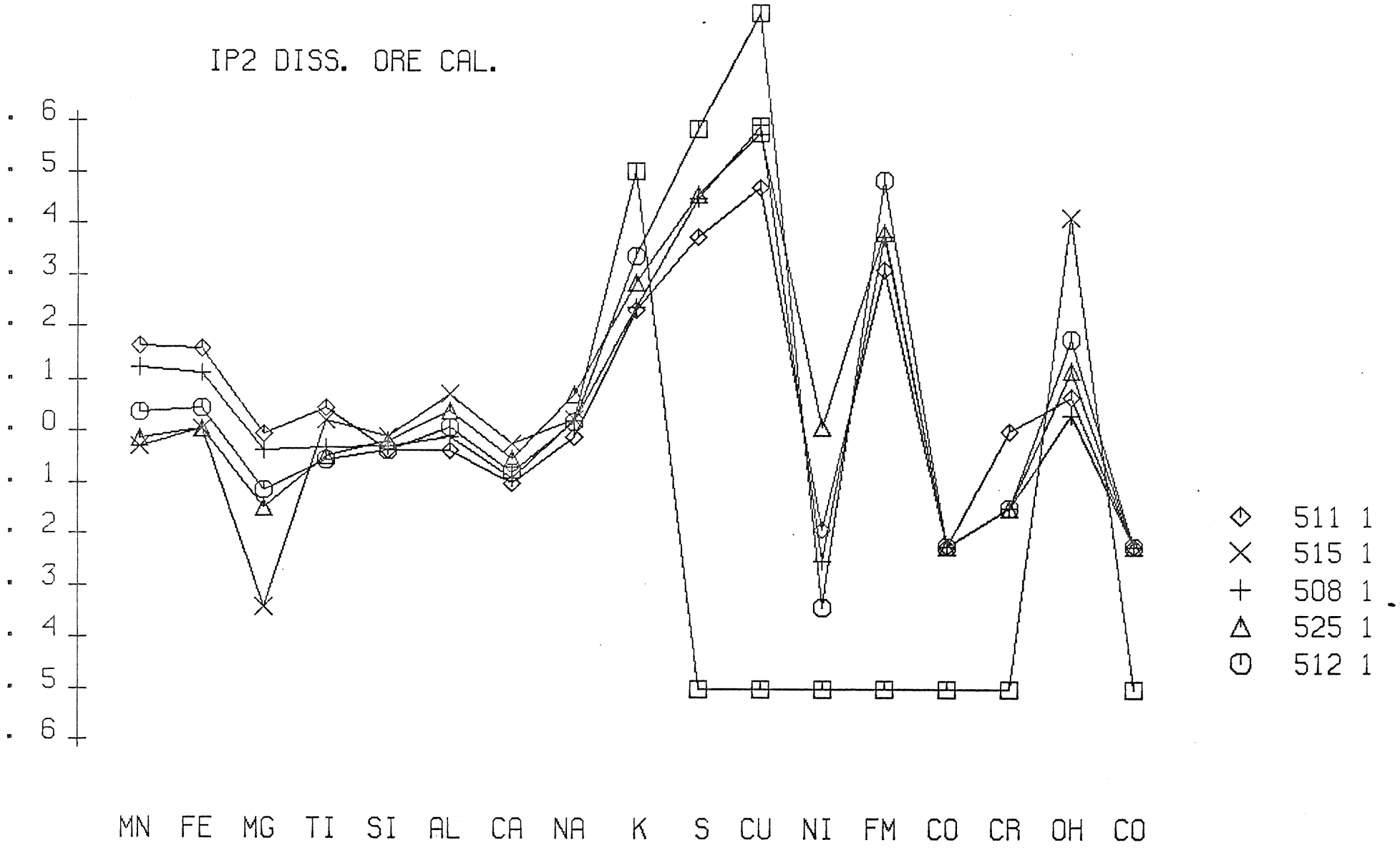

AMAX AX5 DISS. ORE CAL.
6
5
4
3
2
1
0
1
2
3
4
5
6
MN FE MG TI SI AL CA NA K P S CU NI FM CO CR OH CO
1014 2
990 1
1014 1

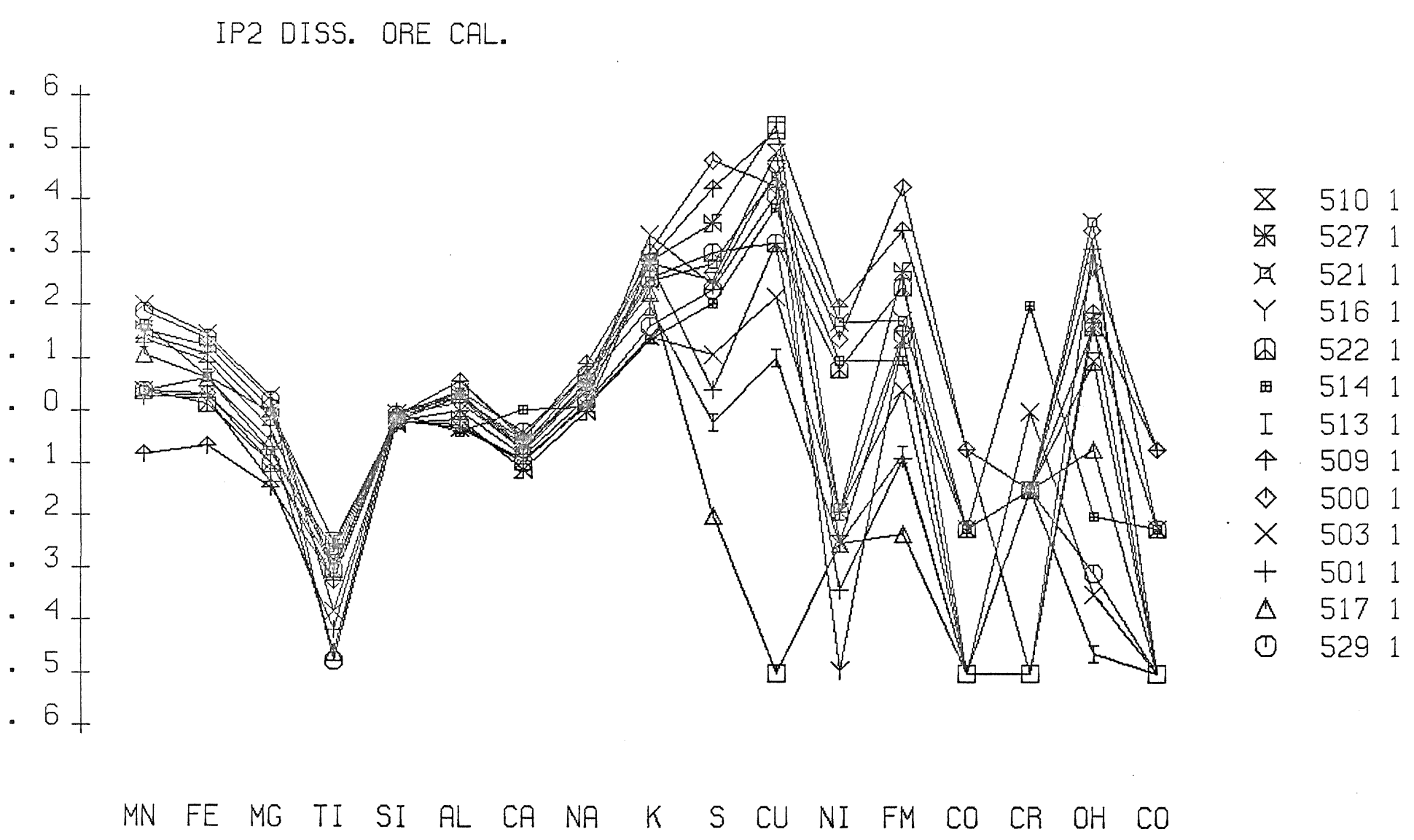

DP2 DISS. ORE CAL.
6
5
4
3
2
1
0
1
2
3
4
5
6
MN FE MG TI SI AL CA NA K S CU NI FM CR OH
310 1
332 2
338 1
314 1
346 1
358 1
334 1
324 1
318 2
354 1
344 1
336 1
350 1

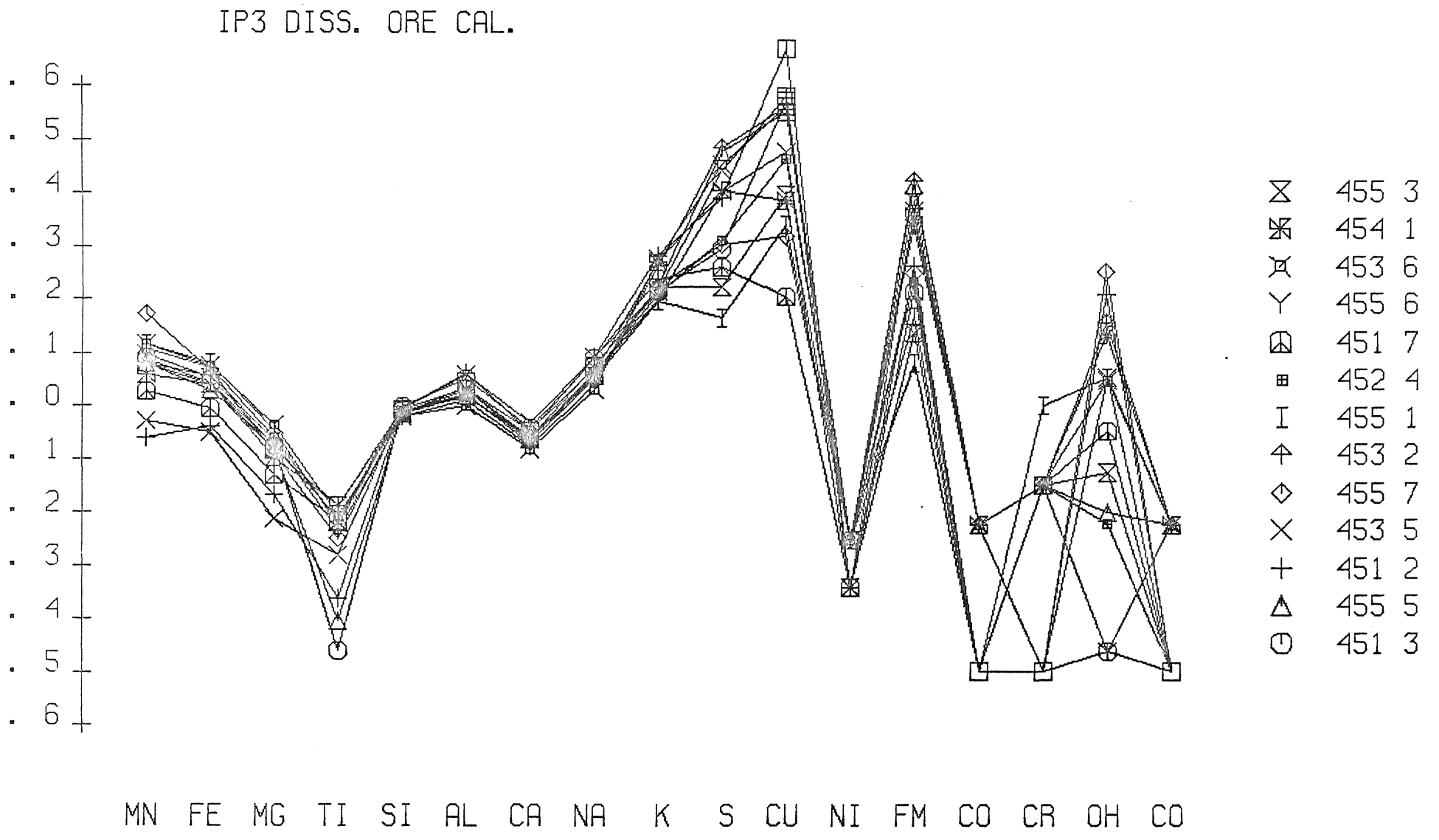

DP2 DISS. ORE CAL.
6
5
4
3
2
1
0
1
2
3
4
5
6
MN FE MG TI SI AL CA NA K S CU NI FM CR OH
312 1
356 1
362 2
340 1
332 1
334 2
362 1
308 1
316 1
338 2
342 1
328 2
360 1

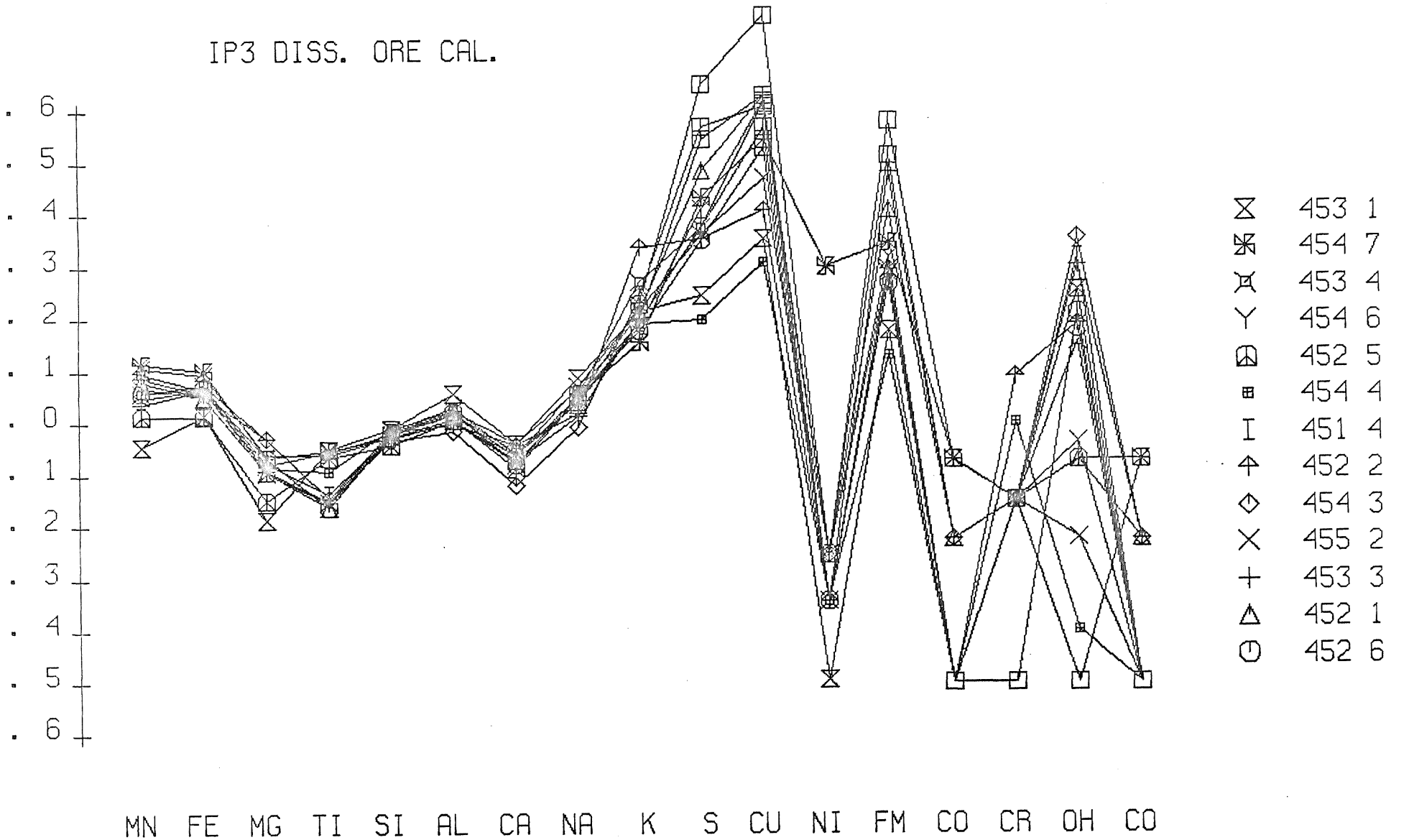

DP2 DISS. ORE CAL.
6
5
4
3
2
1
0
1
2
3
4
5
6
MN FE MG TI SI AL CA NA K S CU NI FM CR OH
352 1
330 1
350 2
360 2
348 1
328 1
348 2
312 2
318 1

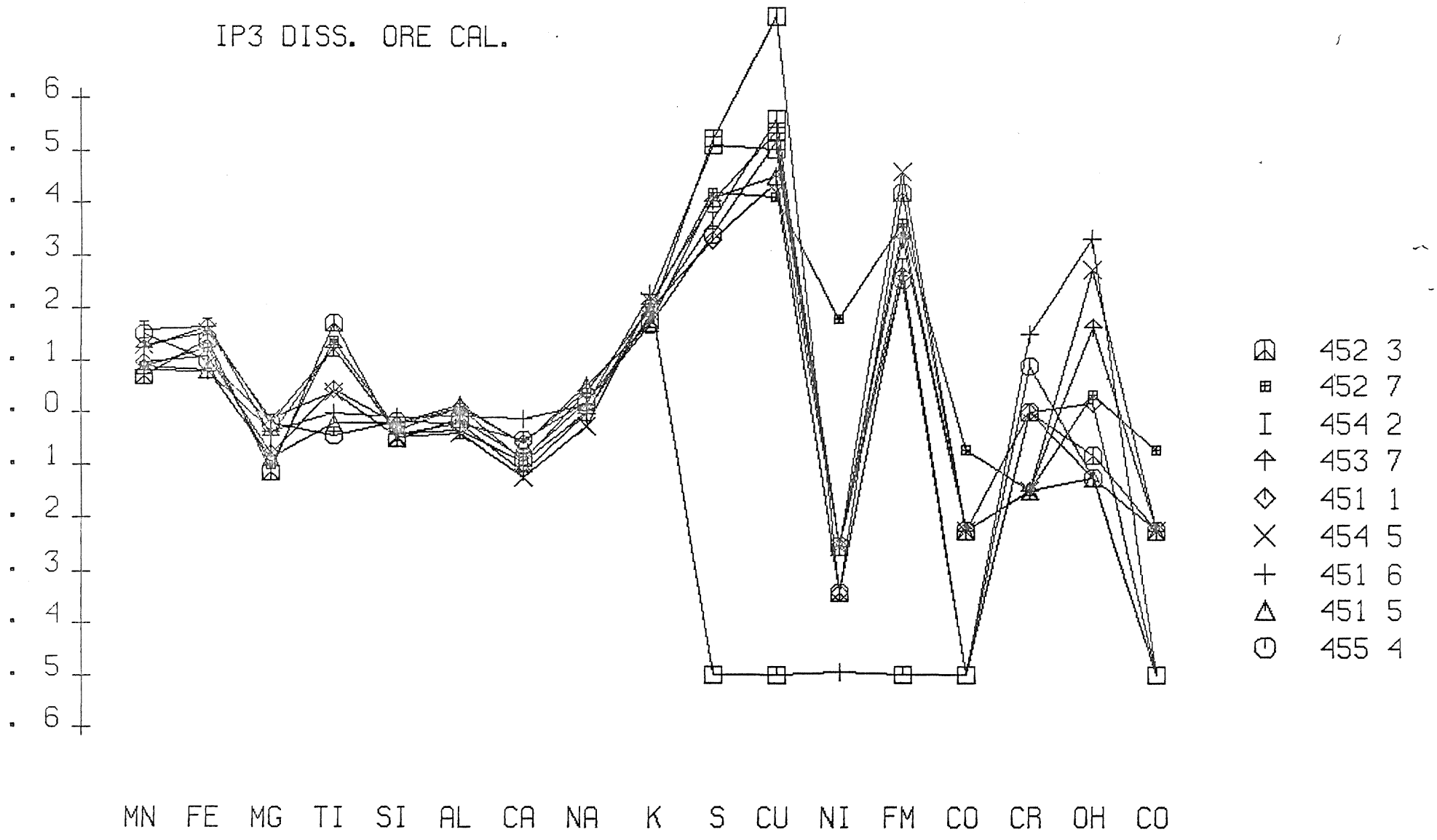

IP2 DISS. ORE CAL.
6
5
4
3
2
1
0
1
2
3
4
5
6
MN FE MG TI SI AL CA NA K S CU NI FM CO CR OH CO
524 1
520 1
530 1
528 1
518 1
519 1
505 1
523 1
504 1
506 1
502 1
526 1
507 1


IP2 DISS. ORE CAL.
6
5
4
3
2
1
0
1
2
3
4
5
6
MN FE MG TI SI AL CA NA K S CU NI FM CO CR OH CO
511 1
515 1
508 1
525 1
512 1


IP2 DISS. ORE CAL.
6
5
4
3
2
1
0
1
2
3
4
5
6
MN FE MG TI SI AL CA NA K S CU NI FM CO CR OH CO
510 1
527 1
521 1
516 1
522 1
514 1
513 1
509 1
500 1
503 1
501 1
517 1
529 1


IP3 DISS. ORE CAL.
6
5
4
3
2
1
0
1
2
3
4
5
6
MN FE MG TI SI AL CA NA K S CU NI FM CO CR OH CO
455 3
454 1
453 6
455 6
451 7
452 4
455 1
453 2
455 7
453 5
451 2
455 5
451 3


IP3 DISS. ORE CAL.
. 6
. 5
. 4
. 3
. 2
. 1
. 0
. 1
. 2
. 3
. 4
. 5
. 6
MN FE MG TI SI AL CA NA K S CU NI FM CO CR OH CO
453 1
454 7
453 4
454 6
452 5
454 4
451 4
452 2
454 3
455 2
453 3
452 1
452 6


IP3 DISS. ORE CAL.
6
5
4
3
2
1
0
1
2
3
4
5
6
MN FE MG TI SI AL CA NA K S CU NI FM CO CR OH CO
452 3
452 7
454 2
453 7
451 1
454 5
451 6
451 5
455 4