# 37. RARE EARTH AND OTHER TRACE ELEMENTS IN BASALTS FROM THE MID-ATLANTIC RIDGE 36°N, DSDP LEG 37

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## INTRODUCTION

We have investigated both major and dispersed element contents of 60 samples of basalt from Leg 37. This report deals only with the dispersed elements; the relationships between trace and major element chemistry will be discussed elsewhere.

Previous work on basaltic rocks from the ocean ridges (Engel et al., 1967; Tatsumoto et al., 1965; Frey and Haskin, 1964; Kay et al., 1970; Schilling, 1971) suggests that many have a unique composition and distinctive rare earth element (REE) distribution patterns. REE data have previously been used qualitatively for testing fractional crystallization and partial melting petrogenetic models for these basalts (Schilling and Winchester, 1969; Zielinsky and Frey, 1970; Philpotts et al., 1971; Zielinsky, 1975).

## ANALYTICAL TECHNIQUES

REE were determined by instrumental neutron activation analysis (INAA). X-ray fluorescence and atomic absorption techniques were used for determination of the other trace elements. Some elements such as Cr, Ni, Co, Sr, etc. were determined by more than one technique. Where more than one technique was utilized, the quoted results are the average of the values obtained from the different methods. Some samples are also being checked for REE by Radio Chemical methods. This work is still in progress. The conditions and equipment used for INAA are described by Puchelt and Kramar (1974).

## RESULTS

Accuracy can be estimated from the values obtained for BCR-1 (Table 1 and Figure 1). The dispersed element and REE data for investigated samples are given in Chapters 2-5 (this volume).

The chondrite-normalized REE patterns (cf. Masuda, 1962; Coryell et al., 1963) of samples are given in Figures 2-6 with sample number and bore-hole depth shown for each curve. The chondrite values given by Herrman (1970) were used and curves were drawn using a computer program. Nd values were not considered in drawing the curves due to low precision. Results from each bore hole are discussed separately and a brief summary is given at the end.

### Site 335

Six samples from this site were analyzed (Figure 2). No significant differences either in total REE content or relative distribution pattern with depth are observed. All samples are depleted in the light RE as compared to the heavy RE. The La/Sm enrichment factor (ef) is in all cases less than one, similar to ocean ridge tholeiites described by Kay et al. (1970) and Schilling (1971).

Cr, Ni, Co, and Cu are likewise very similar in all samples. Of the six analyzed samples, four have Ba contents of about 55 ppm and two have more than 100 ppm. Sc content is constant at about 37 ppm. Hf, Th, Ta, U, and Sb are always less than 1 ppm.

### Site 334

From this site one sample of basalt and two samples of plagioclase peridotite were analyzed. The RE pattern of the basalt is shown in Figure 3. In contrast to the basalts from Site 335, it shows relative enrichment of the lighter rare earths. The La/Sm ef is 2.13 and the Yb ef is 17.63. Both samples of plagioclase peridotite have RE contents below 1 ppm except for Yb and Ce which are slightly more than 1 ppm.

Other trace element contents of the basalt from this site are similar to those from Site 335 although Cr and Ni are somewhat less.

### Hole 333A

Nine basalt samples were analyzed from this hole. Large variations are shown by RE and other trace elements. Fox example, the Cr varies from 150 to 577 ppm, Ni from 42 to 119 ppm, Co from 42 to 62 ppm, and Ba from 34 to 100 ppm. These variations, however, do not show any relation to depth.

The REE patterns given in Figure 4 reflect three distinct patterns within the basalts: (1) light RE enriched over heavy RE, (2) near chondritic, and (3) either of the above with positive Eu anomaly. The first type is found in the upper part of the section, the second in the middle, and the third in the lower part. The Eu anomaly is most pronounced in the lower part of the section.

The basalts from this site can be classified into at least six chemical units in terms of their trace elements.

### Hole 332A

From this hole 21 samples ranging in depth from approximately 113 to 408 meters were analyzed. Our trace and REE data suggest few major differences in the basalts. Except for a few samples which show a positive Eu anomaly, all other samples show a very similar distribution pattern with marked enrichment of the light RE over heavy RE (Figures 5a, b). The (La/Sm) ef ranges from 1.25 to 2.91, and relative light RE-enrichment corresponds with higher overall RE abundance.

Ni, Co, Cu, Ba, and Sr show only limited variation. Cr shows a large variation from 40 to 210 ppm.

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TABLE 1
Results of the Replicate Analyses of the BCR-1

| | Values Obtained During Present Work (ppm) | Values Recommended by Flanagan, 1973 (ppm) |
|---|---|---|
| Cr | 18 ±3 | 17.6 |
| Ni | 15 ±2 | 15.8 |
| Co | 37 ±1 | 38 |
| Cu | 17 ±3 | 18.4 |
| Sc | 32 ±0.5 | 33 |
| Ba | 675 ±10 | 675 |
| Sr | 335 ±8 | 330 |
| Li | 12 ±3 | 12.8 |
| Zn | 110 ±5 | 120 |
| Rb | 40 ±3 | 46.6 |
| Sb | 1.10 ±0.50 | 0.69 |
| Cs | 1.73 ±1.53 | 0.95 |
| La | 27.50 ±0.75 | 26 |
| Ce | 48 ±3 | 53.9 |
| Nd | 27 ±5 | 29.0 |
| Sm | 6.46 ±0.46 | 6.60 |
| Eu | 1.89 ±0.17 | 1.94 |
| Tb | 1.24 ±0.24 | 1.0 |
| Dy | 5.60 ±1.60 | 6.3 |
| Yb | 3.69 ±1.0 | 3.36 |
| Lu | 0.46 ±0.05 | 0.55 |
| Hf | 5.28 ±0.75 | 4.70 |
| Ta | 0.88 ±0.67 | 0.91 |
| Th | 6.17 ±0.6 | 6.0 |
| U | 1.15 ±1.07 | 1.74 |

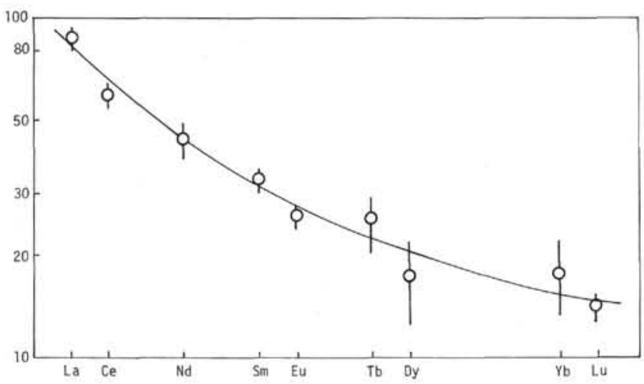


Figure 1. *REE distribution patterns of the BRC-1.*

Based on the REE (La/Sm) ef and the Cr content, the basalts can be grouped into six or seven chemical types with only minor differences.

### Hole 332B

Twenty-two samples of basalt were analyzed from this hole. The chondrite-normalized patterns are shown in Figures 6a and b. Compared to the basalts of Hole 332A, these basalts show large variations in their dispersed element content, especially for Cr and Ni. Abundance ranges are as follows; Cr >1200 ppm to 70 ppm, Ni 15 to >250 ppm, and Sr 70 to 130 ppm. The dispersion of Co is limited and Cu is almost constant. In general, the basalts in the upper and lower parts of the section are poor in Cr, Ni, and Co and rich in Sr. Basalts in the middle (410 to 650 m depth) are rich in Cr and Ni.

The basalts in the upper part (down to 400 m depth), except for one sample from the upper 35 meters, have RE patterns similar to basalts in Hole 332A. Total RE contents are also similar. At intermediate depths (410 to 650 m) patterns of RE abundance and distribution are entirely different. In this interval total RE contents are much lower, ranging from 5 to 10 times chondritic values. The distribution patterns are also very variable. In general, there are three types of patterns: (1) relative light RE enrichment, (2) chondritic with overall enrichment ranging from 5 to 8 times, and (3) light RE depleted with a negative Eu anomaly.

According to the RE and other dispersed elements the basalts from this hole can be grouped into six distinct groups.

## GENERAL SUMMARY

The basalts from the five locations on the flank of the Mid-Atlantic Ridge in general have certain characteristic differences from previously reported basalts from oceanic ridges. Most of them have an (La/Sm) ef greater than 1, reflecting light RE relative enrichment. In most earlier reported analyses this ratio is less than 1 and Schilling (1971) has used this as a criterion for distinguishing between oceanic and subaerial tholeiites. However, Schilling (1975) points out that dredged basalts from the Mid-Atlantic Ridge between 36°N and 40°N show relative enrichment of the light RE and that in all cases the (La/Sm) ef is more than 1. This generalization does not appear to be correct because in the present samples (most from 36° and 37°N) both types of patterns are present. Furthermore, in a single hole, e.g., 332B, all patterns assigned to the Mid-Atlantic Ridge by Schilling (1975) are present. Thus, it may not be correct to correlate these variations to the geographic location of the sample.

Samples with chondritic patterns from Hole 332B show the lowest enrichment level, being between five to eight times the chondrite value. Relative light RE enrichment is accompanied by high contents of heavy REs. This can result from progressive fractional crystallization. The chief mineral phases of these basalts are plagioclase, clinopyroxene, and olivine. The partition coefficients of REE for these minerals are rather small (Schnetzler and Philpotts, 1970) and fractional crystallization of these phases will result in REE enrichment in the magma. Furthermore, partition coefficients for the light and heavy rare earths in olivine and pyroxene differ by at least a factor of 2. Thus, separation of olivine and pyroxene and subordinate plagioclase from the magma would result in light RE enrichment, the enrichment of the lighter rare earths being about double that of the heavier ones.

## ACKNOWLEDGMENTS

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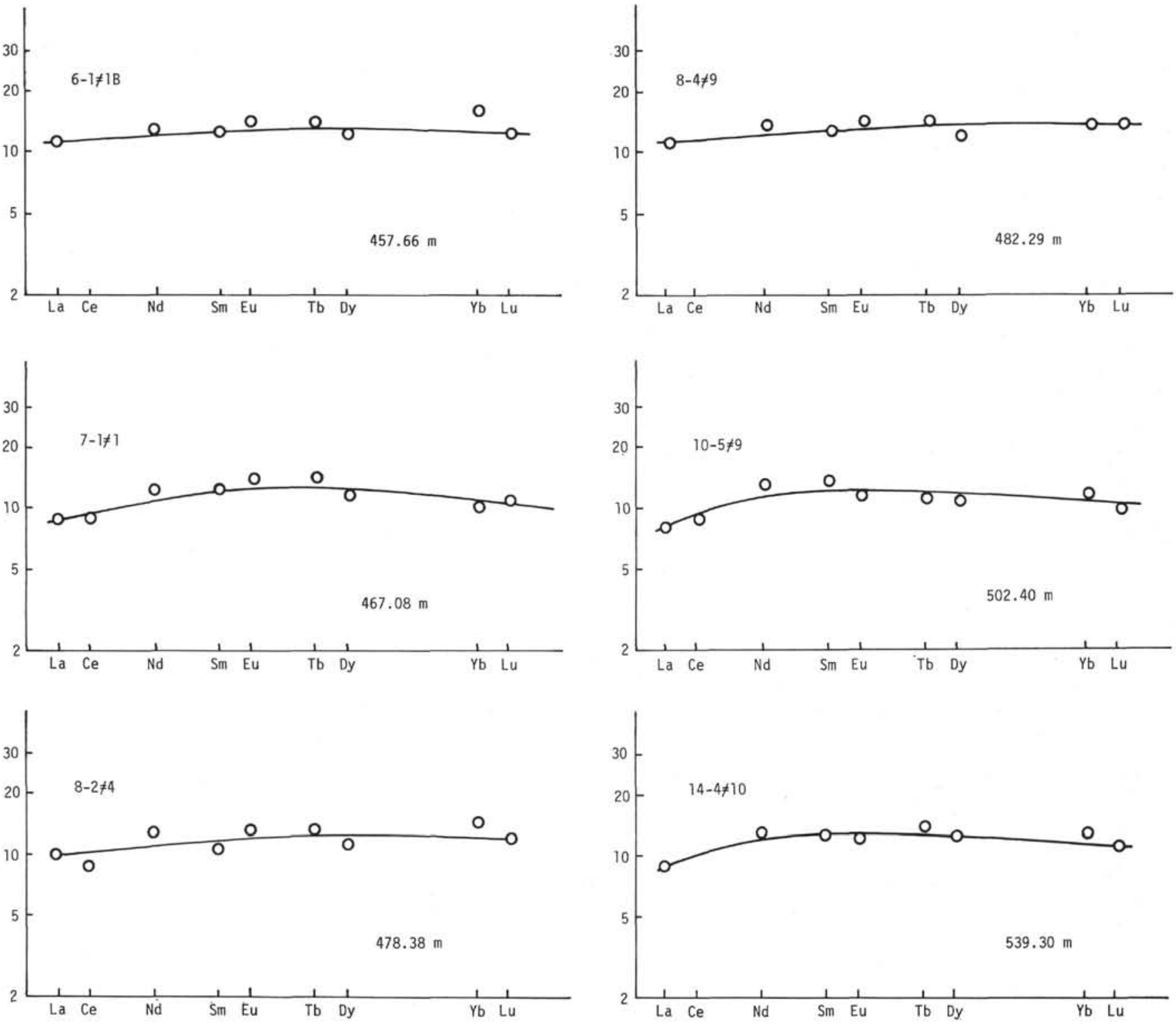


Figure 2. *REE distribution patterns of basalts from Site 335.*

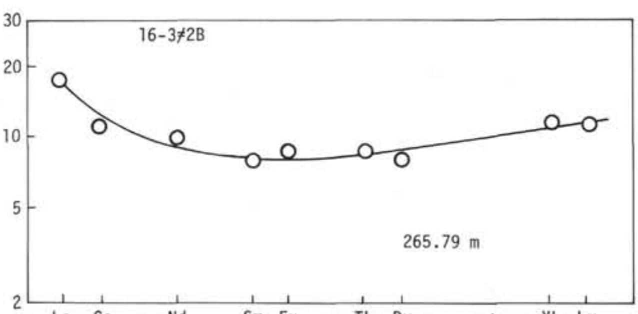


Figure 3. *REE distribution patterns of basalts from Site 334.*

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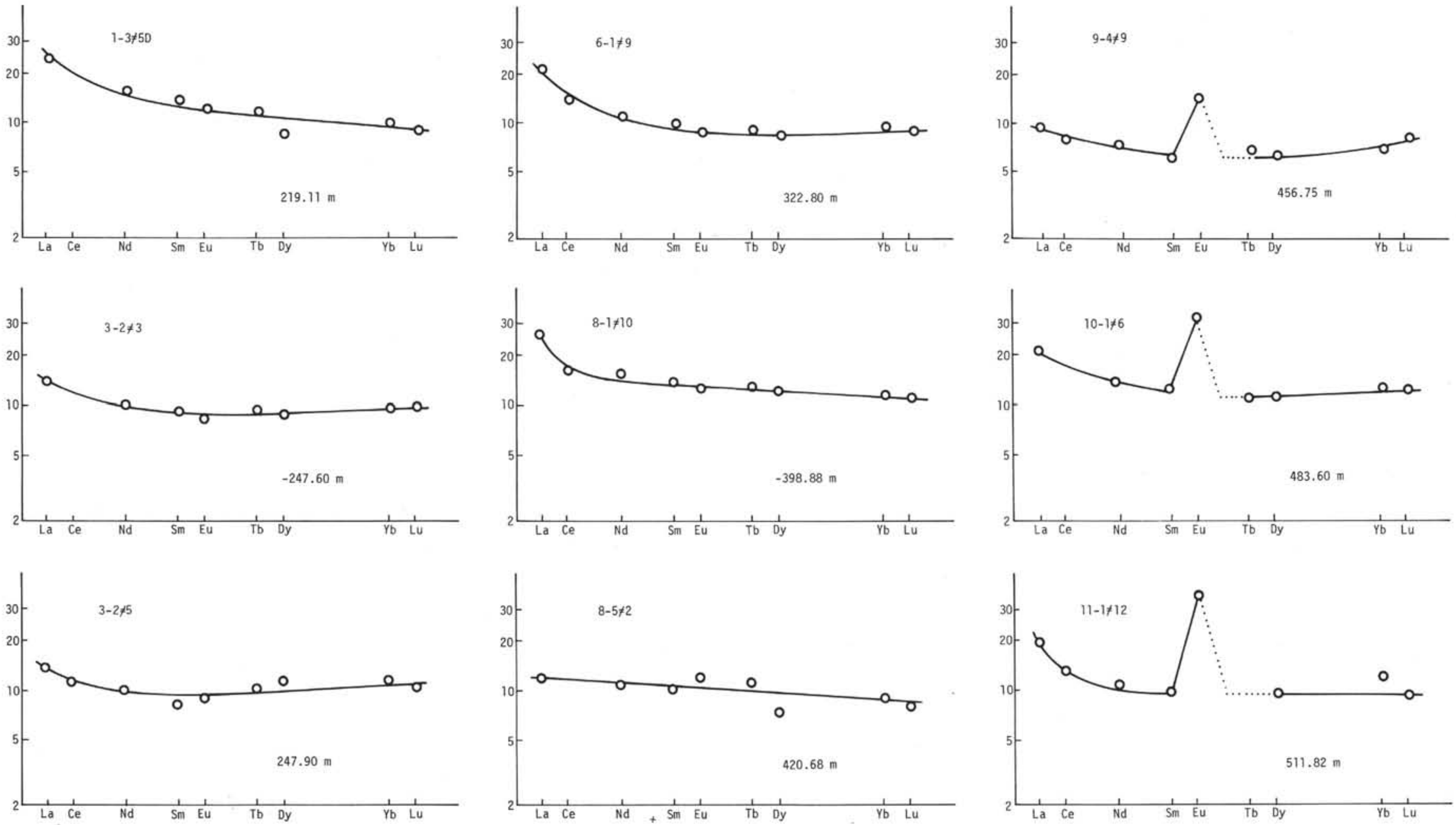


Figure 4. *REE distribution patterns of basalts from Hole 333A.*

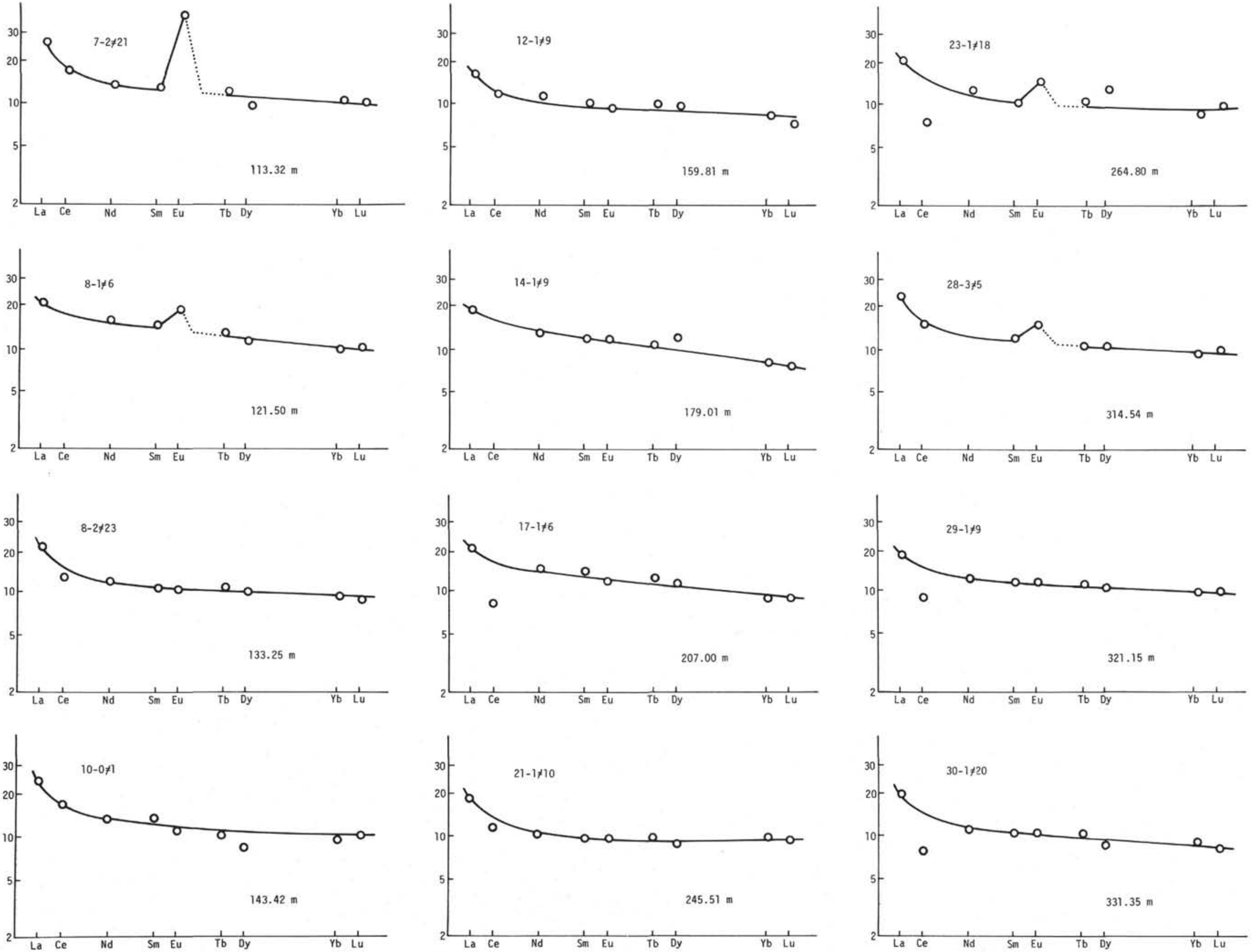


Figure 5a. *REE distribution patterns of basalts from Hole 332A.*

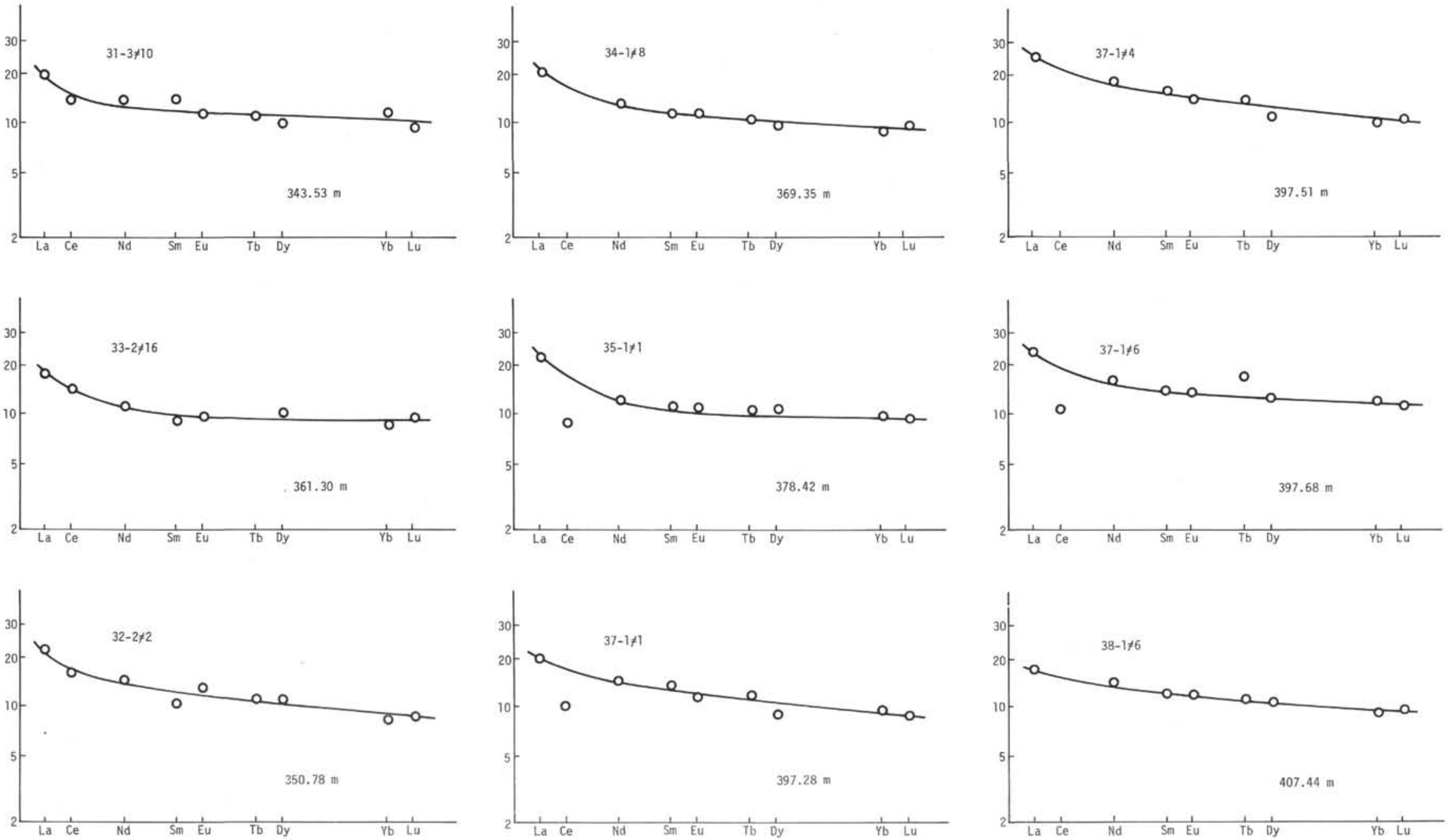


Figure 5b. *REE distribution patterns of basalts from Hole 332A.*

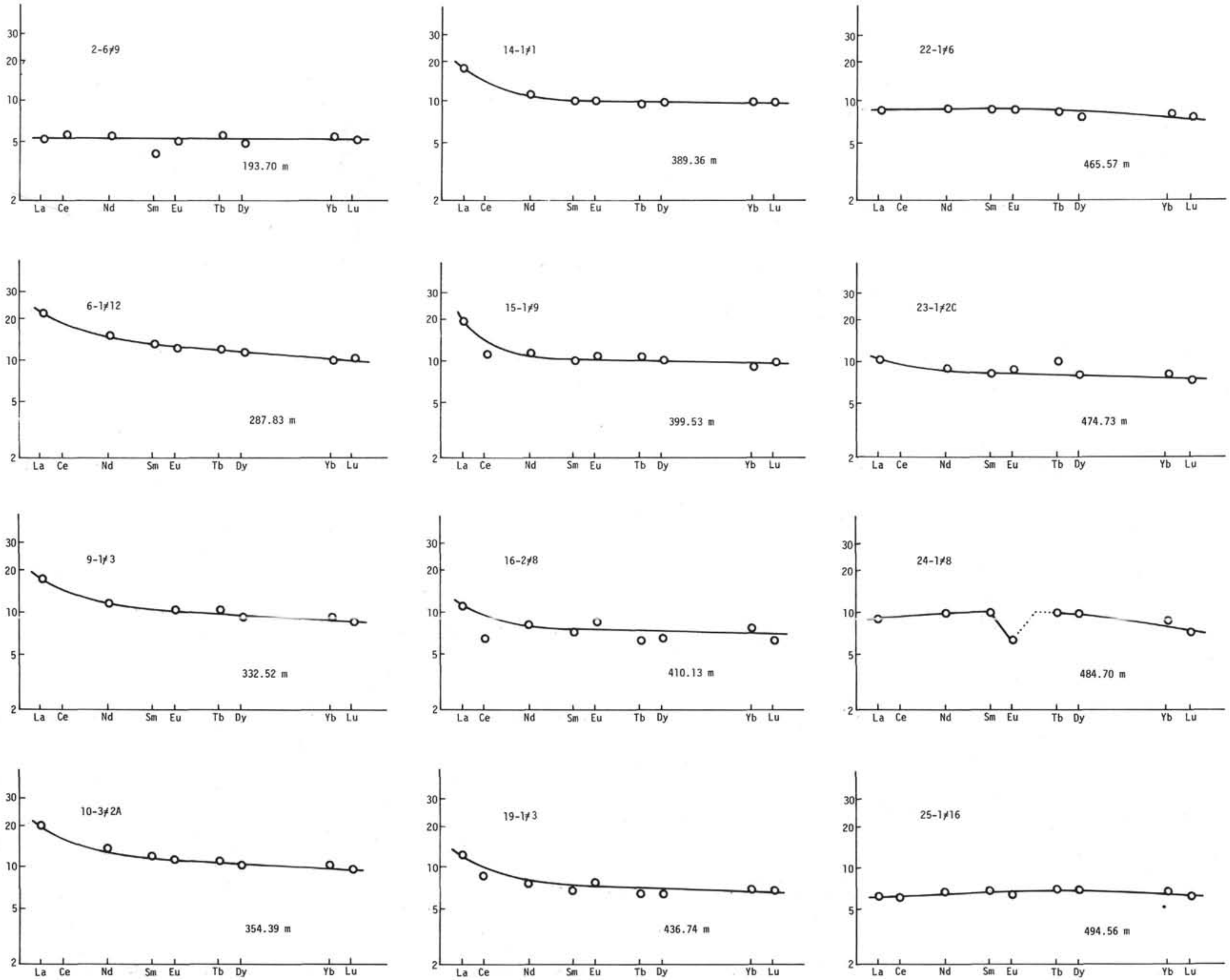


Figure 6a. *REE distribution patterns of basalts from Hole 332B.*

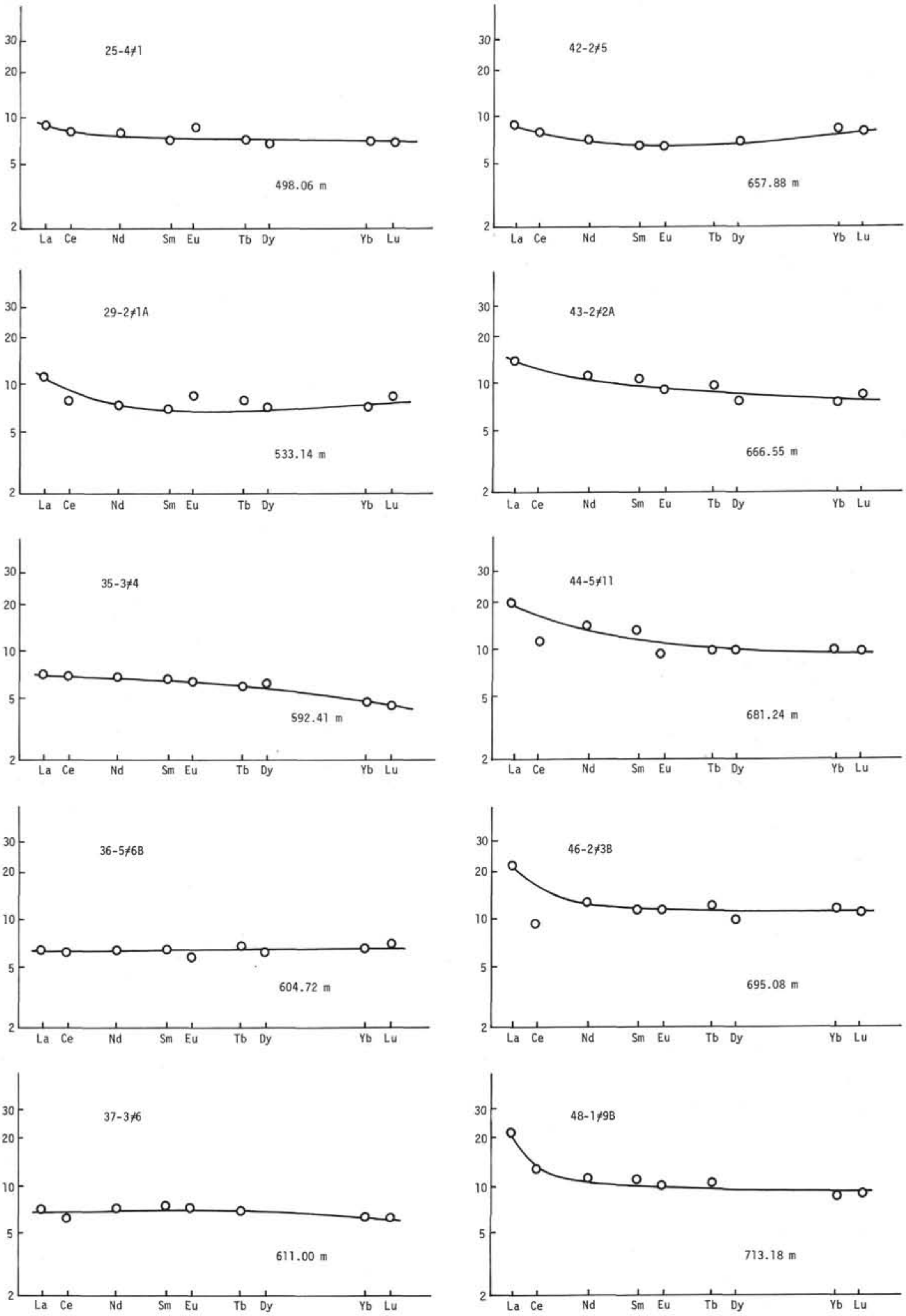


Figure 6b. *REE distribution patterns of basalts from Hole 332B.*

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