A STUDY OF SILICIC PLUTONIC ROCKS IN THE ZUNI AND FLORIDA MOUNTAINS TO EVALUATE THE POSSIBLE OCCURRENCE OF DISSEMINATED URANIUM AND THORIUM DEPOSITS

Uranium and Thorium Abundances, Whole Rock Chemistry and Trace Element Chemistry, Zuni Mountains, New Mexico

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abstract

The uranium and thorium abundances in the Precambrian silicic, core rocks of the Zuni Mountains have been determined by delayed neutron activation analysis. The average uranium content of 57 surface and drill core samples is 3.75 ppm and the average thorium content of 25 samples is 17.53 ppm. The Th/U ratio for 25 samples is 4.55 which is slightly higher than the range of 3.7 - 4.2 reported for many granitic rocks. The uranium in the Zuni Mountains has, in part, been redistributed; and significant amounts may have been removed by weathering or other processes. Combined rare earth element distribution patterns, positive U vs. K_2O correlation, and high U content in surface samples suggest local redistribution was significant. No data support the core rocks of the Zuni Mountains as a large potential *in situ* resource for uranium.

Introduction

The Zuni Mountains of New Mexico are of interest for nuclear energy considerations for several reasons. First, it has been proposed by numerous workers that, because of the proximity of the Zuni Mountains to the Grants Mineral Belt, the core rocks of the Zunis contributed uranium to the numerous deposits (See discussion in Brookins, 1976). If true, then more uranium than has been found between the Grants Mineral Belt and the Zuni Mountains may be concentrated yet undiscovered. Second, if widespread uranium loss from the Zuni Mountains can be documented, then sedimentary rocks (or other favorable rocks) in all directions surrounding the Zuni Mountains of Laramide (60 million years) or younger may have incorporated relatively high amounts of uranium. Third, some original reports of high uranium contents in the Zuni Mountains (5.6 ppm eU_3O_8; Malan and Sterling, 1969) open the possibility that the core rocks of the Zuni Mountains may be a low grade, potential in situ source for future uranium. All these possibilities have prompted the present study.

The reference map for the Zuni Mountains, modified from Goddard (1966) is shown as Fig. 1 with sample locations marked as indicated. Further, as only reconnaisance chemistry and petrography have been attempted previously (See Fitzsimmons, 1963), whole rocks have been analyzed for their major element chemistry and some for trace element abundance as well. The sample locations and descriptions are given in the Appendix.

Possible Uranium Loss from Precambrian Rocks of the Zuni Mountains

The surface (ZS) and drill core (ZM1, etc.) samples from the Zuni Mountains are of interest in that the Th/U ratio is slightly above the average for typical granitic rocks; viz. 4.5 as opposed to 3.7 - 4.0. Further, the data in Table 1, when divided into surface and specific drill hole groups, show that for drill holes ZM1 and ZM7 the Th/U ratios are quite high, vis. 5.56 and 4.78 respectively. If the assumption is made that, in view of these data, the average for the entire Zuni Mountains samples of 4.5 is due to uranium loss then it is possible to speculate on the amount of uranium which might be released by such loss. If it is further assumed that this uranium was concentrated in the post-Laramide uranium deposits of the Grants Mineral Belt, then a crude comparison can be made.

If a volume of 100 cubic kilometers are assumed to have been eroded in post-Laramide time, and that the high Th/U ratio presently observed has changed from 4.0 to 4.5 due to this weathering, then, based on the average Th content of 17.1 ppm, the original average uranium content for Th/U = 4.0 must have been 4.27 instead of the presently observed 3.75 ppm. Taking the density of granitic rocks to be 2.7 gm/cm^3, the amount of uranium released from the 100 km^3 weathered away is, based on 0.52 ppm U lost, equal to some 1.35 x 10^{11} grams (or 2.97 x 10^8 pounds). At $40/lb. this indicates that twelve billion dollars worth of uranium may have been released from the Precambrian granitic rocks of the Zuni Mountains.

To put this into more proper respective, however, it must be pointed out that the overlying sedimentary rocks also uplifted during the Laramide Orogeny (Permian through Cretaceous) may have contained even greater amounts of uranium (See Brookins and Della Valle, 1977) in which case the contribution from the Zuni Mountain core rocks is small to the overall uranium budget. However, the argument can also be made that the uranium in the sedimentary rocks was more resistant to weathering and/or more easily fixed in the nearby environment. This may be supported by the fact that even in oxidized parts of the nearby Morrison Formation (Jurassic) the uranium content of outcrop varies from 2 to 15 ppm thus suggesting fixation and retention. In the case of granitic rocks, uranium is difficult to be included in even late crystallizates during magmatic cooling, and is thus concentrated along grain boundaries, in grain defects, etc. From such sites it is more easily lost than that uranium bound in minerals such as zircon, apatite, etc. and, in terms of oxidation potentials, it requires less energy to oxidize insoluble U^{4+} to soluble U^{6+} than Fe^{2+} to Fe^{3+}. Since goethitic or hematitic staining are common throughout the Zunis then it is probable that some uranium loss <u>or</u> redistribution has occurred. If loss only occurred, then the slightly high Th/U ratio of 4.5 reflects this; if redistribution occurred, then samples with extreme variation in Th/U would be expected and the evidence for loss more clearly pronounced in surface (ZS) samples. Yet the surface samples possess Th/U = 4.04 (N=7) and at least one drill hole (ZM6) also possesses Th/U = 3.81 (n=6). In view of these arguments no clear cut case can be made for the Zuni Mountain silicic rocks to have unequivocally been responsible for the post-Laramide uranium deposits of the Grants Mineral Belt, but it is also possible that at least some of the uranium may have been derived from the Zunis.

Further, the data do not apparently support the widely accepted hypothesis that uranium content in Precambrian rocks in New Mexico (and elsewhere in the southwestern United States) increases from northeast to southwest (Malan and Sterling, 1969). While uranium content varies considerably (Table 1), the mean of 3.75 ppm is close to some of the Precambrian rocks uranium content reported by Brookins and Della Valle (1977).

Of additional interest is the behavior of thorium relative to uranium and other trace elements. The correlation of Th with U (Fig. 2) is similar to that for other rocks; the lack of correlation of Th with Hf (Fig. 3) is interesting in that in most igneous rocks a positive correlation of Th with Hf is noted. This supports the idea that weathering (or similar processes) has locally redistributed Th as well as U, and that both were largely concentrated in Zr-poor phases along grain boundaries, etc. Thus a correlation between thorium as well as uranium with the rare earth elements would not be expected.

Thorium and Uranium Abundances in the Zuni Mountains: Implications to the Grants Mineral Belt

As part of a State of New Mexico funded project the uranium and thorium abundance in a wide variety of all major Precambrian rocks exposed in the Zuni Mountains have been determined by DNAA. The data include surface samples from fresh outcrop (ZS), from quarry or road cut (Z) and from shallow drilling (ZM). The data are of interest in that the Zuni Mountains lie to the southwest of and parallel to the Grants Mineral Belt. If the ancestral Zuni Mountains directly or indirectly served as a source for uranium for the Grants Mineral Belt then this should be reflected in the Th and U abundances and in the Th/U ratio remaining in presently exposed rocks. While it is generally accepted that the presently exposed rocks were covered by Paleozoic rocks during the deposition of the Jurassic Morrison Formation, at least part of the area may have been uplifted in the Cretaceous and certainly in post-Laramide time. Consequently, if the uranium for the Grants Mineral Belt was deposited in Cretaceous or younger time then the Zuni Mountains are a convenient source due to their location at the southwestern edge of the San Juan Basin with the regional drainage presumably to the northeast.

While data for uranium are available for 57 samples only 25 samples have yet been analyzed for Th. The data are shown in Table 1 and Fig. 2. The Th samples vary from 4 to 29 ppm with a mean of 17.5 ppm while U varies from 1.8 to 7.4 ppm with a mean of 3.9 ppm. For the Th/U ratios, variation is noted between 2.27 and 7.82 with a mean of 4.55.

The Th, U contents and the Th/U ratios are typical of rocks which have not lost appreciable amounts of U or else very low U contents and proportionately higher Th/U ratios (i.e., 20-50) would be common. Since the REE plots also indicate normal behavior for granitic rocks (Figs. 5-27) then, in support of other evidence, we propose that the presently exposed rocks of the Zuni Mountains were not important contributors for the uranium of the Grants Mineral Belt.

Whole Rock Chemistry for Zuni Mountains

The detailed report on the significance of whole rock chemical study of the Zuni Mountains will be reported separately. This report will address only the aspects of relation (if any) of major element chemical variation with uranium or other trace element data.

The data for the Zuni Mountain Precambrian silicic rocks (Table 2) supports their identification as granitic; total SiO_2 varies from 62.66% (ZM7-7) to 78.16% (ZS-2) but most values fall in the 70 - 76% range. Of interest, no significant variation of SiO_2 content with depth is noted (with a few exceptions) nor is there widespread difference from drill core to surface samples. Total iron (as Fe_2O_3) varies significantly from location to location, but within individual drill holes the variation is slight. This is of importance as significant variation would indicate possible loss or redistribution of iron.

Rare Earth Distribution Patterns for the Zuni Mountains

The rare earth elements were determined by instrumental neutron activation analysis and presented in Table 3 and in Figures 4 to 26. An interesting correlation between high uranium content with negative europium anomalies is indicated for the surface (ZS) and some (ZM1) drill core samples. In Figures 4 to 26 the rare earths are ratioed to the North American Shale composite (NAS) in order to properly make comparisons with the nearby sedimentary rocks. That high uranium would be found in zones of a negative europium anomaly does not support widespread uranium loss. In fact, just the opposite is indicated (note: although it is readily admitted that correlations of this type can be challenged as the Eu is housed in rock forming minerals whereas much of the U is located along grain boundaries, etc.). In theory, a negative europium anomaly is interpreted to indicate oxidizing conditions and thus uranium loss (i.e., low abundance) would be expected. That the opposite is noted supports arguments made elsewhere that widespread uranium loss from the Zuni Precambrian rocks may have been small as opposed to local redistribution.

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TABLE 1

Thorium and Uranium Abundances Data - Zuni Mountains

Sample	Th	U	Th/U
ZM1A-2P	18.79	5.98	3.14
ZS1P	15.98	3.53	4.53
ZS4P	7.92	2.14	3.70
ZM1A-6P	18.02	3.37	5.35
ZS3P	4.07	1.79	2.27
ZM1A-5P	20.51	3.65	5.62
ZS7P	18.30	5.33	3.43
ZS2P	30.36	5.60	5.42
ZS5P	11.29	3.49	3.23
ZM65P	16.86	2.94	5.73
ZM1A-1	22.76	2.91	7.82
ZM1A-4	21.91	4.02	5.45
ZM1A-7P	20.24	3.64	5.56
ZS8P	28.60	5.02	5.70
ZM62P	14.02	2.97	4.72
ZM64P	16.54	4.44	3.73
ZM77P	17.48	3.28	5.33
ZM76P	13.63	3.46	3.94
Z10P	24.35	4.32	5.64
Z16P	14.04	4.07	3.45
ZM78P	13.44	2.64	5.09
ZM61P	11.98	3.46	3.46
ZM63P	12.22	3.67	3.33
Z25P	15.79	3.74	4.22
Z41P	29.15	7.37	3.96

TABLE 1 (continued)

Uranium Data - Zuni Mountains

#	U (ppm)	#	U (ppm)
Z-10	3.70	ZU-108	1.82
Z-13	5.88	ZU-112	3.77
Z-16	3.95	ZU-114	3.22
Z-17	5.97	ZU-104	7.23
Z-25a	3.20	ZU-115A	2.28
Z-25b	3.31	ZU-115B	2.40
Z-25c	2.99	ZU-115C	2.46
Z-28	3.06	ZU-115D	3.42
Z-30	2.58	ZU-115E	2.95
Z-35	3.04	ZU-106	5.28
Z-39	2.68	ZU-109	2.61
Z-40	3.05	ZU-110	4.74
Z-41	8.22	ZU-111	3.19
ZU-101	3.35	ZU-116	3.94
ZU-103	3.35	ZU-117	3.62
ZU-105	3.24	ZU-118	2.54

NOTES:

1) ZM = drill core samples
2) ZS = surface samples
3) Z = road cut samples
4) ZU = road cut and quarry samples; See Brookins et al. (1978)

TABLE 2

Whole Rock Analyses -- Zuni Mountains

	ZM1-1	ZM1-2	ZM1-3	ZM1-4	ZM1-5	ZM1-6	ZM1-7	ZM2-1
SiO_2	77.56	77.33	78.06	77.20	77.45	77.26	77.60	68.97
TiO_2	.18	.16	.19	.17	.17	.19	.17	.38
Al_2O_3	12.78	13.01	12.40	12.70	12.66	12.50	12.36	15.49
Fe_2O_3	1.02	1.07	1.25	1.05	1.02	1.26	1.13	3.42
MgO	.11	.09	.02	.15	.09	.07	.07	.47
CaO	.28	.10	.17	.26	.17	.26	.26	2.16
Na_2O	1.92	2.04	1.85	2.45	2.20	2.63	2.82	3.61
K_2O	5.24	5.39	5.35	5.27	5.57	5.26	5.13	4.03
total	99.09	99.19	99.29	99.25	99.33	99.43	99.54	98.53

	ZM2-2	ZM2-3	ZM2-4	ZM2-5	ZM2-6	ZM2-7	ZM2-8	ZM6-1
SiO_2	69.90	71.62	71.95	63.12	72.54	71.82	70.05	69.66
TiO_2	.34	.31	.34	.37	.30	.31	.32	.91
Al_2O_3	15.17	14.80	14.95	18.52	13.66	14.04	14.71	14.67
Fe_2O_3	3.10	2.91	2.99	2.94	2.73	2.88	2.91	5.19
MgO	.33	.09	nd	.75	nd	.18	.25	.20
CaO	2.14	1.68	1.46	3.52	2.30	1.95	2.66	.79
Na_2O	3.72	3.18	2.80	5.37	3.30	3.23	3.68	4.53
K_2O	3.79	3.88	3.99	3.67	3.59	4.12	3.60	3.90
total	98.49	98.47	98.48	98.26	98.42	98.53	98.18	99.85

	ZM6-2	ZM6-3	ZM6-4	ZM7-1	ZM7-2	ZM7-3	ZM7-4	ZM7-5
SiO_2	69.77	70.22	69.88	73.60	73.15	73.16	73.24	75.31
TiO_2	.96	.89	.85	.25	.30	.33	.34	.30
Al_2O_3	14.61	14.53	14.06	14.05	14.01	14.46	14.82	13.52
Fe_2O_3	5.11	4.97	4.56	1.25	1.89	1.36	1.48	1.62
MgO	.49	.58	.47	.03	.16	.11	.12	.12
CaO	.46	.77	1.60	1.77	1.26	1.13	.62	.44
Na_2O	4.71	3.95	3.58	3.43	3.82	4.20	4.50	3.34
K_2O	3.96	3.83	4.17	4.25	4.34	4.39	4.30	4.69
total	100.07	99.74	99.17	98.63	98.93	99.14	99.42	99.34

	ZM7-6	ZM7-7	ZM7-8	ZM8-1	ZM8-2	ZM8-3	ZM8-4	ZM8-5
SiO_2	72.48	62.66	76.73	77.92	75.13	75.30	76.33	76.88
TiO_2	.54	.45	.26	.11	.16	.19	.20	.08
Al_2O_3	14.18	19.90	12.33	11.63	13.40	13.29	13.22	13.00
Fe_2O_3	2.00	1.82	1.21	1.30	1.43	1.33	1.19	.56
MgO	.25	.34	.10	.06	.08	.09	nd	.11
CaO	.67	.57	1.15	.56	.36	.42	.16	.15
Na_2O	5.49	11.99	2.81	3.54	3.84	3.52	3.22	3.55
K_2O	4.18	3.34	4.53	4.60	5.12	5.33	5.26	5.30
total	99.79	101.07	99.12	99.72	99.52	99.47	99.58	99.63

	ZM8-6	ZM8-7
SiO_2	77.26	75.62
TiO_2	.12	.20
Al_2O_3	12.76	13.38
Fe_2O_3	.81	1.08
MgO	.02	.07
CaO	.18	.45
Na_2O	3.25	4.00
K_2O	5.26	4.79
total	99.66	99.59

ZUNI MOUNTAINS -- SURFACE SUITE

	ZS-1	ZS-2	ZS-3	ZS-4	ZS-5	ZS-6	ZS-7	ZS-8
SiO_2	72.96	78.16	69.28	65.09	70.60	76.97	75.95	77.51
TiO_2	.46	.12	.26	.61	.50	.14	.28	.04
Al_2O_3	13.72	12.19	16.72	16.12	15.28	12.23	12.84	12.34
Fe_2O_3	2.64	.98	2.28	4.29	3.39	1.22	1.66	.83
MgO	.08	.04	.62	1.26	.34	.16	.05	.17
CaO	1.08	.26	2.50	2.75	1.38	.34	.55	.20
Na_2O	3.48	3.04	5.48	5.07	2.51	3.16	3.78	3.35
K_2O	4.71	4.85	2.65	4.47	4.62	5.23	4.44	4.87
total	99.13	99.64	98.79	99.66	98.62	99.45	99.55	99.31

	ZS-9	ZS-10
SiO_2	67.56	75.01
TiO_2	.63	.10
Al_2O_3	14.37	13.12
Fe_2O_3	4.61	1.49
MgO	.83	.20
CaO	2.49	.51
Na_2O	4.62	3.99
K_2O	3.84	4.98
total	98.95	99.40

TABLE 3

INAA Data

	ZS-1	ZS-2	ZS-3	ZS-4	ZS-5	ZS-6	ZS-7	ZS-8
Na(%)	2.98	3.52	4.02	3.81	2.13	2.89	3.27	3.32
Fe(%)	2.71	1.38	2.44	3.70	3.04	1.60	1.73	1.02
K (%)	3.18	2.86	1.59	2.45	2.41	4.07	3.17	2.59
La	109.6	24.10	16.40	37.22	37.15	54.46	56.24	13.31
Ce	161.1	81.00	32.62	63.71	79.32	103.06	102.18	47.64
Nd	88.51	20.51	14.00	36.47	53.00	81.74	45.65	15.76
Sm	13.20	4.73	2.49	4.70	7.31	10.13	10.34	5.24
Eu	3.10	0.21	0.72	1.43	1.89	0.56	1.96	0.34
Gd	---	---	---	---	---	---	---	---
Tb	1.88	0.82	0.36	0.72	0.75	1.57	1.33	1.11
Ho	---	---	---	---	---	---	---	---
Tm	0.72	0.49	0.17	0.24	0.45	0.64	0.56	0.54
Yb	7.79	5.12	1.12	1.20	4.22	5.40	5.47	6.42
Lu	1.07	0.86	0.14	0.18	0.65	0.98	0.94	1.00
Ba	863.01	287.3	712.0	1077.5	1264.4	302.9	725.9	
Th		27.32	5.67	7.76	12.88	28.06	18.75	
Cr	29.21	16.51	19.34	53.83	19.85	19.30	16.45	18.93
Rb	211.10	344.6	83.26	175.12	234.9	287.6	174.4	252.7
Hf	10.52	4.18	2.62	5.56	7.63	6.19	7.80	5.40
Zr	356.6	158.9	246.75	287.3	253.1	316.7	310.0	
Ni	22.64	1.86	5.34	6.51	19.05	19.55	33.31	
Sc	8.75	2.40	4.19	7.29	8.87	3.73	5.13	
Co	2.48	1.14	5.45	9.31	5.01	1.63	1.92	0.73
Sb	0.13	---	---	---	2.71	0.16	0.52	0.19

TABLE 3

INAA Data

	Z-17	Z-28	Z-30	Z-35
Na(%)	2.90	3.60	3.01	2.41
Fe(%)	1.07	0.88	3.91	1.03
K (%)	3.52	2.54	2.11	2.14
La	26.78	27.17	25.44	37.77
Ce	63.13	40.41	54.10	64.96
Nd	47.15	44.18	28.10	48.11
Sm	4.94	8.89	3.66	6.47
Eu	0.40	0.66	0.86	1.25
Gd	---	---	---	---
Tb	0.56	1.23	0.42	0.93
Ho	---	---	---	---
Tm	0.52	0.60	0.31	0.39
Yb	4.39	6.55	1.48	3.26
Lu	0.72	1.02	0.39	0.56
Ba		49.34	797.0	706.9
Th	39.92	16.65	10.26	11.16
Cr	8.87	7.05	41.45	7.65
Rb	299.6	246.9	125.17	125.7
Hf	3.97	5.84	4.28	5.50
Zr	136.4	293.4	169.8	177.4
Ni	3.88	5.64	4.89	
Sc	0.97	5.32	10.00	4.22
Co	1.31	0.80	12.44	1.56
Sb	0.24	0.23	0.01	0.86

TABLE 3

INAA Data

	ZM1A-1	ZM1A-2	ZM1A-3	ZM1A-4	ZM1A-5	ZM1A-6	ZM1A-7
Na(%)	2.16	3.39	3.72	2.30	4.37	2.37	2.57
Fe(%)	1.35	1.88	2.36	1.27	2.61	1.58	1.39
K (%)	3.04	5.69	4.88	3.41	6.83	3.06	3.56
La	56.22	85.21	108.46	59.45	137.03	68.77	62.95
Ce	85.93	138.32	158.44	105.17	190.14	98.09	125.09
Nd	63.15	109.80	125.10	64.53	23.25	75.71	83.20
Sm	11.11	17.91	21.21	11.92	26.21	12.52	12.76
Eu	1.09	2.11	2.76	1.27	2.59	1.48	1.43
Gd	---	---	---	---	---	---	---
Tb	1.64	2.88	2.92	0.20	4.17	1.54	1.87
Ho	---	---	---	---	---	---	---
Tm	0.81	1.19	1.20	0.72	1.25	0.68	0.80
Yb	7.98	11.66	12.34	6.73	15.15	7.30	7.00
Lu	1.20	1.79	1.87	1.08	2.22	1.08	1.17
Mo	---	---	---	---	---	---	---
Ba	285.0	417.4	665.2	389.1	764.49	407.4	309.2
Ga	---	---	---	---	---	---	---
As	---	---	---	---	---	---	---
Br	---	---	---	---	---	---	---
Th	20.83	34.24	35.58	22.06	41.76	19.85	21.73
Cr	24.88	18.15	27.76	26.48	34.69	26.08	19.33
Rb	262.1	401.70	465.8	250.8	521.9	278.2	286.5
Hf	5.22	9.27	11.37	5.63	11.54	5.60	5.73
Zr	265.0	204.9	718.72	203.8	480.52	175.0	338.16
Cs	---	---	---	---	---	---	---
Ni	7.97	5.56	13.04	10.62	16.20	1.54	4.00
Sc	5.00	7.37	8.97	4.94	9.75	4.86	5.08
Co	1.34	1.31	1.61	1.29	1.39	0.90	1.73
Sb	0.24	0.63	1.02	0.29	1.56	0.10	0.21
Ta	---	---	---	---	---	---	---

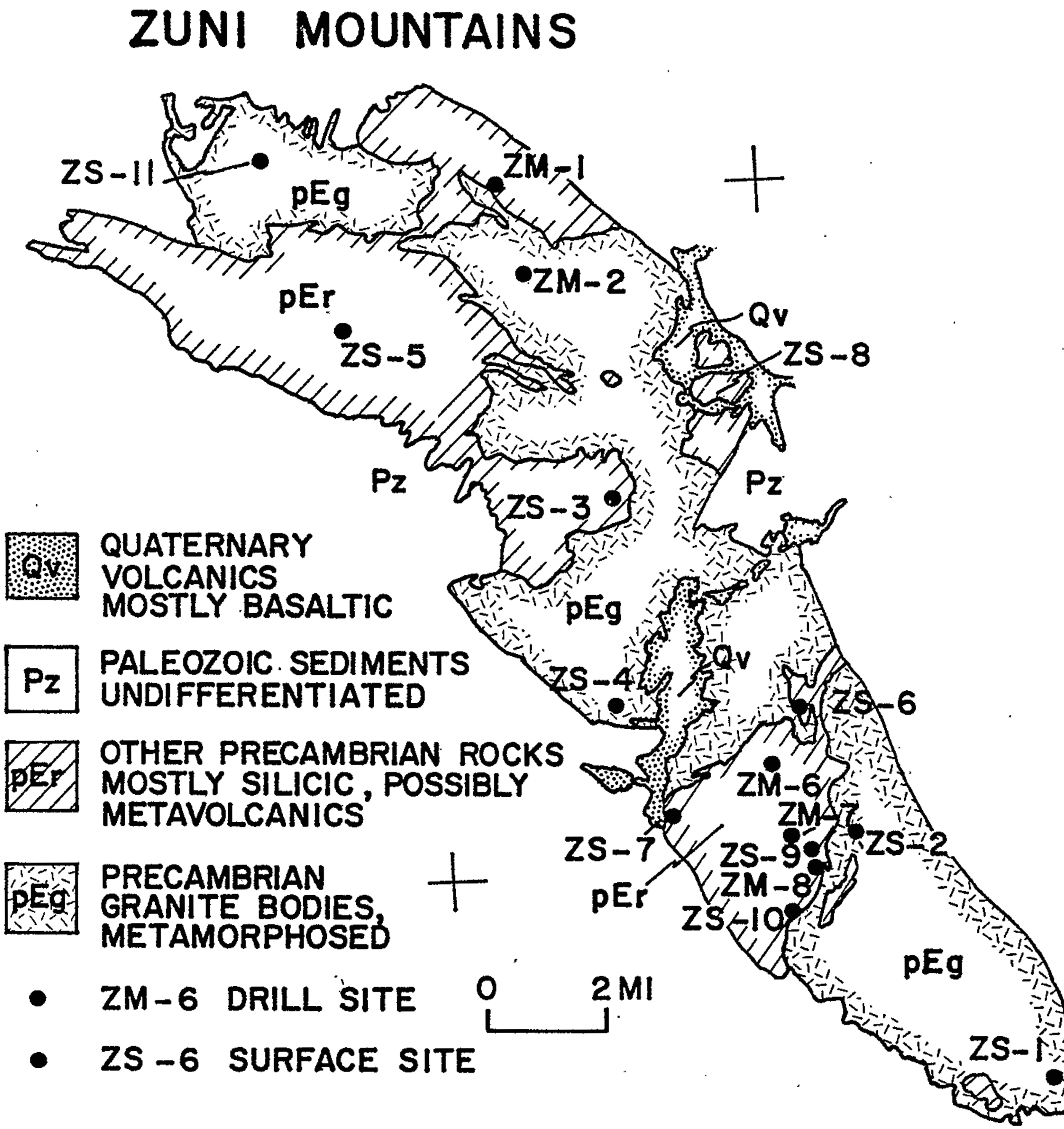

ZUNI MOUNTAINS
ZS-11
pEg
ZM-1
ZM-2
pEr
ZS-5
Qv
ZS-8
Pz
ZS-3
Pz
QUATERNARY
VOLCANICS
MOSTLY BASALTIC
Qv
PALEOZOIC SEDIMENTS
UNDIFFERENTIATED
Pz
OTHER PRECAMBRIAN ROCKS
MOSTLY SILICIC, POSSIBLY
METAVOLCANICS
pEr
PRECAMBRIAN
GRANITE BODIES,
METAMORPHOSED
pEg
ZM-6 DRILL SITE
ZS-6 SURFACE SITE
0
2 MI
pEg
ZS-4
Qv
ZS-6
ZM-6
ZM-7
ZS-2
ZS-7
ZS-9
ZM-8
pEr
ZS-10
pEg
ZS-1

FIGURE 1

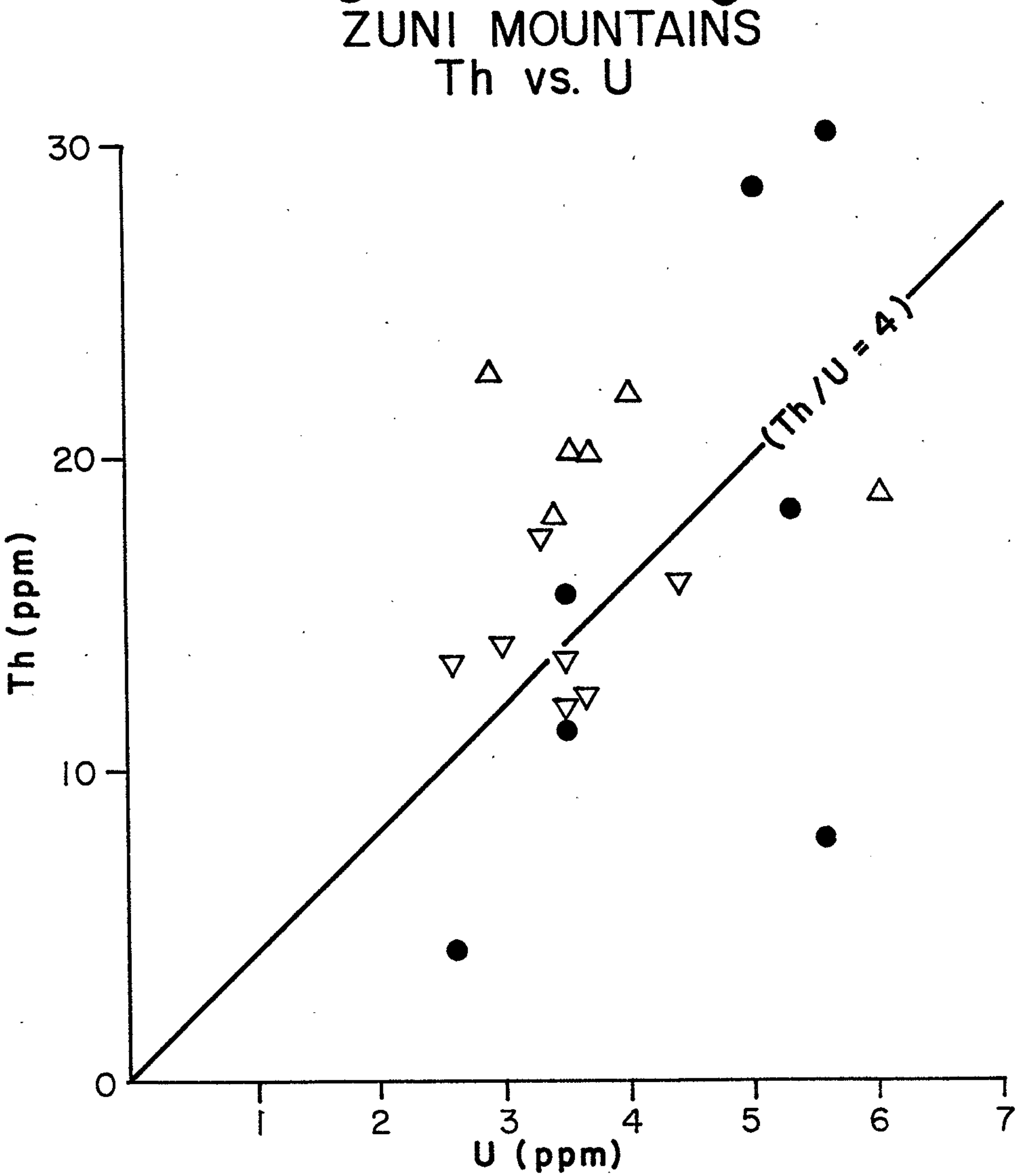


FIGURE 2

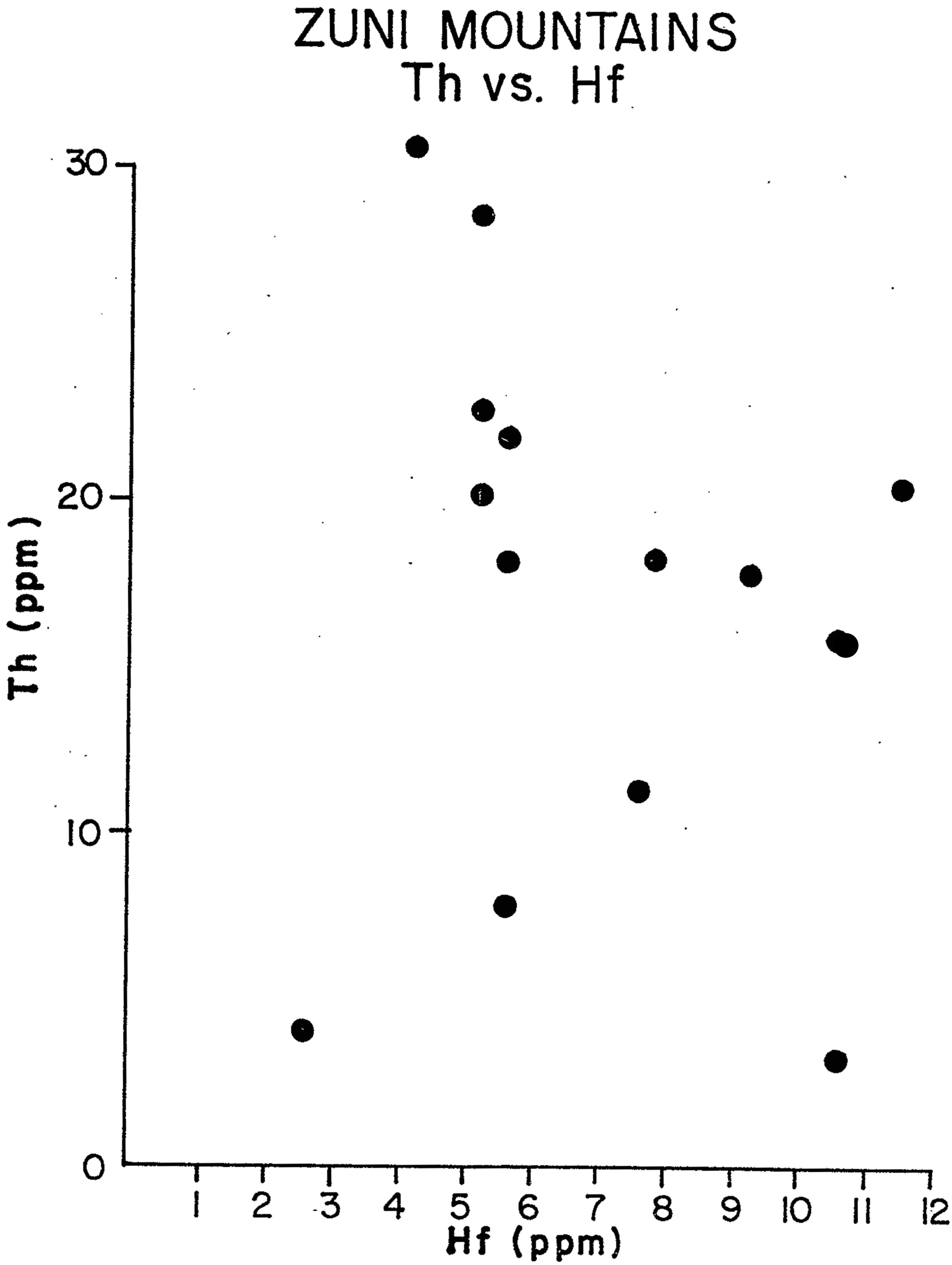

ZUNI MOUNTAINS
Th vs. Hf
30
20
10
0
Th (ppm)
1
2
3
4
5
6
7
8
9
10
11
12
Hf (ppm)

FIGURE 3

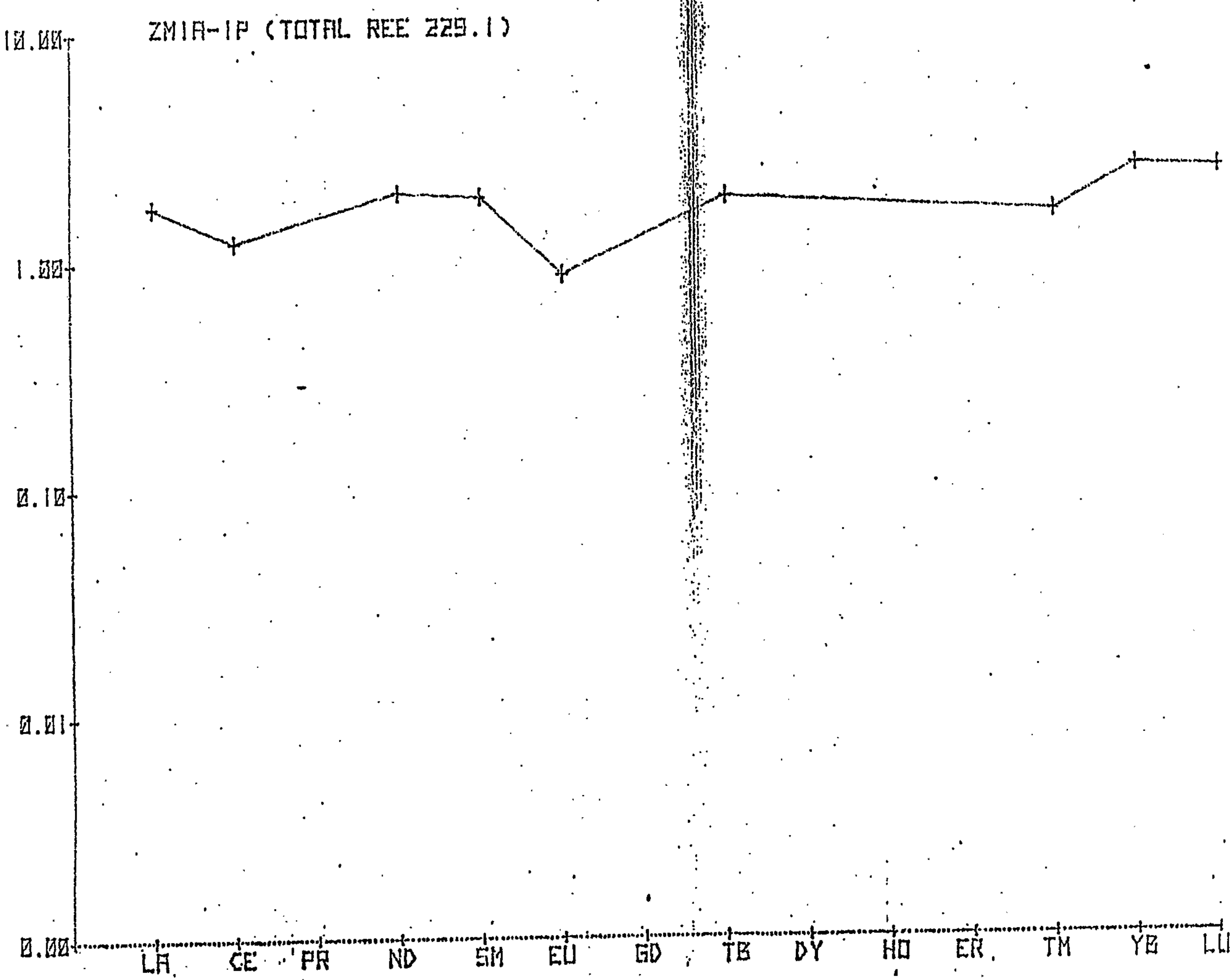

ZM1A-1P (TOTAL REE 229.1)
10.00
1.00
0.10
0.01
0.00
LA
CE
PR
ND
SM
EU
GD
TB
DY
HO
ER
TM
YB
LU

Figure 4

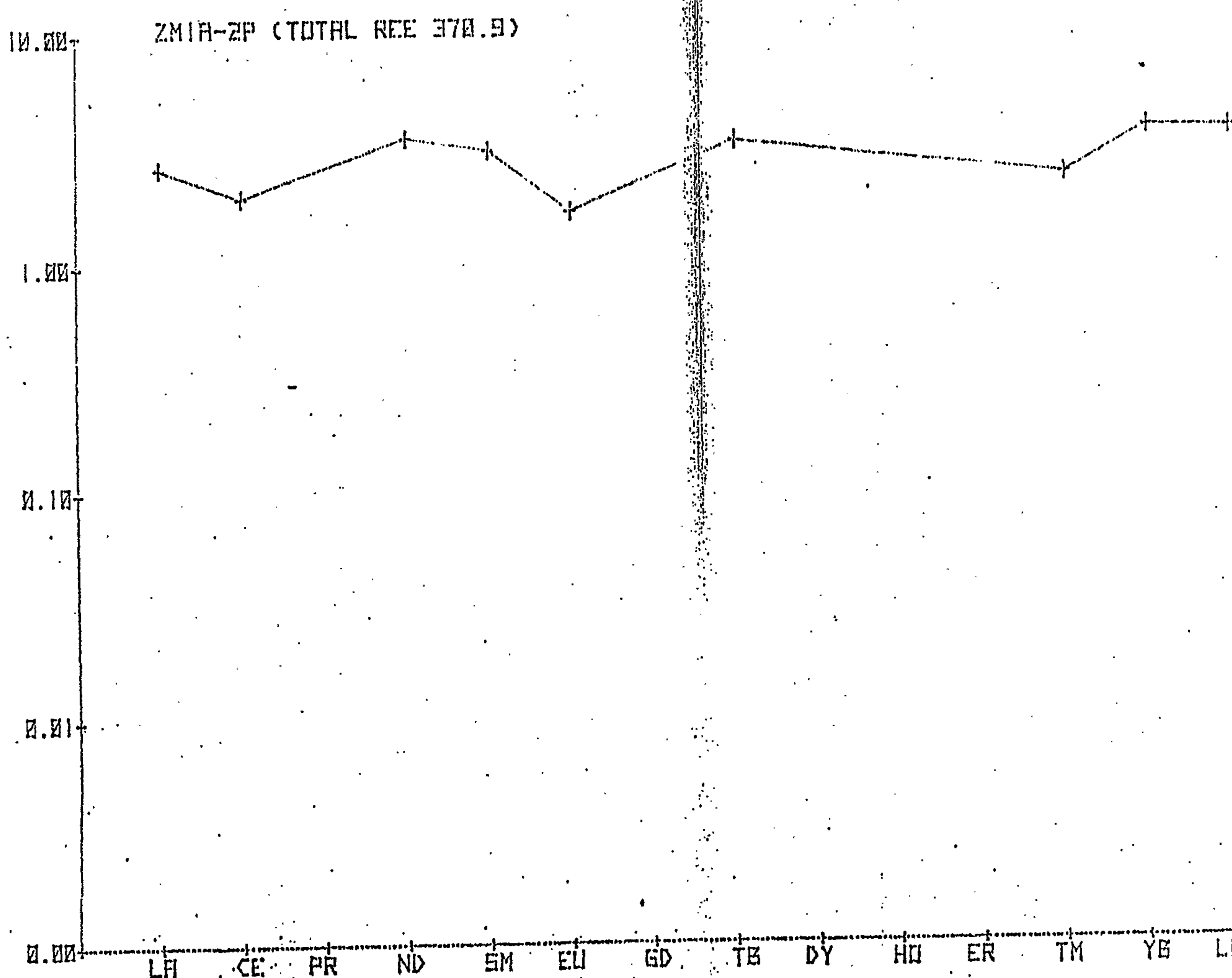

ZMIA-ZP (TOTAL REE 370.9)
10.00
1.00
0.10
0.01
0.00
LA
CE
PR
ND
SM
EU
GD
TB
DY
HO
ER
TM
YB

Figure 5

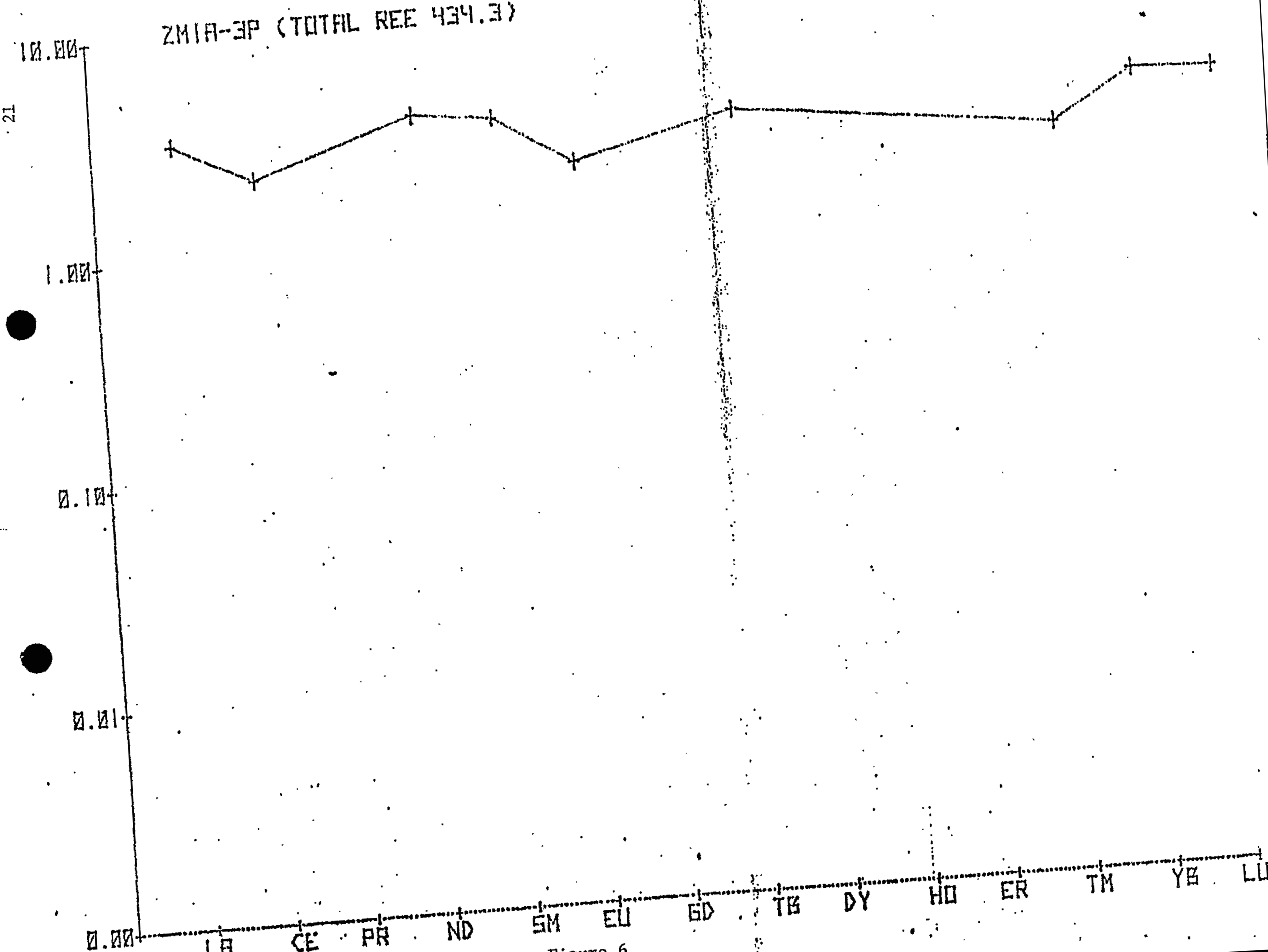

ZMIA-3P (TOTAL REE 434.3)
10.00
1.00
0.10
0.01
0.00
LA
CE
PR
ND
SM
EU
GD
TB
DY
HO
ER
TM
YB
LU

Figure 6

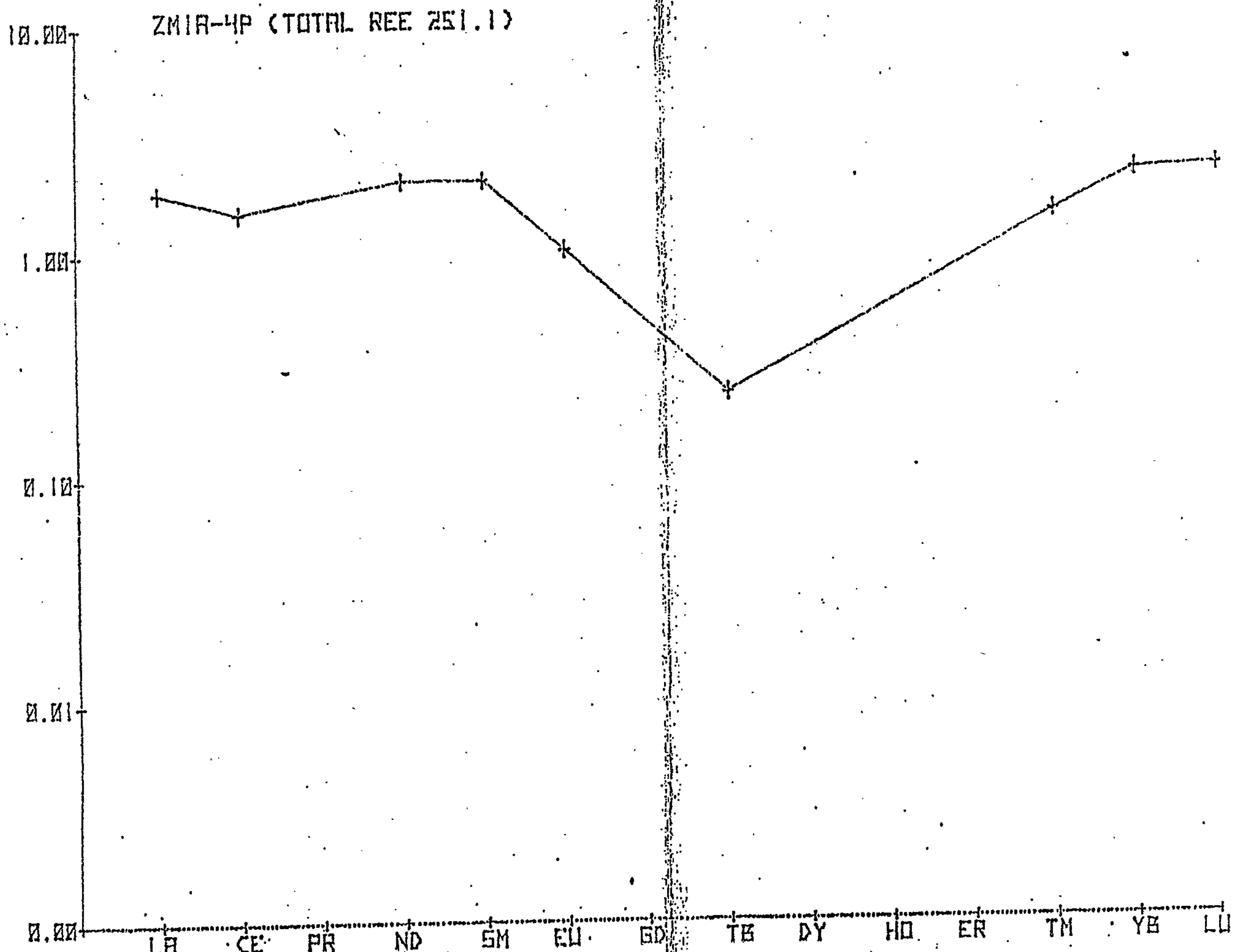

ZMIA-4P (TOTAL REE 251.1)
10.00
1.00
0.10
0.01
0.00
LA
CE
PR
ND
SM
EU
GD
TB
DY
HO
ER
TM
YB
LU

Figure 7

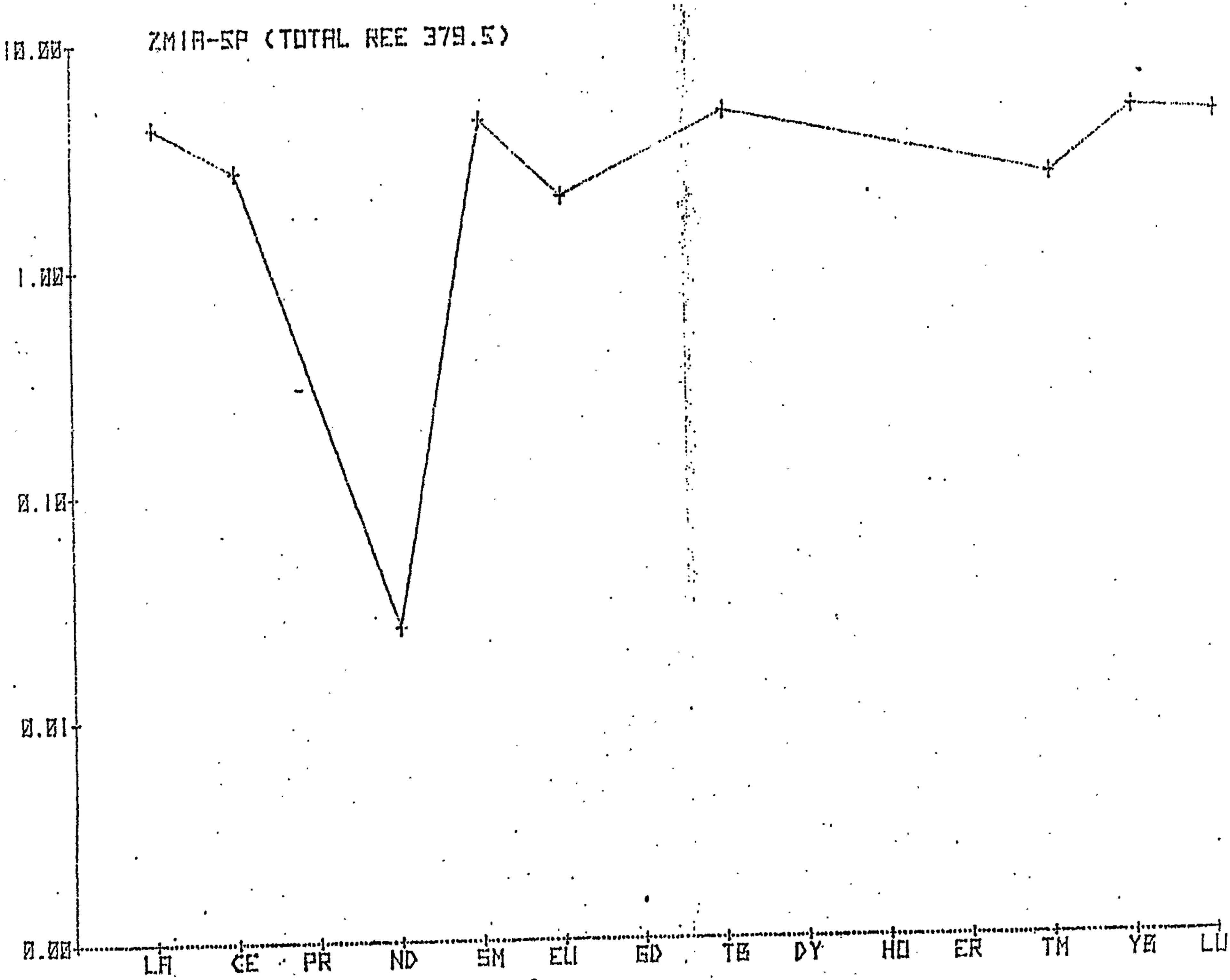

ZMIA-5P (TOTAL REE 379.5)
10.00
1.00
0.10
0.01
0.00
LA
CE
PR
ND
SM
EU
GD
TB
DY
HO
ER
TM
YB
LU

Figure 8

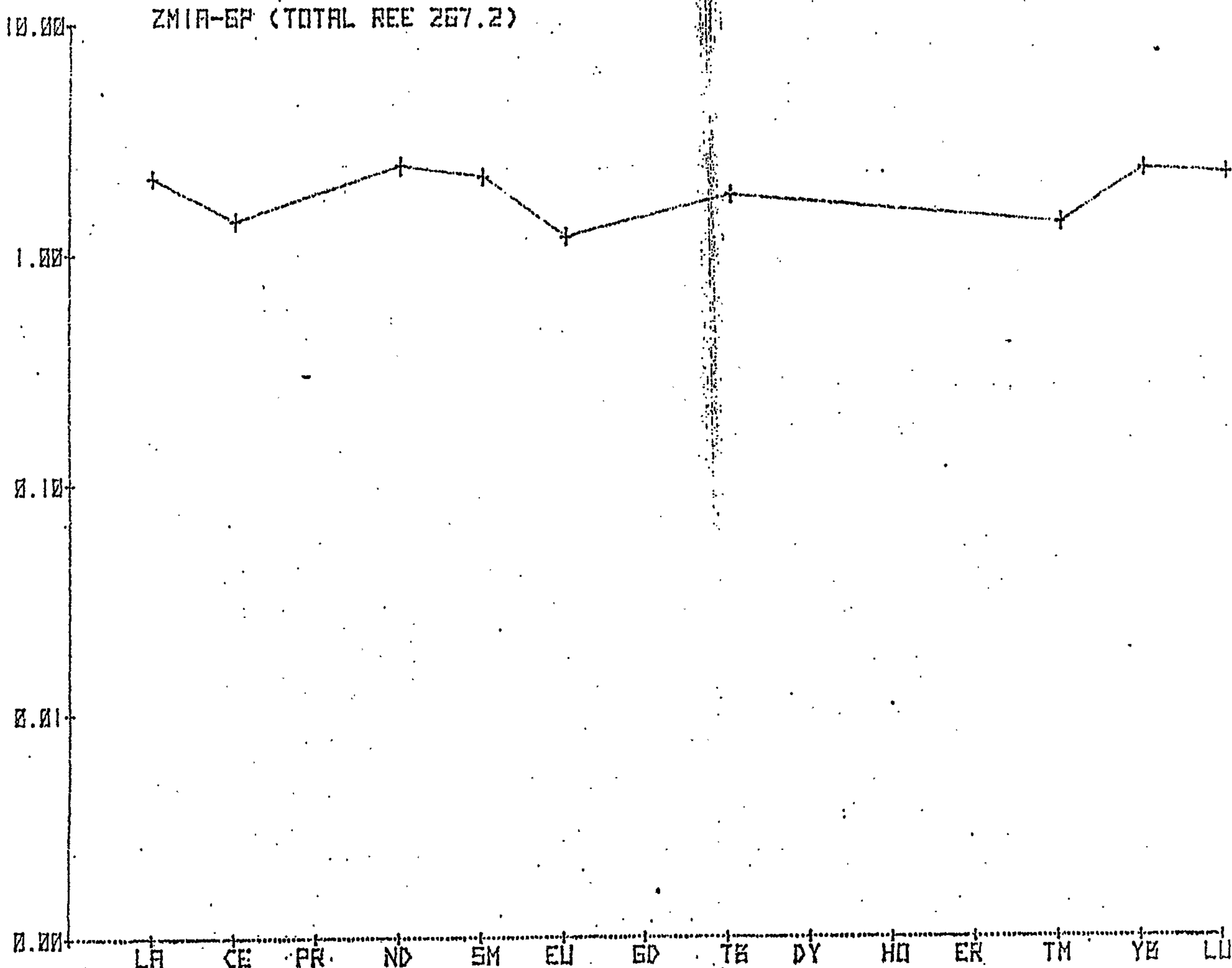

ZM1A-GP (TOTAL REE 267.2)
10.00
1.00
0.10
0.01
0.00
LA
CE
PR
ND
SM
EU
GD
TB
DY
HO
ER
TM
YB
LU

Figure 9

25

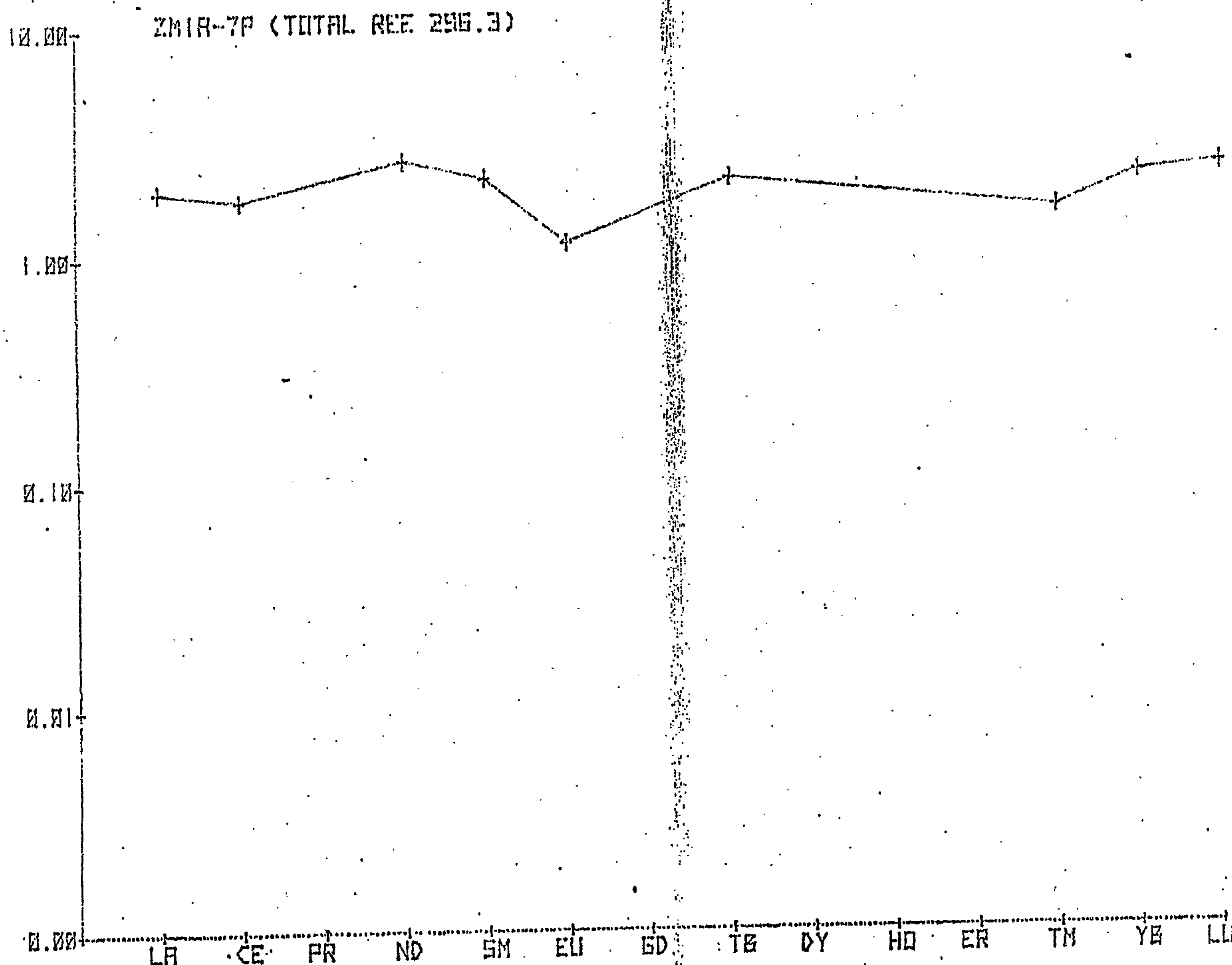

ZMIA-7P (TOTAL REE 296.3)
10.00
1.00
0.10
0.01
0.00
LA
CE
PR
ND
SM
EU
GD
TB
DY
HO
ER
TM
YB
LU

Figure 10

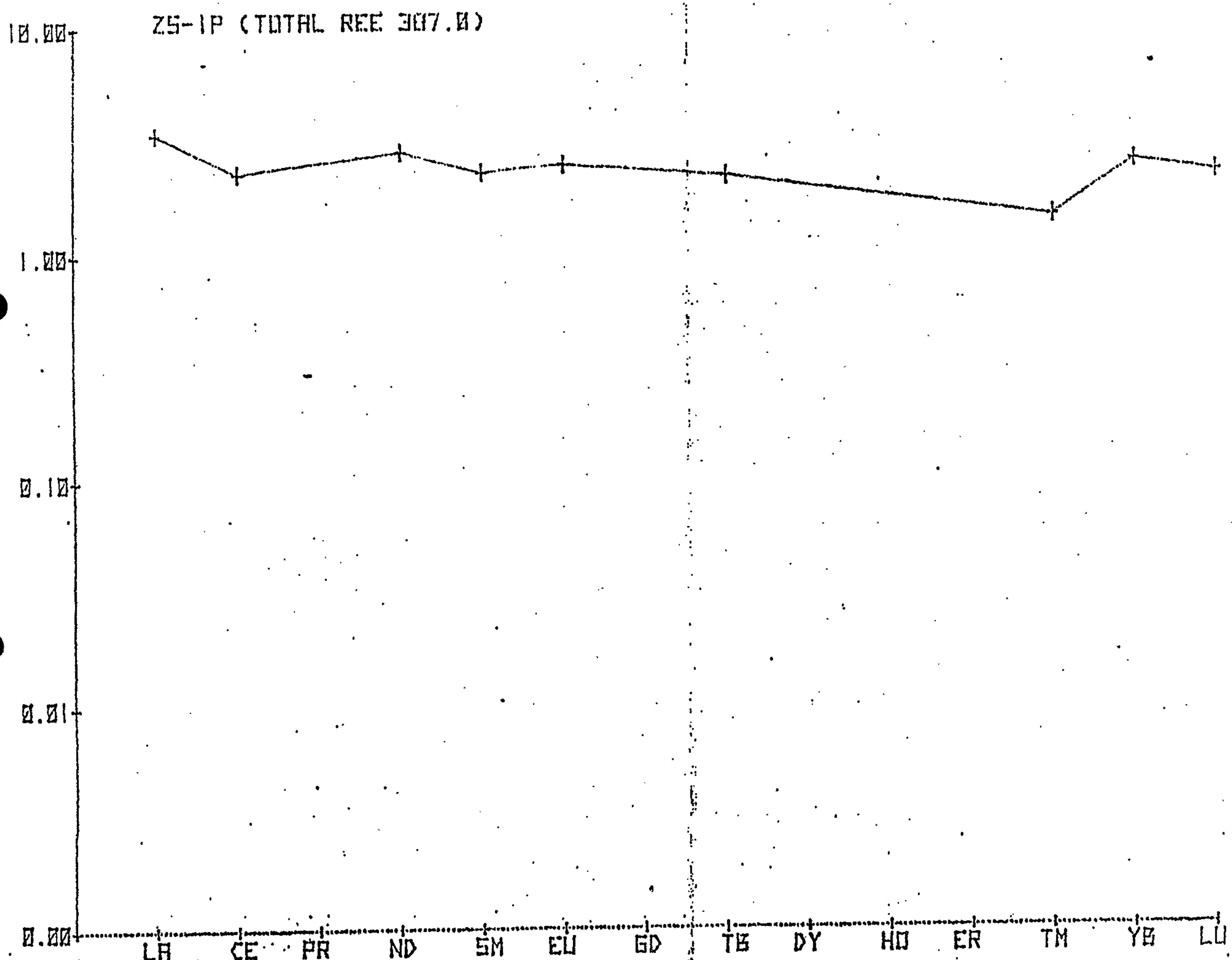

ZS-1P (TOTAL REE 307.0)
10.00
1.00
0.10
0.01
0.00
LA
CE
PR
ND
SM
EU
GD
TB
DY
HO
ER
TM
YB
LU

Figure 11

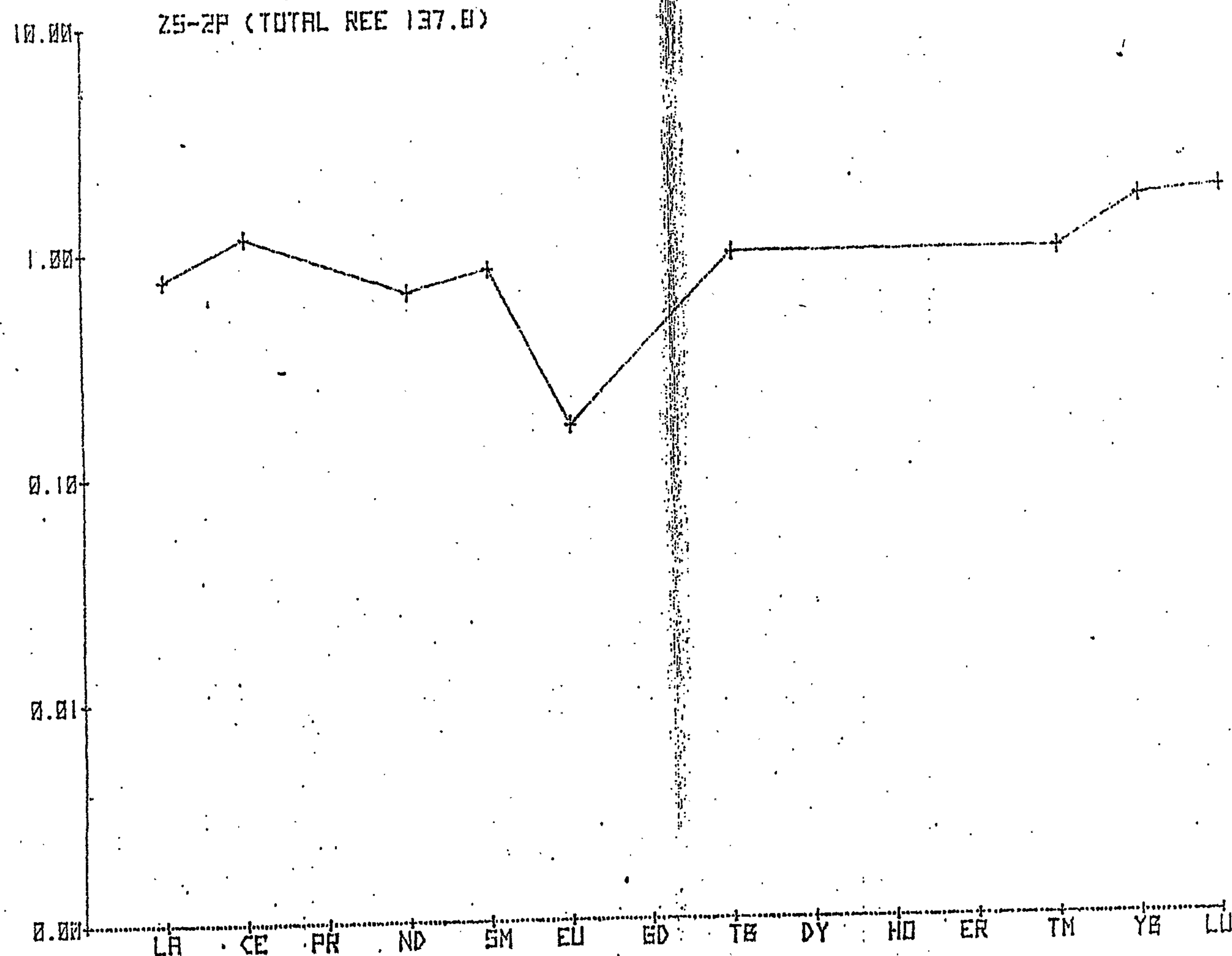

ZS-2P (TOTAL REE 137.0)
10.00
1.00
0.10
0.01
0.00
LA
CE
PR
ND
SM
EU
GD
TB
DY
HO
ER
TM
YB
LU

Figure 12

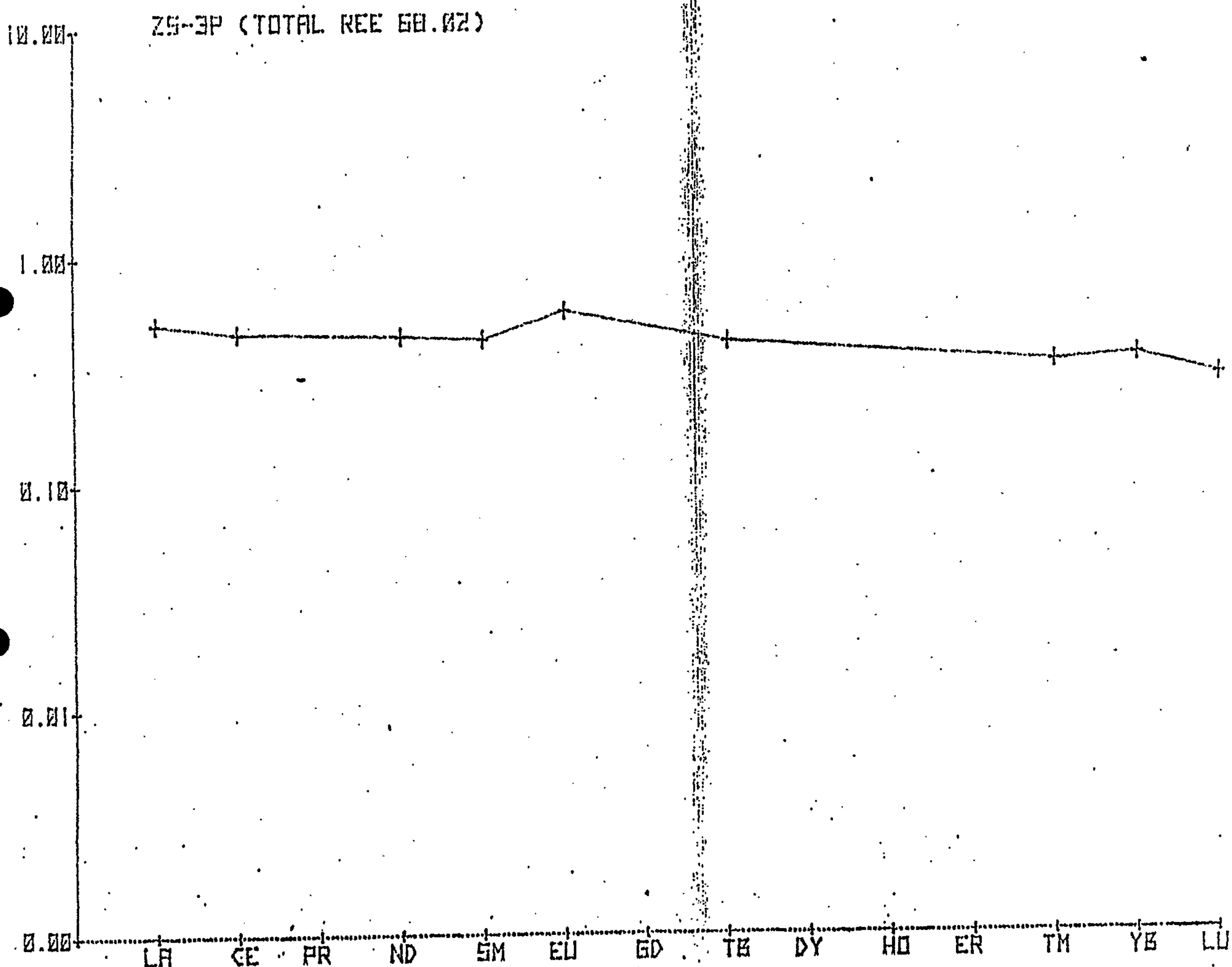

ZS-3P (TOTAL REE 60.02)
10.00
1.00
0.10
0.01
0.00
LA
CE
PR
ND
SM
EU
GD
TB
DY
HO
ER
TM
YB
LU

Figure 13

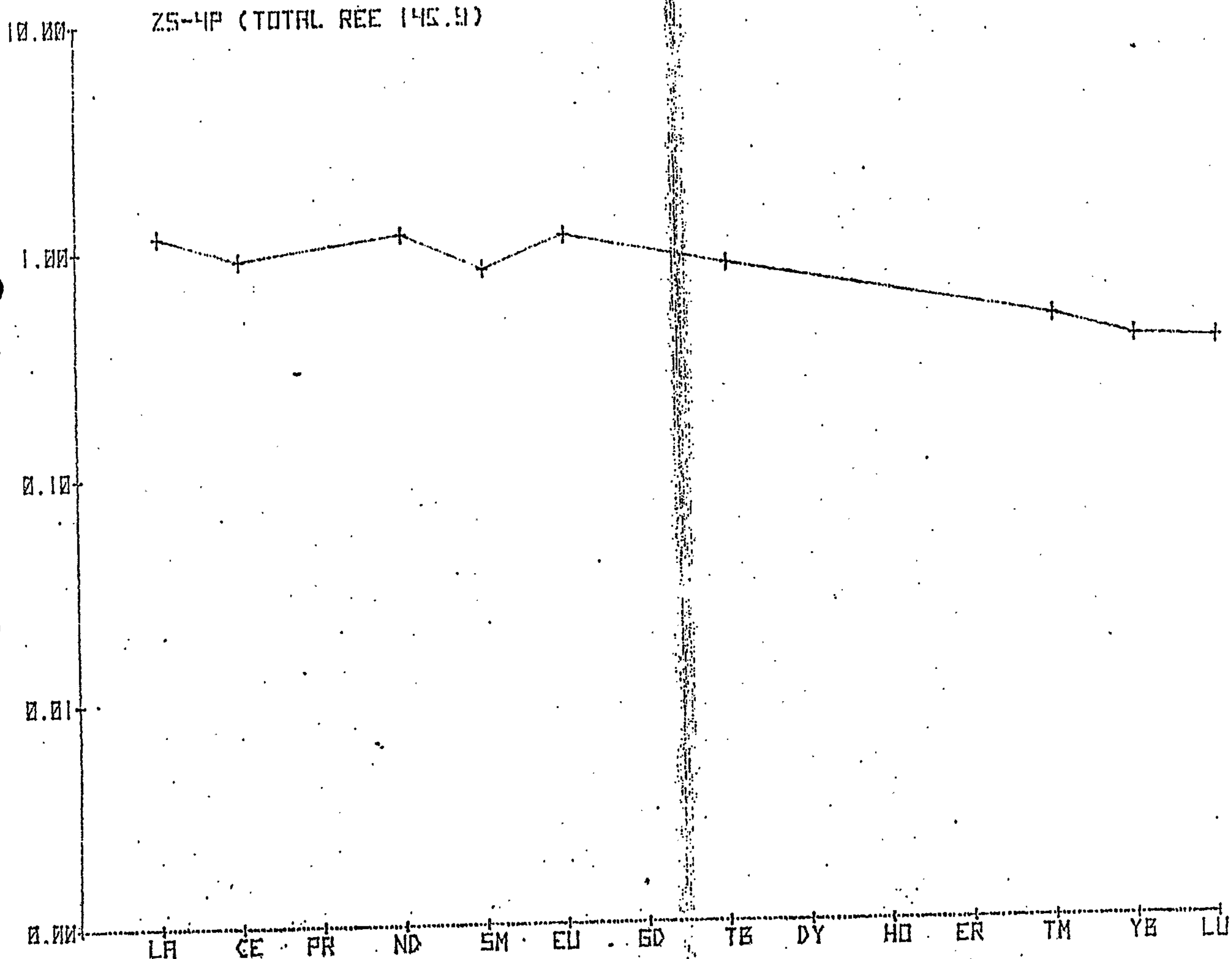
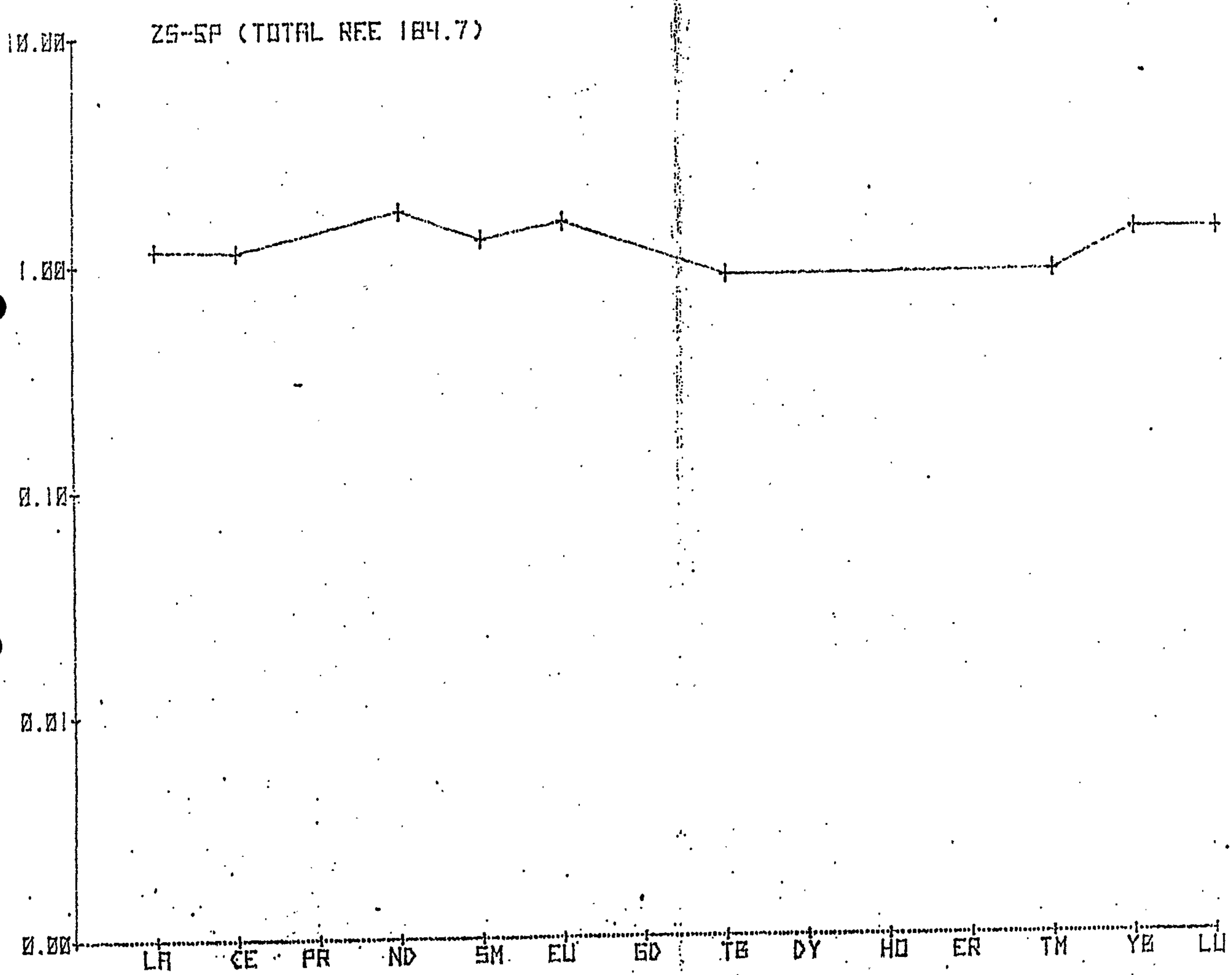

ZS-4P (TOTAL REE 145.9)
10.00
1.00
0.10
0.01
0.00
LA
CE
PR
ND
SM
EU
GD
TB
DY
HO
ER
TM
YB
LU

Figure 14



ZS-5P (TOTAL REE 184.7)
10.00
1.00
0.10
0.01
0.00
LA
CE
PR
ND
SM
EU
GD
TB
DY
HO
ER
TM
YB
LU

Figure 15

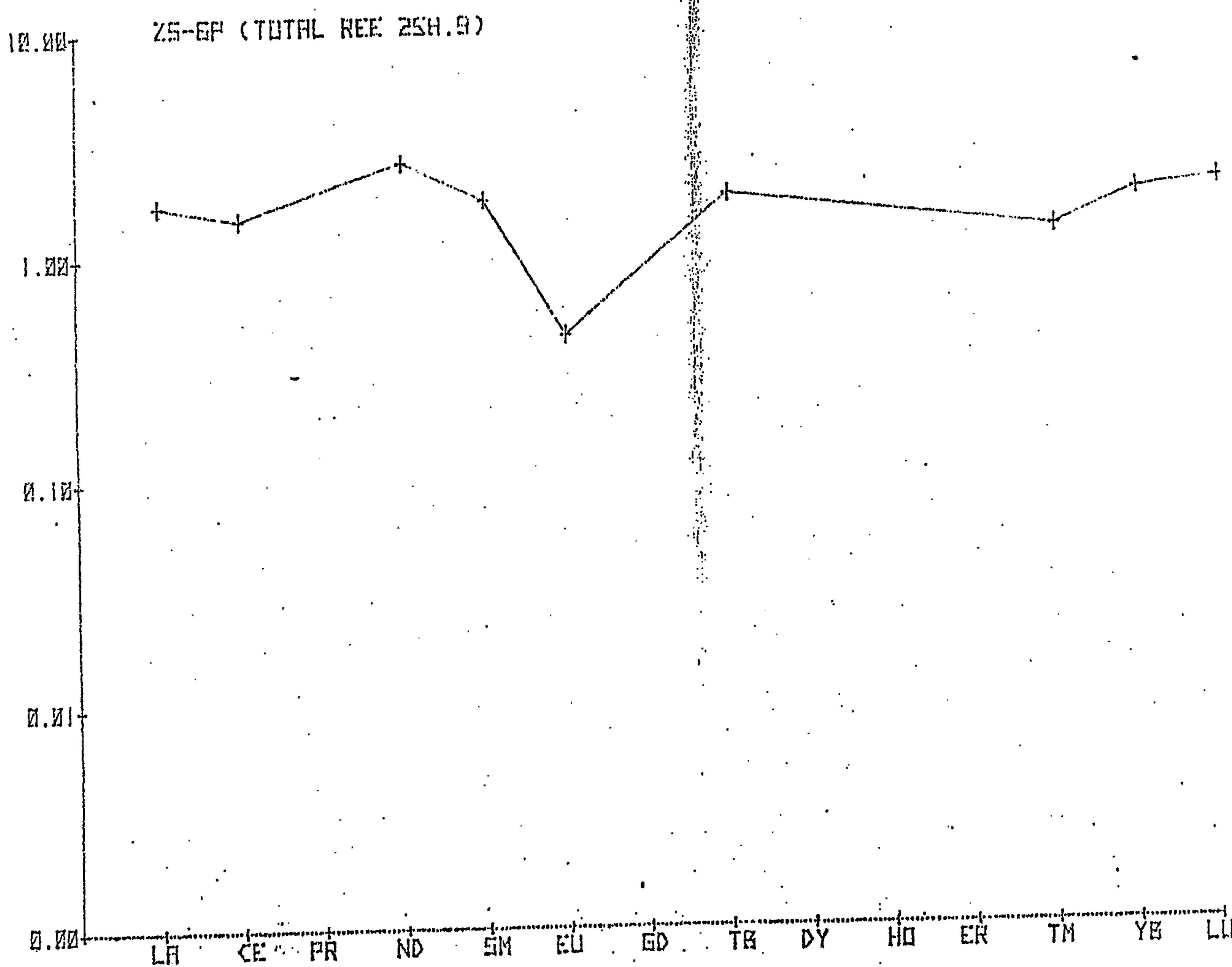

ZS-6P (TOTAL REE 254.9)
10.00
1.00
0.10
0.01
0.00
LA
CE
PR
ND
SM
EU
GD
TB
DY
HO
ER
TM
YB
LU

Figure 16

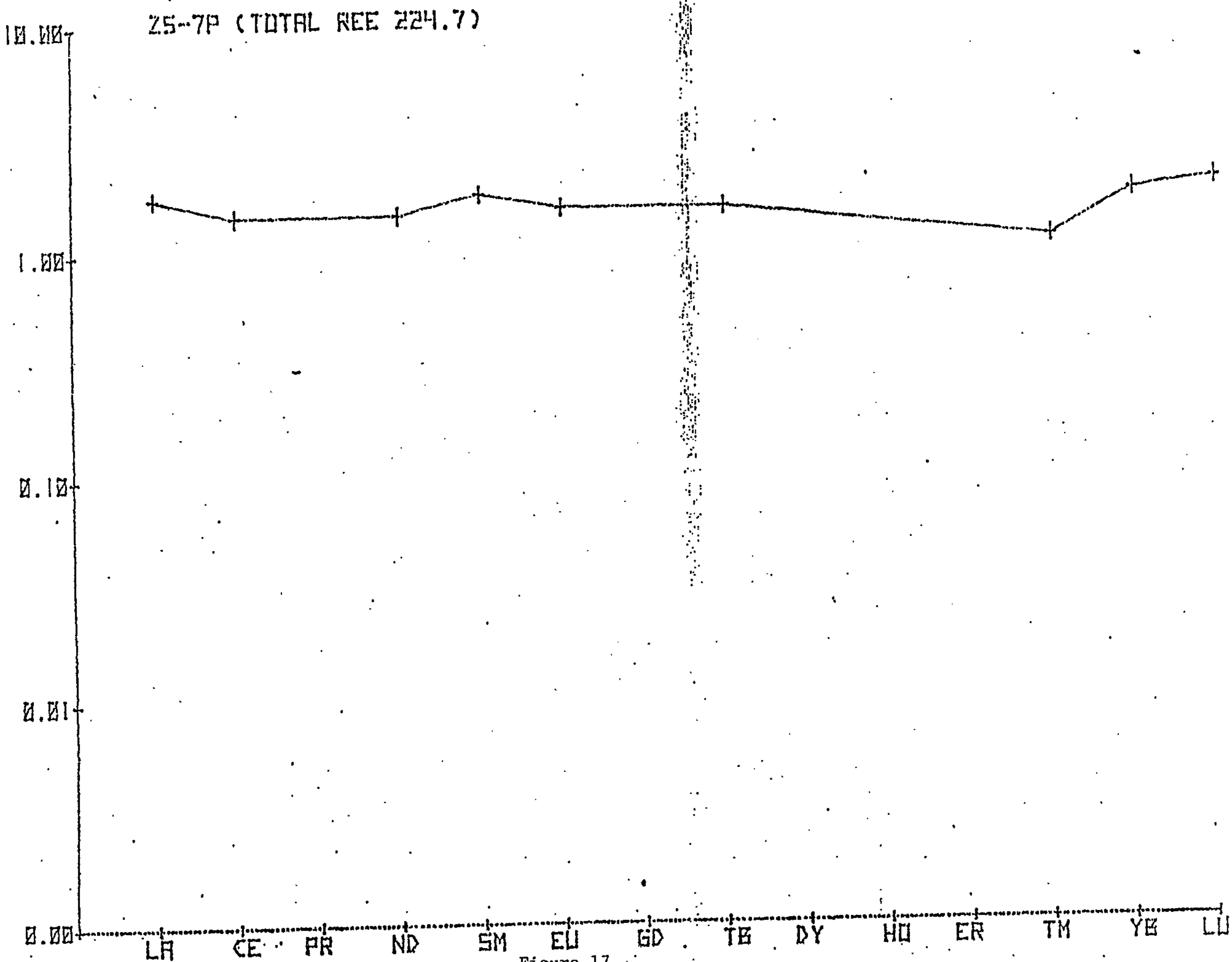

Z5-7P (TOTAL REE 224.7)
10.00
1.00
0.10
0.01
0.00
LA
CE
PR
ND
SM
EU
GD
TB
DY
HO
ER
TM
YB
LU

Figure 17.

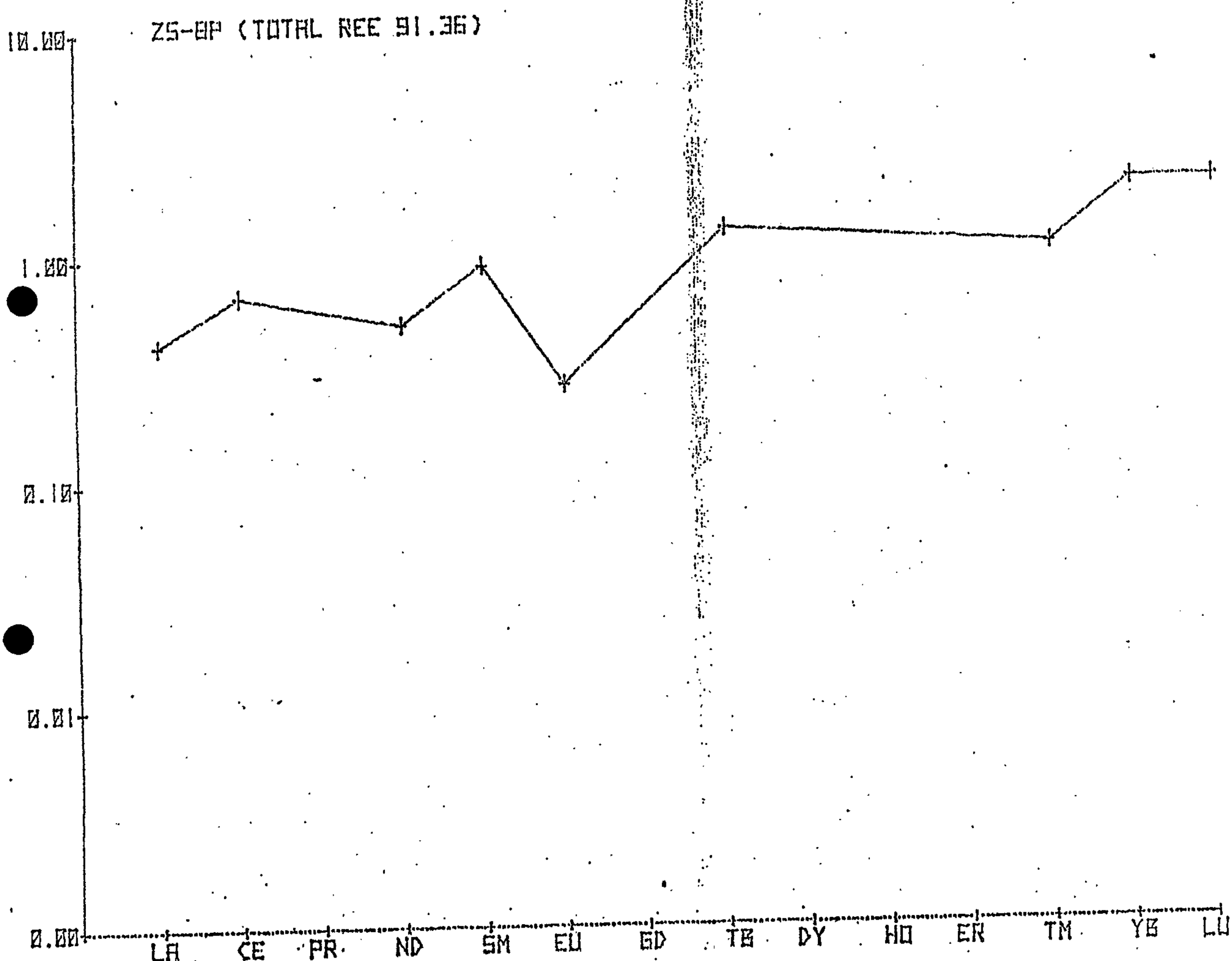
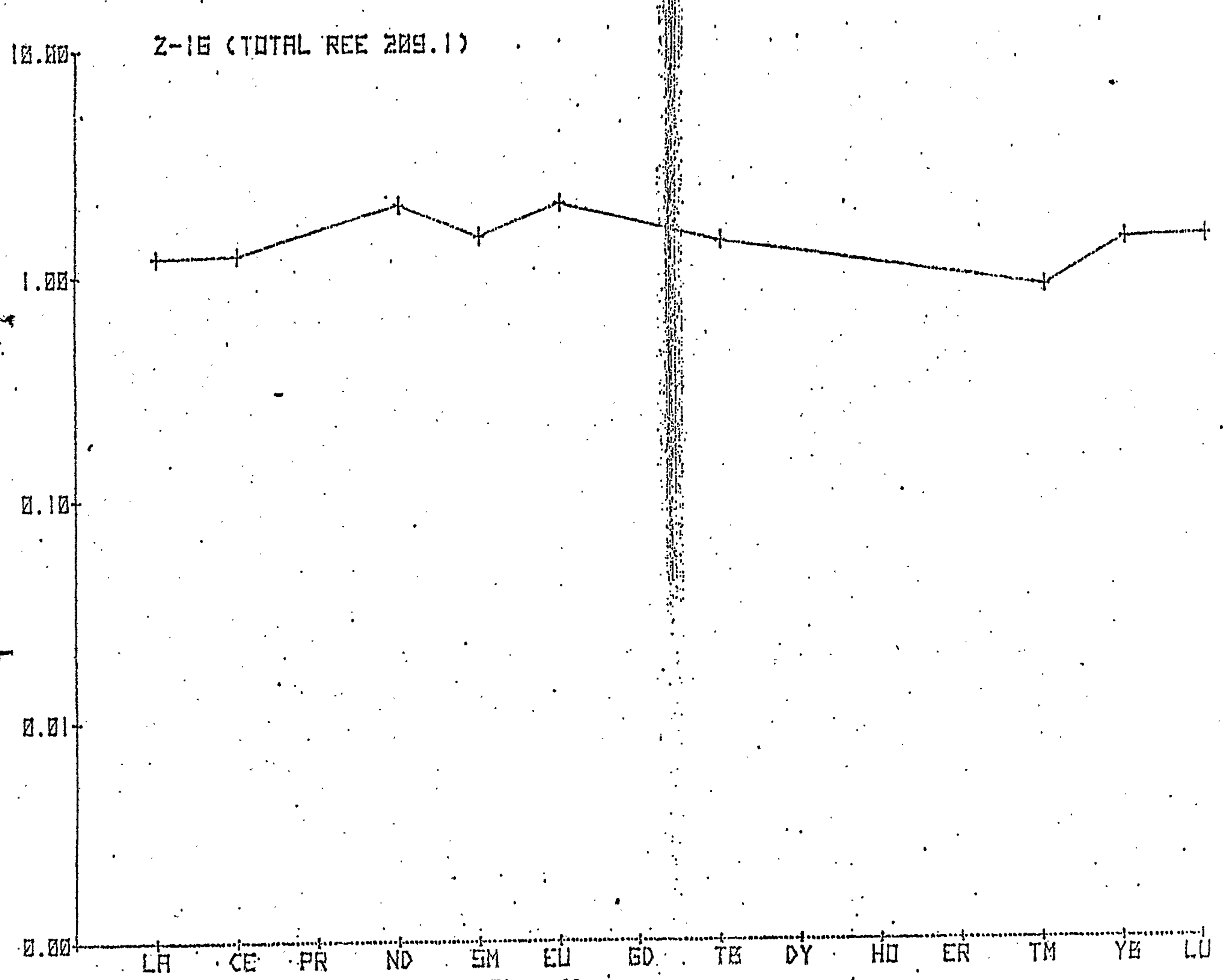
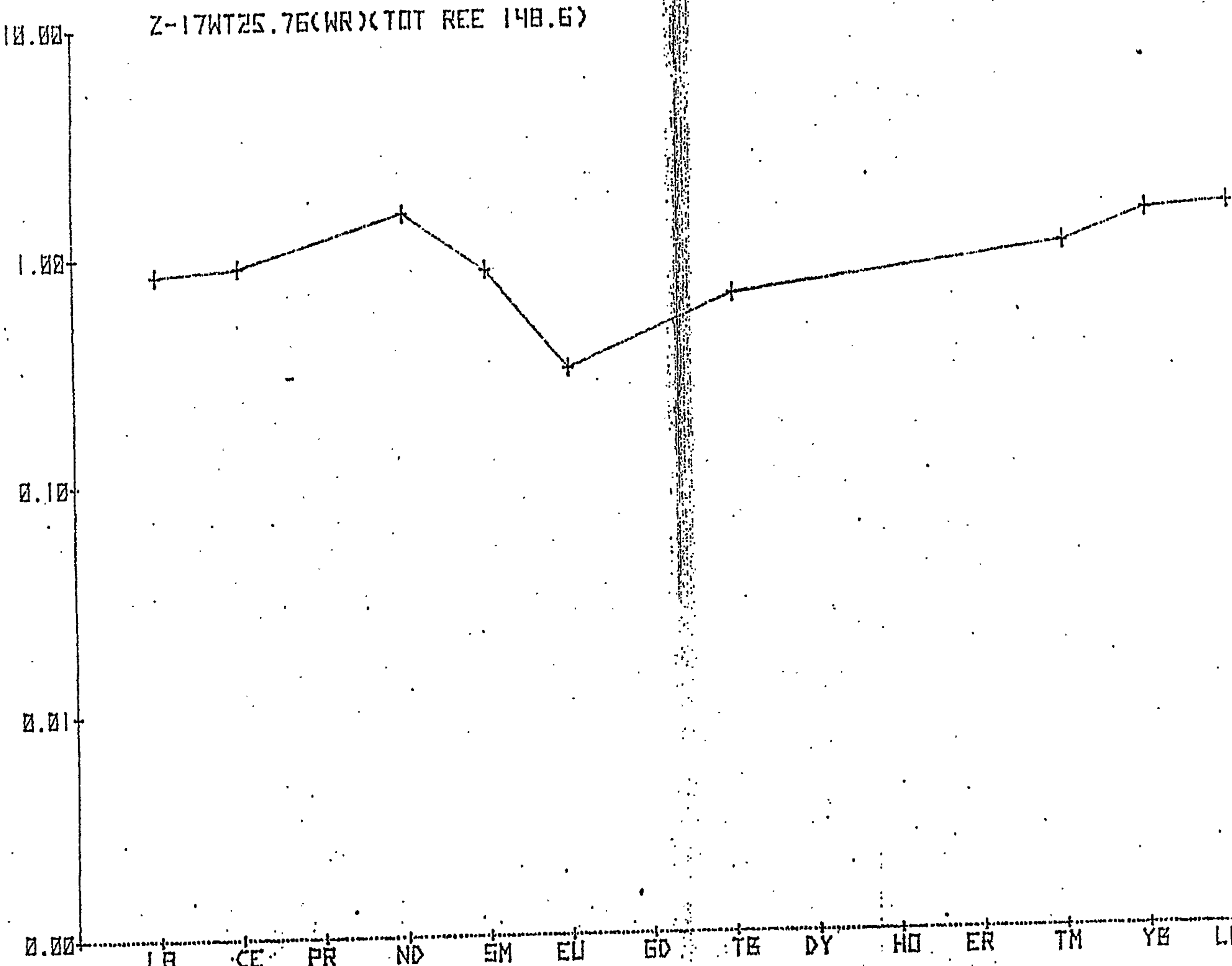

ZS-8P (TOTAL REE 91.36)
10.00
1.00
0.10
0.01
0.00
LA
CE
PR
ND
SM
EU
GD
TB
DY
HO
ER
TM
YB
LU

Figure 18


Z-16 (TOTAL REE 209.1)
10.00
1.00
0.10
0.01
0.00
LA
CE
PR
ND
SM
EU
GD
TB
DY
HO
ER
TM
YB
LU
Figure 19



Z-17WT25.76(WR)(TOT REE 148.6)
10.00
1.00
0.10
0.01
0.00
LA
CE
PR
ND
SM
EU
GD
TB
DY
HO
ER
TM
YB
LU

Figure 20

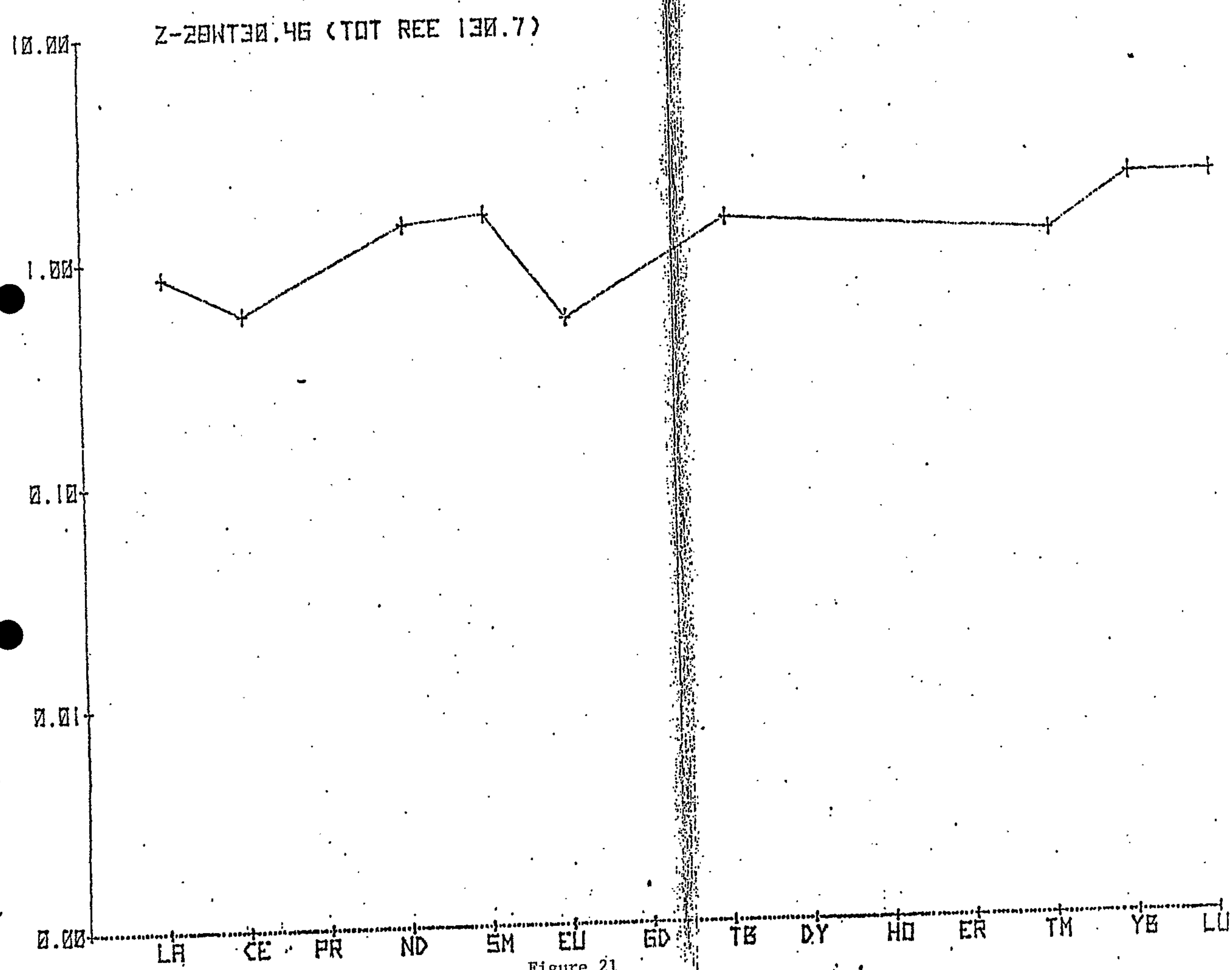

Z-20WT30.4G (TOT REE 130.7)
10.00
1.00
0.10
0.01
0.00
LA
CE
PR
ND
SM
EU
GD
TB
DY
HO
ER
TM
YB
LU

Figure 21

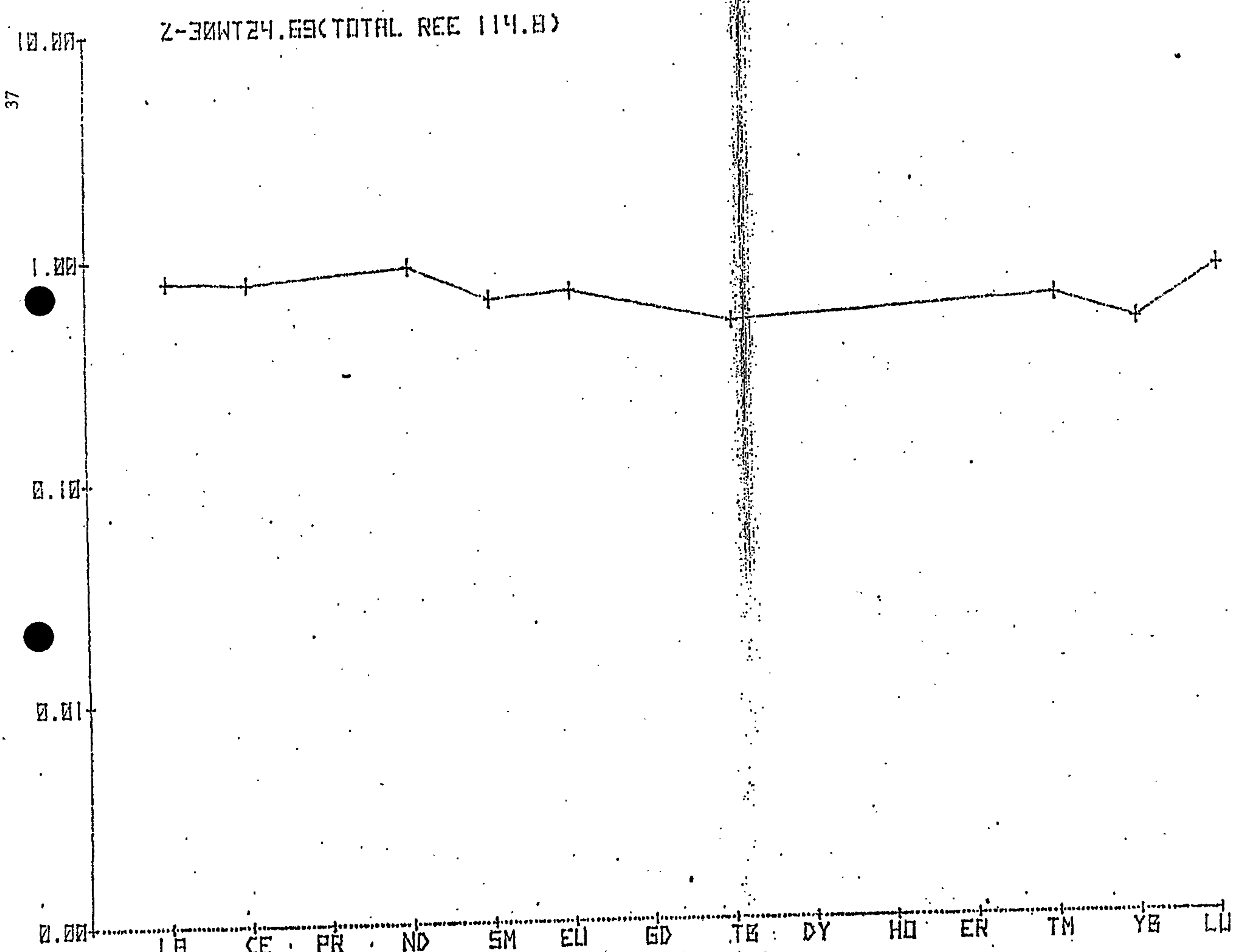

Z-30WT24.69(TOTAL REE 114.8)
10.00
1.00
0.10
0.01
0.00
LA
CE
PR
ND
SM
EU
GD
TB
DY
HO
ER
TM
YB
LU

Figure 22

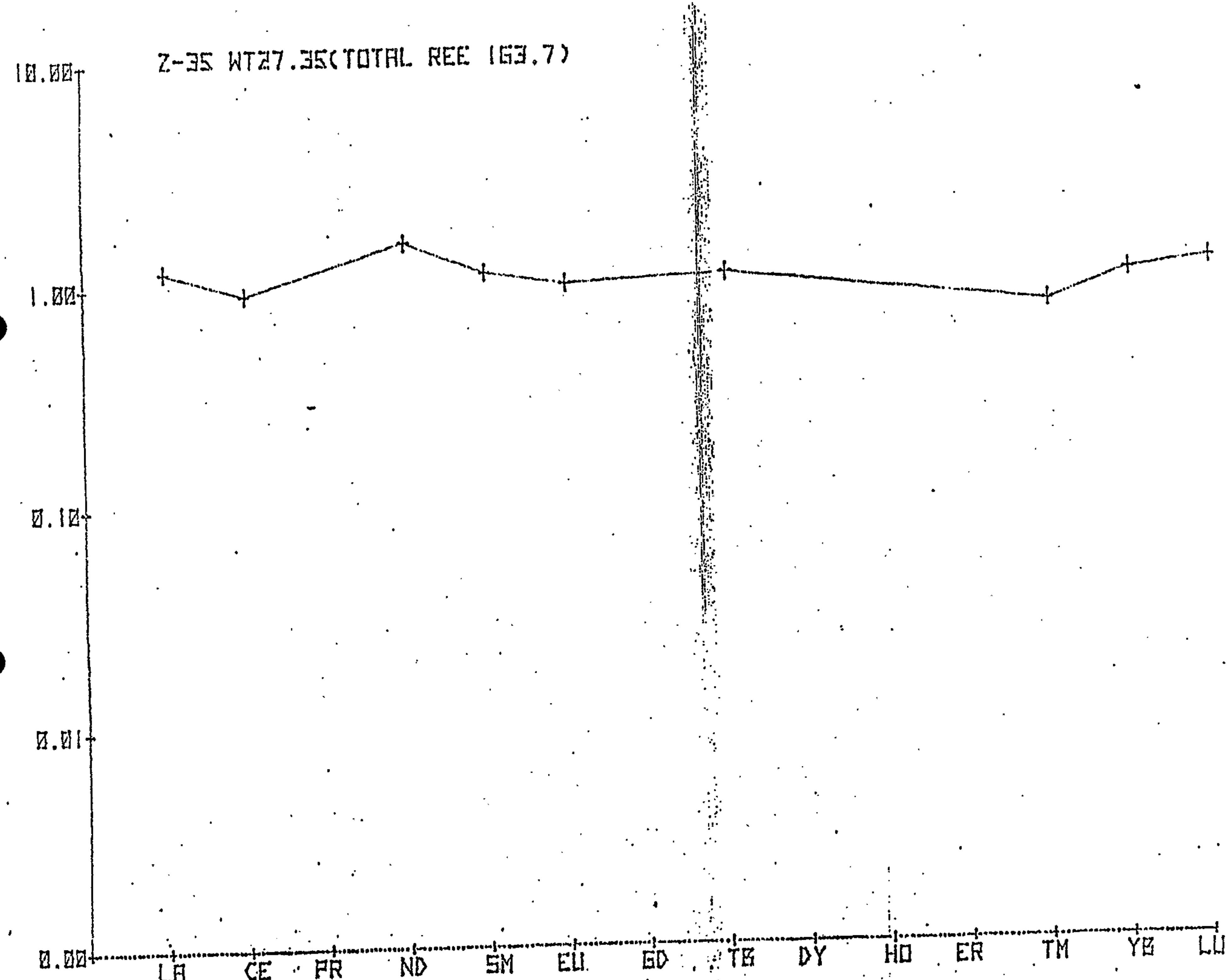
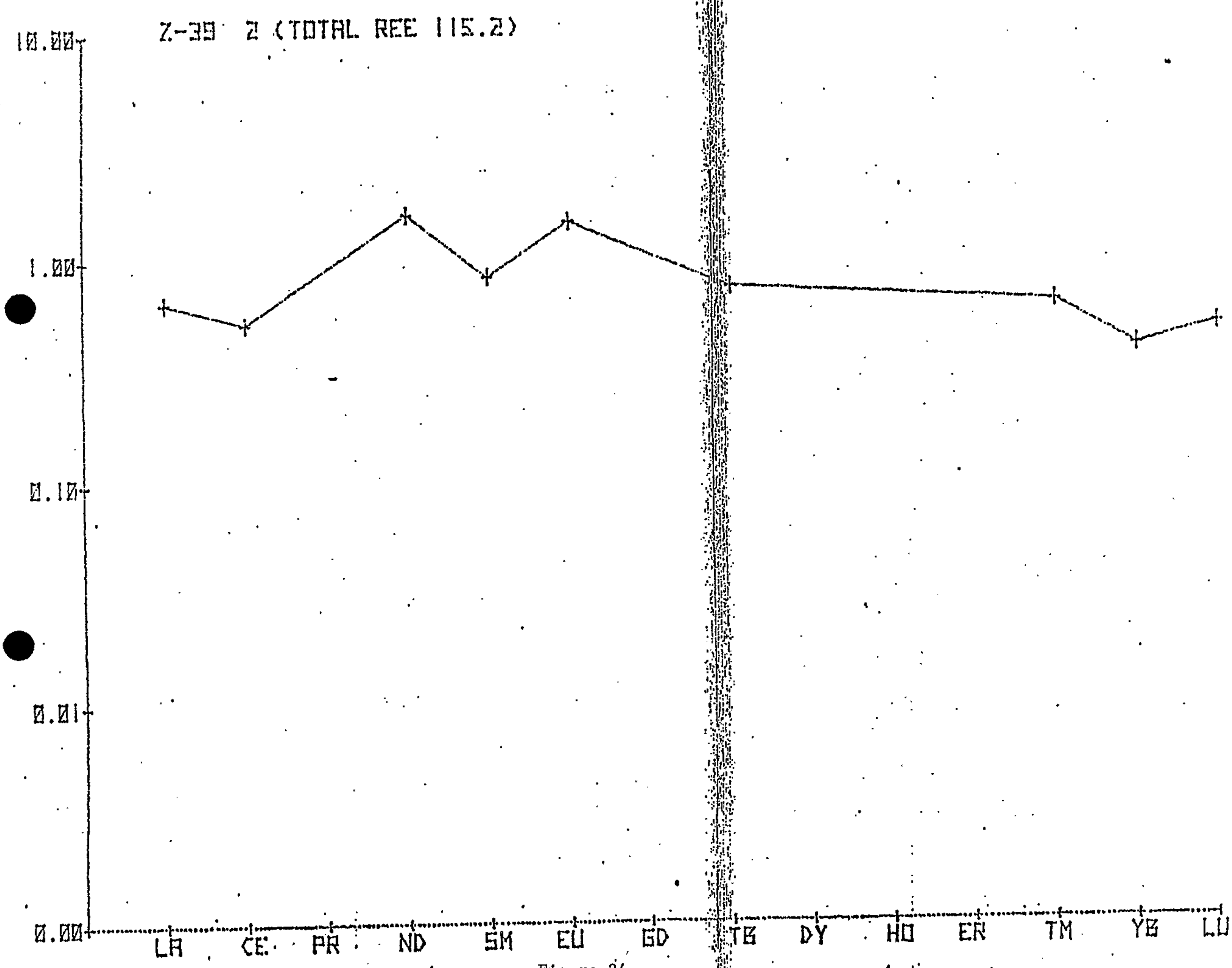

Z-35 WT27.35(TOTAL REE 163.7)
10.00
1.00
0.10
0.01
0.00
LA
CE
PR
ND
SM
EU
GD
TB
DY
HO
ER
TM
YB
LU

Figure 23



Z-39 2 (TOTAL REE 115.2)
10.00
1.00
0.10
0.01
0.00
LA
CE
PR
ND
SM
EU
GD
TB
DY
HO
ER
TM
YB
LU

Figure 24

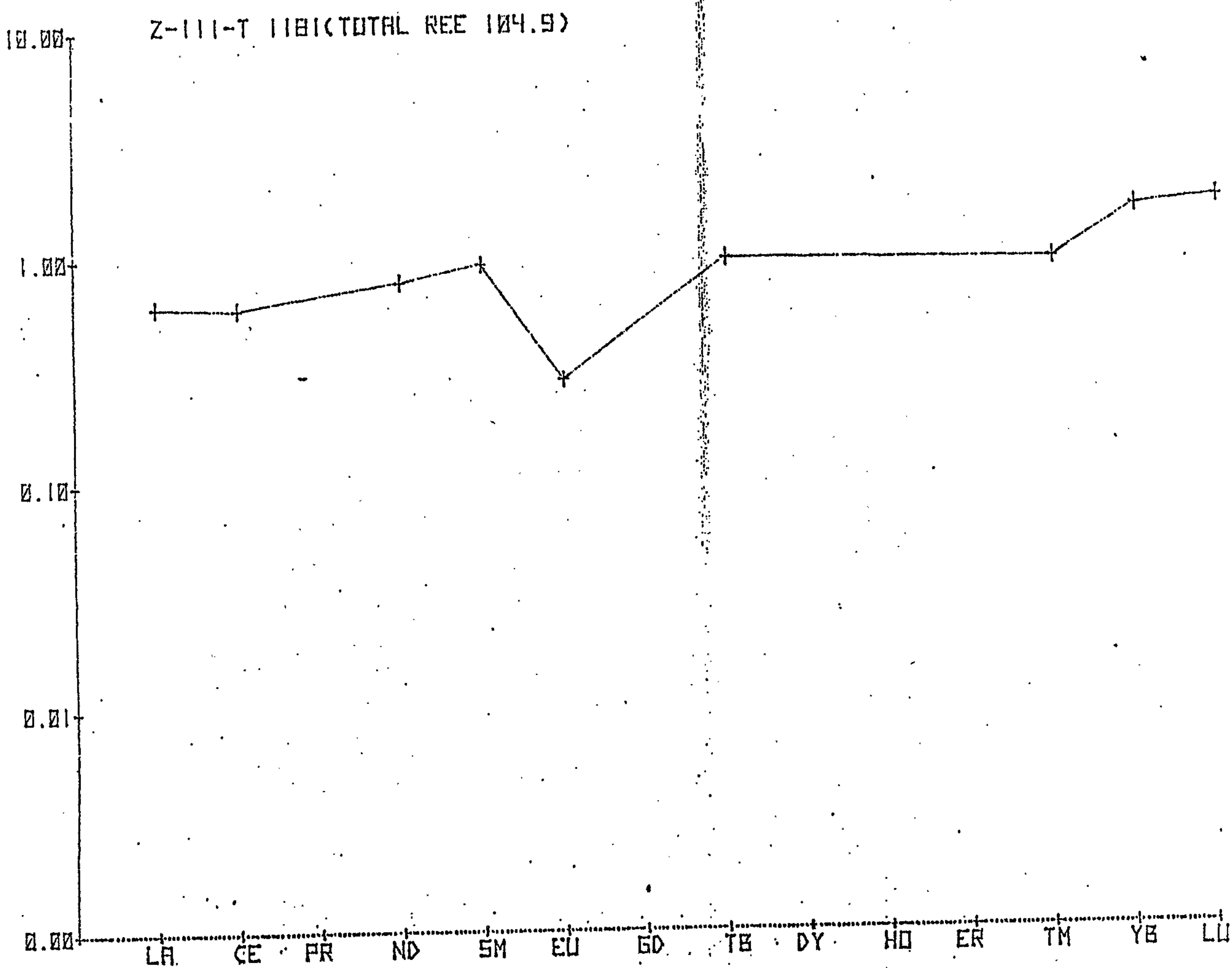

Z-111-T 1181(TOTAL REE 104.9)
10.00
1.00
0.10
0.01
0.00
LA
CE
PR
ND
SM
EU
GD
TB
DY
HO
ER
TM
YB
LU

Figure 25

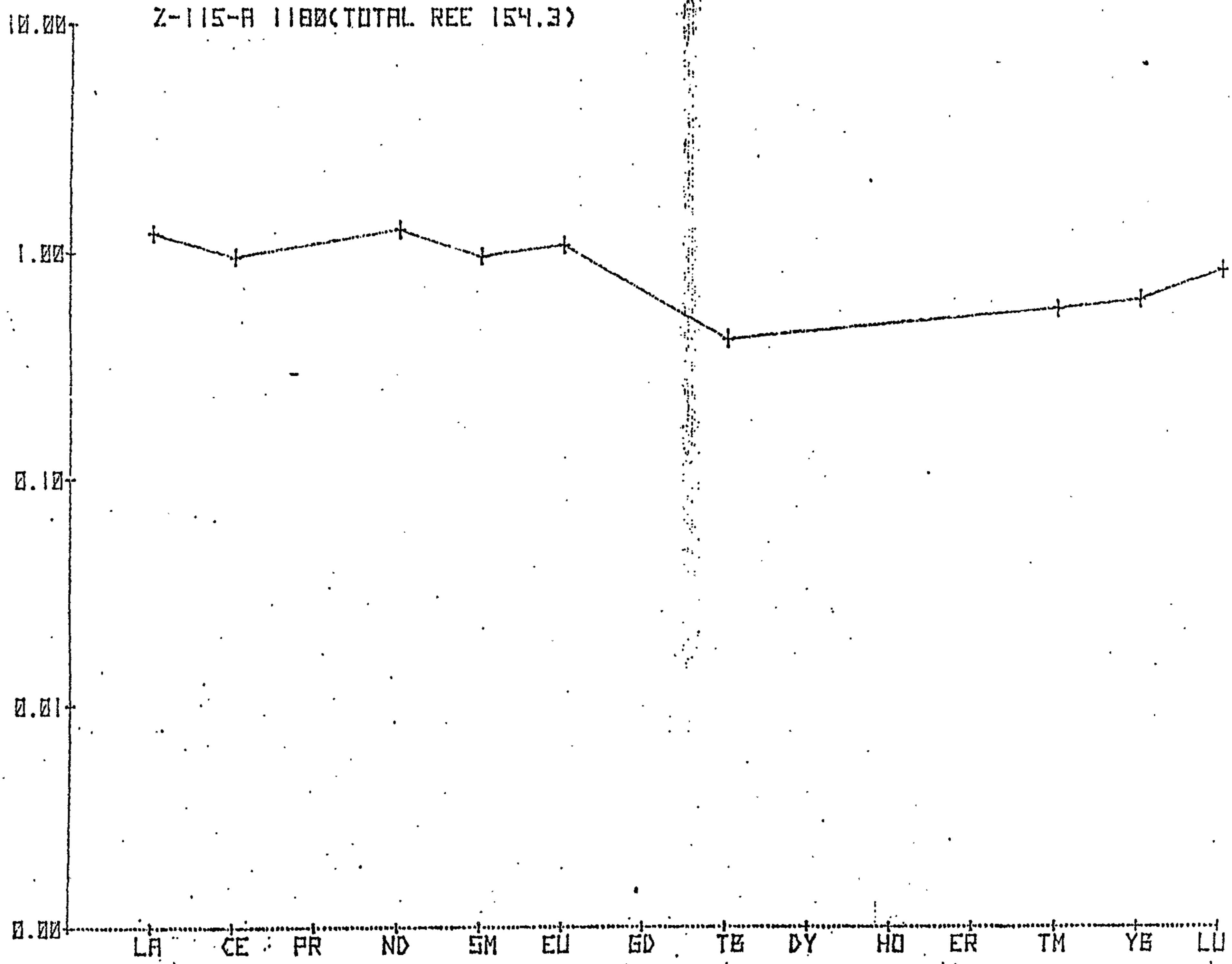

Z-115-A 1180(TOTAL REE 154.3)
10.00
1.00
0.10
0.01
0.00
LA
CE
PR
ND
SM
EU
GD
TB
DY
HO
ER
TM
YB
LU

Figure 26

APPENDIX

ZUNI MOUNTAINS

Sample Descriptions and Specimen Status

Spec. No.	Location	Depth	Map Unit
ZM1a-1	/11N/12W	0- 5	pa
-2		5-10	pa
-3		10-15	pa
-4		15-20	pa
-5		20-25	pa
-6		25-30	pa
-7		30-35	pa
M2-1	NW/SW/22/11N/12W	0- 5	gg
-2		5-10	gg
-3		10-15	gg
-4		15-20	gg
-5		20-25	gg
-6		25-30	gg
-7		30-35	gg
-8		35-40	gg
ZM6-1	NE/NE/6/9N/11W	0- 5	pa
-2		5-10	pa
-3		10-15	pa
-4		15-20	pa
-5		20-25	pa
-6		25-30	pa
ZM7-1	C/8/9N/11W	0- 5	pa
-2		5-10	pa
-3		10-15	pa
-4		15-20	pa
-5		20-25	pa
-6		25-30	pa
-7		30-35	pa
-8		35-40	pa
ZM8-1	SW/SE/8/9N/11W	0- 5	ap
-2		5-10	ap
-3		10-15	ap
-4		15-20	ap
-5		20-25	ap
-6		25-30	ap
-7		30-35	ap

ZUNI MOUNTAINS

Sample Descriptions and Specimen Status

Spec. No.	Location	Depth	Map Unit
ZS-1	SW/36/9N/11W	0	gg
-2	NW/9/9N/11W	0	gg
-3	C/11/10N/12W	0	ag
-4	SW/26/10N/12W	0	gg
-5	SW/30/11N/12W	0	mr
-6	NW/32/10N/11W	0	ap
-7	SW/1/9N/12W	0	pa
-8	SW/36/11N/12W	0	ap
-9	C/8/9N/11W	0	gm
-10	SW/17/9N/11W	0	pa

ZUNI MOUNTAINS PETROGRAPHY

In the course of the investigation, five petrographically similar groups, with quartz-hematite rich igneous affinities were recognized.

I. ZMla 1-7 series. This group is characterized by its relict igneous porphyroclasts, low epidote content, and a well developed foliation defined by abundant muscovite laths.

Mode- 30-60% quartz
15-20% muscovite
20-40% relict microcline
0- 6% relict plagioclase (andesine)
minor hematite, biotite, epidote

Rock Name- Qtz.-Musc. Orthoschist (granitic protolith)

II. ZM7 1-5 series. This group is characterized by its large quartz prophyroclasts, relatively high epidote content, and very fine grained, well foliated matrix.

Mode- 55-65% quartz
10-20% microcline relicts
5-25% plagioclase relicts (oligoclase)
1- 5% epidote
1-10% muscovite
minor hematite, ilmenite/luecoxene, biotite/chlorite

Rock Name- Qtz. augen-Musc. Orthoschist (volcanic protolith)

III. ZM7-6. This single sample has a dominantly igneous texture with a static recrystallization overprint evident in quartz grains.

Mode- 40% quartz
25% plagioclase (An-?)
30% microcline
minor epidote, hematite, biotite/chlorite

Rock Name- Metagranite

IV. ZM8 1-6 series. This group is characterized by dominantly igneous textures, abundant perthitic microcline, graphic quartz intergrowths, and magmatic interstitial epidote.

<u>Mode</u>- 25-60% quartz
30-50% perthitic microcline
10-40% plagioclase (An25-30)
1% biotite
minor epidote, hematite, ilmenite/luecoxene

<u>Rock Name</u>- Graphic (to varying degrees) Granofels (K-rich granite protolith)

V. <u>ZMZ 1-8 series and ZM2 1&2 series</u>. This group is characterized by a very poor foliation, a high epidote content, very small quartz domains, and large poikiloblasts of Albite.

<u>Mode</u>- 35-50% quartz
5-15% microcline relicts
10-40% albite plates
2-10% epidote
1- 5% biotite
minor muscovite, hematite

<u>Rock Name</u>- Qtz.-Ab.-Epid. Ortho semischist to gneiss (Ca rich granitic protolith)

The metamorphic assemblages observed in these rocks suggest greenschist to lower amphibolite conditions of metamorphism. However, the low alumina content of these lithologies, and the water poor crystalline nature of the protoliths involved, suggest that conditions of middle to upper amphibolite metamorphism were probably achieved. The presence of overgrowths on K-spar supports this contention.

Alteration products are dominantly metamorphic re-equilibrations. Most reactions appear to be of an isochemical nature. The absence of mafic grains, microveinlets of hematite, and alteration of epidote-biotite $\pm$ Kspar-quartz intergranular aggregates to a white amorphous substance indicates some loss of chemical constituents.

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