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Distribution of REE in the Eastern Belt Supergroup (Montana, U.S.A.): Implications for stratigraphic correlations and basin evolution

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Abstract

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Shales of the Mid-Proterozoic Newland Formation, Belt basin, contain a geochemical marker horizon that is characterized by the appearance of negative Eu anomalies in shale REE patterns. REE pattern changes appear to be related to changes in weathering intensity and tectonic activity in the hinterland. Stratigraphic and sedimentologic considerations suggest that this REE marker horizon defines an approximate time-line within the sequence. Comparison of REE patterns of the Newland Formation and the coarse clastic LaHood Formation that was deposited to the south, shows that the lower portions of the Newland Formation were deposited prior to LaHood sedimentation. Such a correlation implies that early Belt sediments may have covered a much larger area than delineated by the outline of the present-day Belt basin and that, contrary to earlier views of basin evolution, the half-graben configuration of the eastern Belt basin was established at some later point of basin history.

1. Introduction

Within sediments of the Helena embayment, an eastern extension of the Mid-Proterozoic Belt basin, Montana, U.S.A., several different types of rare-earth element (REE) patterns (normalized to the North American Shale Composite, or NASC) have been identified (Schieber, 1986a). Three REE pattern types can be distinguished, flat, LREE-enriched and with negative Eu anomalies. In a previous study (Schieber, 1986a) a drastic change of REE patterns has been found at an important stratigraphic boundary in four locations in the Little Belt Mountains (Fig. 1). Below that boundary the REE patterns are flat and light REE (LREE) -enriched. Above that boundary patterns with negative Eu anomalies appear, and are predominant over the other two pattern types. Stratigraphy and history of the Helena embayment were summarized by Schieber (1986a), and only the most essential features are repeated here.

The stratigraphic columns of the northern and southern portions of the Helena embayment differ (Fig. 2). In the north the Belt Supergroup rests nonconformably on crystalline basement, and its lowermost unit, the Neihart Quartzite, is overlain by the Chamberlain Shale, the Newland Formation and the Greyson Shale. According to McMannis (1963), these stratigraphic units pass towards the south into and interfinger with the LaHood Formation, an undifferentiated coarse clastic unit. The Newland

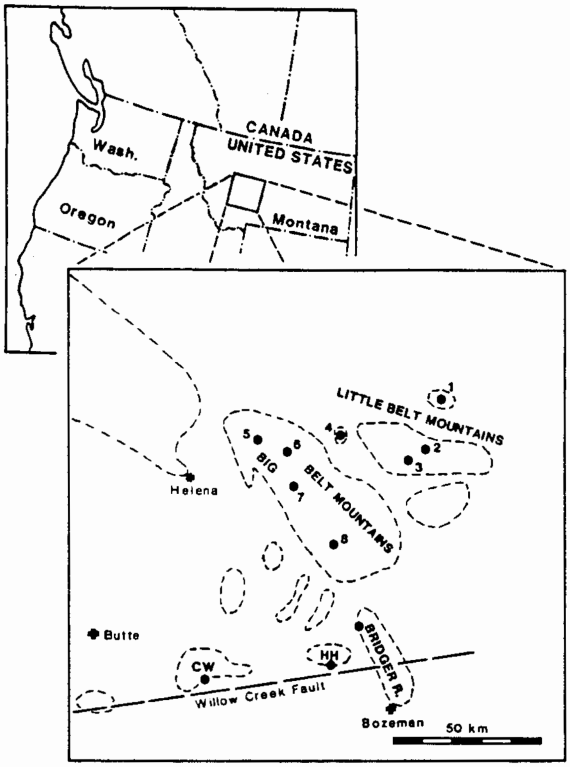

Fig. 1. Location map. *Shaded area* indicates outline of Belt basin. Enlarged portion of map shows location of Belt outcrop areas (*areas enclosed by dashed lines*), of stratigraphic sections (*numbers*) and of sample collection sites (*solid circles*). Sections *1-4* are located in the Little Belt Mountains and data were presented in Schieber (1986a). Section names for Big Belt Mountains: *5*=Trout Creek; *6*=Avalanche Creek; *7*=Confederate Gulch; *8*=Deep Creek. The small outcrop areas in the southern portion of the map (collection areas *marked by solid circles*) are primarily areas of LaHood Formation outcrops (*CW*= Cardwell-Whitehall area; *HH*=Horseshoe Hills).

Formation can be subdivided into a lower member (dolomitic shales) and an upper member (alternating shale and carbonate packages) in most areas (Nelson, 1963). Recent investigations (Schieber, 1985, 1986a) have shown that the Chamberlain Shale is a partial lateral equivalent of the Newland Formation in the northernmost part of the embayment (Fig. 2). In the present paper the name "lower Newland" will be used informally for the lower member of the Newland Formation, and the name "upper Newland" for the upper member.

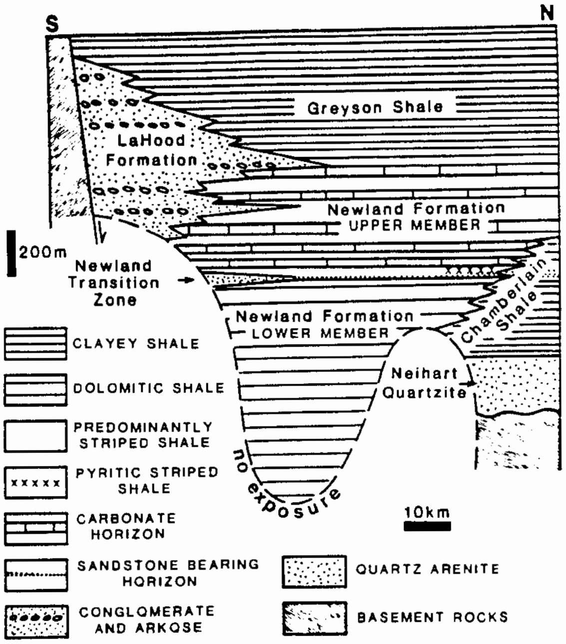

Fig. 2. Stratigraphic overview of the Belt Series in the Helena embayment (based on data from McMannis, 1963; Boyce, 1975; Schieber, 1985). Thickness of stratigraphic units: Neihart Quartzite, ~270 m; Chamberlain Shale, ~600 m; "Lower Newland", ~500-1200 m; "Newland Transition Zone", ~50-100 m; "Upper Newland"; ~500-900 m; Greyson Shale, ~1800-3000 m; LaHood Formation, ~2000-2500 m.

A sandstone-bearing marker unit, provisionally called the "Newland Transition Zone" ("NTZ") (Schieber, 1985, 1987), has been identified between "lower" and "upper Newland" (Fig. 2). The sequence from Neihart Quartzite to Chamberlain Shale/"lower Newland" represents initial transgression of the Beltian sea, deposition of the "NTZ" marks a major regression, and deposition of the "upper Newland" signals renewed transgression (Schieber, 1986b).

1.1. REE *stratigraphy*

In an initial study of REE distribution in the Newland Formation of the Little Belt Mountains (Schieber, 1986a), stratigraphic control of REE patterns types (Fig. 3) was only proven to extend over a distance of 40 km, and it was

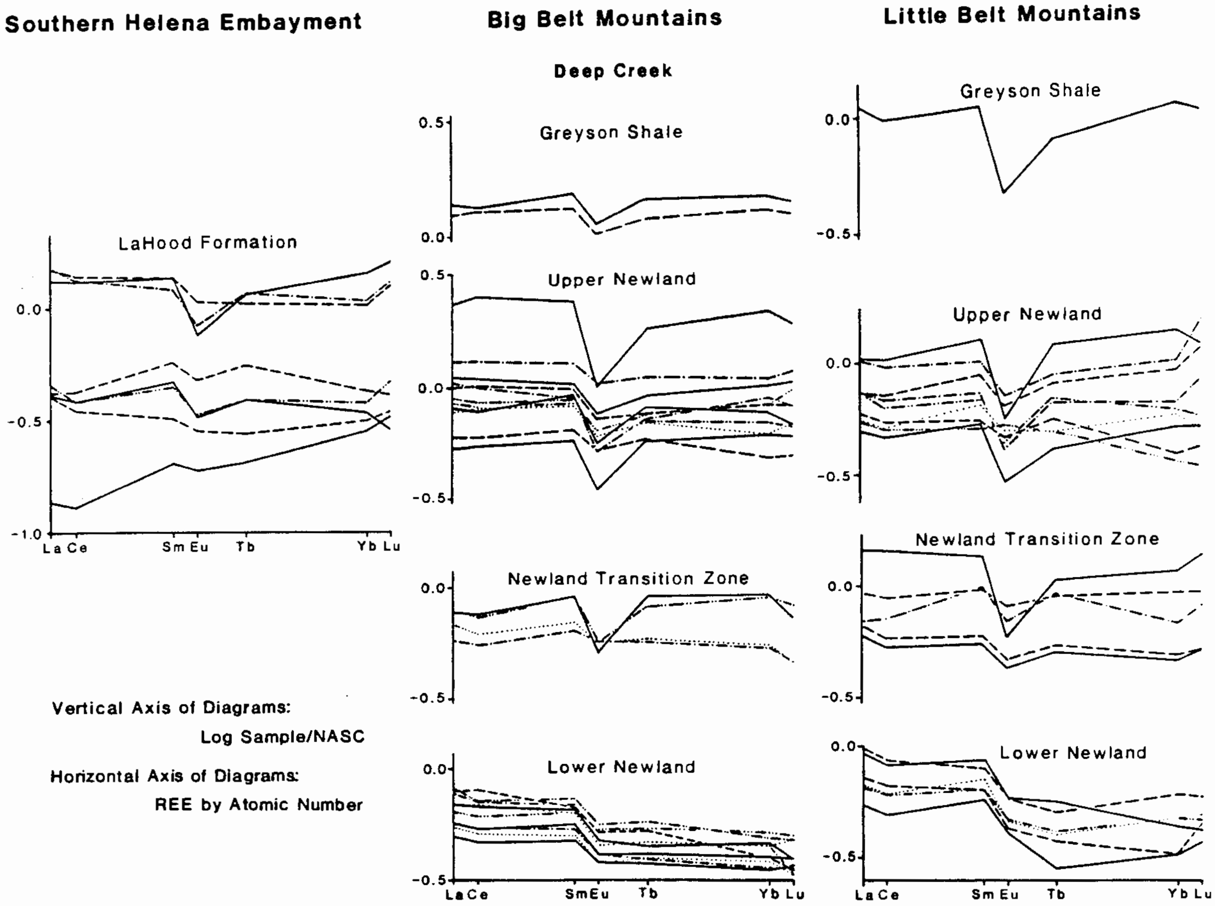

Fig. 3. In this diagram, REE pattern distribution in the Little Belt Mountains (data from Schieber, 1986a), the southern Big Belt Mountains (Deep Creek section), and the LaHood Formation are compared. The Deep Creek section was chosen to represent the Big Belt Mountains because it lacks structural complications and was the most closely and systematically sampled section. Note that REE patterns from the LaHood Formation are comparable to those of "NTZ", "Upper Newland" and Greyson Shale, but not to those of the "Lower Newland". The one sample of LaHood shale that shows depletion of LREE was collected from an interval of interbedded carbonates and shales. Diagenetic REE redistribution from shales to carbonates probably caused the LREE depletion in that sample (Schieber, 1988). Because of the diagenetic influence this sample is not plotted in Fig. 4 and was not included in statistical tests.

therefore thought desirable to test the proposed concept of REE stratigraphy (Schieber, 1986a) over a larger area. For this purpose outcrop areas of the Belt Supergroup south of the Little Belt Mountains were sampled during the measuring of stratigraphic sections. Data reported in this paper are from four stratigraphic sections in the Big Belt Mountains, and from outcrop areas of the LaHood Formation south of the Big Belt Mountains (Fig. 1). Possible reasons for the REE pattern change in the Newland Formation were discussed by Schieber (1986a), and an extended summary is given in the following paragraphs.

A number of processes, such as weathering, erosion, transport and deposition, water chemistry and diagenesis, cause chemical fractionation among the various classes of sediments (e.g., carbonates, sandstones, shales) and cause them to differ in composition from their source rocks. However, not all elements are fractionated equally during the operation of above processes. Two important parameters for evaluating fractionation of a given element are its partitioning into natural waters and its residence time in these waters. Taylor and McLennan (1985) have argued convincingly that elements with small seawater–upper crust partition coefficients and small residence times are transferred almost quantitatively into clastic sedimentary rocks and give therefore the best information about the source rocks. Their considerations suggest that Ti, Zr, Hf, Al, Ga, REE, Y, Th, Sc and Co are most useful for source-rock studies of sediments. Because shales dominate the sedimentary record they also govern to a large extent sedimentary mass-balance calculations for these elements, and this is one of the reasons why only analyses of shales were used in this study. This approach is further facilitated by the dominance of shales in the Belt sequence of the Helena embayment (Schieber, 1985).

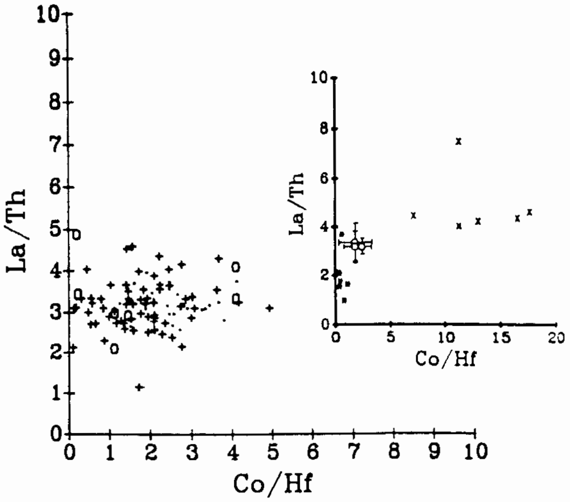

Fig. 4. Plot of La/Th vs. Co/Hf for Newland Formation and LaHood Formation. Symbols: (a) *open circles* = LaHood Formation; (b) *crosses* = "NTZ" and "upper Newland"; (c) *dots* = "lower Newland". In this diagram sediments derived from granitoid source rocks will plot in the lower left-hand corner, whereas sediments derived from mafic source rocks will plot in the upper right-hand corner. Data points from all units of the Newland Formation and from the LaHood Formation fall into the same area, indicating derivation from the same type of source terrane. The *inset diagram* to the right is a plot of La/Th vs. Co/Hf for a collection of mafic (BCR-*1*, W-*1*, W-2, DR-N, BE-N, JB-*1*) and felsic (G-*1*, G-2, GSP-2, RGM-*1*, GM, NIM-G, JG-*1*) standard rocks published in Govindaraju (1984). Mafic rock samples marked by *crosses*, felsic rocks samples marked by *stars*). Also included in the *inset diagram* are the average values of La/Th and Co/Hf for "lower Newland", "NTZ" and "upper Newland" with the standard deviations for each group of samples. The closeness of the averages and the overlap of the standard deviations also indicate that the three groups of samples are derived from the same type of source area.

Variations of REE patterns in a stratigraphic succession are usually interpreted to reflect changes in source-rock composition (Wildeman and Haskin, 1973; Dypvik and Brunfelt, 1976), and such changes are usually mirrored by changes in sediment lithology. However, the change in REE pattern types that is observed in shales of the Newland Formation is not controlled by a change in shale lithofacies (Schieber, 1986a) and probably had a different cause. In the Newland Formation of the Little Belt Mountains, the distribution of elements that are relatively immobile during weathering (Taylor and McLennan, 1985), such as Al, Ti, La, Th, Co and Hf, is essentially the same for "lower Newland", "NTZ", and "upper Newland (Fig. 4; Schieber, 1986a), indicating that the source rocks for these shales were of fairly similar composition throughout. Small La/Th ratios, large Hf contents, and relatively small contents of Cr, Co and Ni indicate that the source rocks of the Newland Formation in the Little Belt Mountains were derived from crust of largely granitic composition (Shiraki, 1978; Turekian, 1978a, b; Bhatia and Taylor, 1981; Condie and Martell, 1983). The same conclusion is reached when exposed basement rocks below the Belt sequence in the Helena embayment (Witkind, 1971; Keefer, 1972; Mueller et al., 1982); Wooden et al., 1982) are examined. These rocks are generally of granitic composition and dominated by granitoid gneisses and migmatites. Considerable thicknesses of these deep crustal rocks are exposed and no drastic compositional changes with depth are known to exist. These observations suggests that Proterozoic uplift in the Beltian hinterland, e.g. at the time of "NTZ" deposition, probably did not produce a drastic change in overall source-rock composition.

If the source rocks of the Belt sequence were dominated by granitoid gneisses and migmatites, they can be expected to have negative Eu anomalies. Data by McCarthy and Kable (1978) show that gneisses and particularly migmatites can show quite pronounced Eu anomalies even when normalized to NASC. Negative Eu anomalies (relative to NASC) also occur in Precambrian granites that are due to partial melting (Condie, 1978). An increase of the magnitude of negative Eu anomalies with pogressive anatexis of gneisses was observed by Emmermann et al. (1975). These negative Eu anomalies were still clearly visible when the data were normalized to NASC. Eu depletion was explained with incongruent melting of biotites. Migmatites from the Beartooth Mountains (Mueller et al., 1982), an outcrop area of pre-Belt basement rocks south of the Helena embayment, also have negative Eu anomalies that are still visible after normalization to NASC. From the above discussion it appears quite possible that the metamorphic source terrane of the eastern Belt Series had an overall negative Eu anomaly when normalized against NASC.

The absence of detrital feldspars in shales of the "lower Newland", and the presence of detrital feldspars and biotite in shales of the "NTZ" and "upper Newland" suggest that chemical weathering went essentially to completion during deposition of the "lower Newland", but not during deposition of "NTZ" and "upper Newland" (Schieber, 1985, 1986a). The hinterland during the deposition of the "lower Newland" was probably of very low relief, and the monotony of the "lower Newland" shale sequence indicates conditions of tectonic quiescence (Reynolds, 1984; Schieber, 1985). Tectonic activity and uplift in the hinterland during deposition of "NTZ" and "upper Newland" is indicated by incursions of feldspathic sandstones in the "NTZ" (Schieber, 1987) and cyclic deposition of shales and carbonates in the "upper Newland" (Schieber, 1985). Because a change of source rock type between "lower Newland" and "NTZ" seems unlikely (Fig. 4), it is possible that changes in other variables such as the degree of chemical weathering, influenced REE distribution in the Newland shales. One could, of course, argue that REE pattern changes between "lower Newland" and "NTZ" reflect differences in depositional environment (REE fractionation via grain-size sorting) rather than changes in the intensity of chemical weathering. However, the various shale facies types of the Newland Formation have been investigated in considerable detail, and were found to be compositionally (Schieber, 1986a) and mineralogically (Schieber, 1989) very similar. Facies differences are mainly of textural nature and are related to differences in depositional environments (Schieber, 1989). Several of the shale facies types that have been described from the Newland Formation by Schieber (1989) occur in the "lower Newland", "NTZ" and "upper Newland" alike. It was shown in Schieber (1986a) that in any given shale facies type, there is a difference in REE patterns when samples from "lower Newland" and "NTZ"/"upper Newland" are compared. In a given facies, samples from below the "NTZ" will lack negative Eu anomalies, whereas samples from "NTZ"/"upper Newland" will in many cases show negative Eu anomalies. Thus, rather than being controlled by shale facies (or sedimentary conditions), REE distribution in the Newland Formation was found to be related to stratigraphic position (Schieber, 1986a). Therefore, differences in depositional environments appear to have had no noticeable influence on REE distribution in these shales, and REE fractionation via grain-size sorting cannot be used to explain changes of REE patterns in the Newland Formation.

In summary, when considering causes of REE pattern changes in the Newland Formation, five main points have to be taken into account: (1) source rocks were probably dominated by gneisses and migmatites of granitic composition; (2) such source rocks are likely to show negative Eu anomalies against NASC; (3) changes in source-rock type with increasing depth of erosion are not likely; (4) the "lower Newland" underwent more intense chemical weathering than overlying units; and (5) sedimentary environment and grain-size sorting probably did not exert a major control over REE distribution.

Even though there are some studies that indicate REE mobility and Eu fractionation during weathering (Ronov et al., 1967; Nesbitt, 1979; Schau and Henderson, 1983; Reimer, 1985; Kimberley and Grandstaff, 1986; Kronberg et al., 1987), in general the REE are considered to undergo little fractionation during weathering, transport and deposition (Taylor and McLennan, 1985), and even during diagenesis (Chaudhuri and Cullers, 1979) and low-grade metamorphism (Taylor and McLennan, 1985). Particularly if one considers the homogenizing effects of transport and deposition on the REE distribution in sediments, the apparent REE and Eu fractionation that has been observed in some soil studies (Nesbitt, 1979; Schau and Henderson, 1983; Kimberley and Grandstaff, 1986; Kronberg et al., 1987) would probably not be visible in basinal shales whose REE distribution is the result of averaging over a large source area. The Newland Formation has undergone no (Little Belt Mountains) or only minor metamorphism (Big Belt Mountains), and because of the likely absence of source-rock change and grain-size effects, it is assumed that overall changes in weathering intensity have been the main influence on REE distribution (Schieber, 1986a). Cullers et al. (1975) pointed out that intense chemical weathering may reduce the total REE content of residual clays, and that negative Eu anomalies in clays (relative to NASC) may be inherited from the source rocks. That these observations are of relevance to the Newland Formation is indicated by the fact that shale samples with the largest total REE contents and the strongest negative Eu anomalies are found only in the NTZ, where the most immature sediments of the sequence are found (Schieber, 1986a). It suggests that characteristics of REE distribution in the source rocks (such as negative Eu anomalies) may more easily be transferred to basinal sediments when weathering conditions are less intense.

For the reasons discussed above it is concluded that the absence of REE patterns with negative Eu anomalies in the "lower Newland" is mainly due to chemical weathering having gone to completion (absence of detrital feldspars). Low relief and tectonic quiescence allowed enough time for thorough breakdown of original silicate minerals and leaching of residual clays, and resulted in the obliteration of source-rock-related negative Eu anomalies. When rejuvenation of the hinterland occurred (deposition of the NTZ) chemical weathering was not as intense because increased relief resulted in faster removal of weathering products to the basin (survival of detrital feldspars and biotites). The decrease in chemical weathering resulted in less REE leaching from residual clays and source-rock-related negative Eu anomalies could survive weathering and transport. That a number of samples from the NTZ and "upper Newland" lack negative Eu anomalies may be due to later erosion of remnants of the pre-NTZ weathering blanket, and also to the accumulation of more strongly leached weathering blankets during periods of muted relief in the "upper Newland" (related to episodic uplift and cyclic deposition). Thus, whereas in shales of the "lower Newland" only flat and LREE-enriched REE patterns are found, shales of the NTZ and "upper Newland" are characterized by a common occurrence of REE patterns with negative Eu anomalies in addition to the other two pattern types (Schieber, 1986a). The occurrence of REE patterns with negative Eu anomalies with the onset of NTZ deposition is the basis for REE stratigraphy in the Newland Formation.

2. Analytical methods

Weathered portions of shale samples were trimmed off, and the remaining material was crushed and then ground in a ceramic shatterbox. Abundances for seven REE (La, Ce, Sm, Eu, Tb, Yb, Lu) and for Co, Hf and Th were determined by instrumental neutron activation analysis (INAA) following the technique of Gordon et al. (1968). Samples were irradiated together with U.S.G.S. standard rocks AGV-*1* and BCR-*1*, the shale standard rock Tb (Zentrales Geologisches Institut, Berlin, F.R.G.), and internal laboratory standards. Samples were analysed in the INAA laboratory at the University of Oregon and at the Radiation Center of Oregon State University. Multiple analyses of standard rocks (see Schieber, 1988, table 1) indicate that precision for La, Ce, Sm and Eu is ±5% or better, and ±10% or better for Tb, Yb and Lu. Precision is ±5% for Co and Th, and ±8% for Hf (Schieber, 1985).

3. Results

Analyses of shales from the Big Belt Mountains and the LaHood Formation are included in Table I. Analyses of shales from the Little Belt Mountains have been published in Schieber (1986a). REE abundances of all samples have been normalized to NASC as published by Haskin et al. (1968).

3.1. Belt strata in the Little Belt Mountains

Petrographic and REE data from Beltian shales in this area have been reported and discussed by Schieber (1986a), thus only the major features will be summarized here. As pointed out above, "lower Newland" shales are characterized by flat and ramp-shaped REE patterns, whereas shales of "NTZ" and "upper Newland" have patterns with negative Eu anomalies in addition to the flat and ramp-shaped types (Fig. 3). Occurrence of REE patterns with negative Eu anomalies at the base of the "NTZ" can be used for geochemical correlation between sections, and is the basis of the REE stratigraphy approach proposed by Schieber (1986a). The REE content of these shale resides predominantly in the clays. As pointed out on p. 87, REE pattern are facies independent and appear to be stratigraphically controlled.

Schieber (1986a) also pointed out that small La/Th ratios and large Hf contents indicate a generally granitic source area for shales of the Newland Formation (Bhatia and Taylor, 1981; Condie and Martell, 1983). Because fine crystalline dolomite in these shales dilutes the terrigenous fraction and causes increased scatter of data points along the Hf axis, the samples are presented here on a La/Th vs. Co/Hf plot (Fig. 4). This approach serves the same purpose of differentiating between granitic vs. mafic affinities (Taylor and McLennan, 1985) and avoids "interference" by dolomite. Small La/Th and small Co/Hf ratios as seen in Fig. 4 are consistent with derivation from crust of largely granitic composition. That the data point clusters from "lower Newland" and "NTZ"/"upper Newland" are superimposed in Fig. 4 indicates that overall source-rock composition did not change significantly throughout deposition of the sequence. Applying a non-parametrical statistical test (the Kolmogorov–Smirnov two-sample test; in Till, 1974) to the data in Fig. 4 also indicates that there is no significant difference in the La/Th and Co/Hf distribution between "lower Newland" and "NTZ"/"upper Newland".

3.2. Belt strata in the Big Belt Mountains

The Newland Formation is the most prominently exposed unit of the Belt Series in the Big Belt Mountains. The same stratigraphic scheme as in the Little Belt Mountains can be applied to the Big Belt Mountains (Schieber, 1985), and the various stratigraphic units are lithologically identical (Fig. 2).

Fifty-nine shale samples from four strati-

TABLE I

Analytical data (elemental abundance in ppm)

Sample No.	LH*1*	LH2	LH*3*	LH*4*	LH5	LH*6*	LH7	LH*8*	BB*1*	BB2
Ser. sect.									TC	TC
Str. unit									LN	LN
La	48.8	14.6	13.2	4.4	48	13.5	42.5	13	19.8	23.6
Ce	97.4	28.3	28.1	9.5	102	31.1	95.7	25.8	42.4	48.5
Sm	6.91	2.58	2.73	1.19	7.89	3.3	7.79	1.86	3.34	3.89
Eu	1.06	0.42	0.41	0.24	1.35	0.6	0.97	0.36	0.45	0.57
Tb	1	0.34	0.34	0.18	0.91	0.48	0.99	0.24	0.31	0.38
Yb	3.4	1.2	1.08	0.9	3.3	1.35	4.5	1	1.25	1.51
Lu	0.64	0.23	0.14	0.16	0.62	0.2	0.78	0.17	0.19	0.21
Co	1.31	1.9	2	7.6	12.3	3.69	2	3.33	2	1.68
Hf	6.5	1.68	1.37	0.72	3	0.9	8.6	3	1.7	1.65
Th	10	4.9	4.5	2.5	14.4	3.3	12.4	6.2	6.5	7.9

Sample No.	BB*3*	BB*4*	BB5	BB*6*	BB7	BB*8*	BB*9*	BB*10*	BB*11*	BB*12*
Str. sect.	TC	TC	TC	TC	TC	TC	TC	TC	TC	TC
Str. unit	LN	LN	NTZ	NTZ	UN	UN	UN	UN	UN	UN
La	23.9	28	17.1	23.7	20.2	32.7	34.2	96.4	37.5	20
Ce	50.7	55.9	37.4	51.1	41.2	65.2	75.7	211	77	43.4
Sm	4.69	5.08	3.7	4.99	4.01	5.61	6.28	17.9	7.33	4.41
Eu	0.57	0.89	0.6	0.71	0.64	0.79	0.79	1.33	1.03	0.65
Tb	0.56	0.53	0.42	0.57	0.45	0.59	0.69	2.4	0.85	0.57
Yb	2.3	1.71	1.53	2.2	1.7	2.05	2.6	7.96	3.64	2.1
Lu	0.3	0.26	0.19	0.32	0.22	0.34	0.38	1.25	0.58	0.31
Co	4.4	8.65	3	6.5	3.3	5.1	7.36	1.2	2.1	3.4
Hf	2.9	2.1	1.95	3.1	1.34	2.3	3.5	6.6	3.6	1.52
Th	9	7.5	6	9.2	5	7.5	11.6	30.9	11.6	5.47

Sample No.	BB*13*	BB*14*	BB*15*	BB*16*	BB*17*	BB*18*	BB*19*	BB*20*	BB*21*	BB22
Str. sect.	TC	AC	AC	AC	AC	AC	AC	AC	AC	AC
Str. unit	GREY	NTZ	NTZ	NTZ	NTZ	UN	UN	UN	UN	GREY
La	35.4	22	16.7	33.4	35.4	14.5	27.6	21.8	52.5	59.9
Ce	80.2	45.2	35.7	68.6	70.4	31.2	56	43.2	96.3	132.3
Sm	7.94	4.39	3.44	6.54	6.31	2.91	5.69	3.69	8.06	13.17
Eu	1.24	0.67	0.49	0.82	0.8	0.71	0.91	0.51	1.14	1.49
Tb	0.99	0.5	0.4	0.72	0.65	0.3	0.62	0.43	0.8	1.35
Yb	4.1	1.6	1.51	2.39	2.15	1.29	2.44	1.59	3.2	5.5
Lu	0.61	0.23	0.22	0.37	0.35	0.235	0.39	0.21	0.49	0.85
Co	5.8	6.6	3.5	6.45	5.75	12.7	4.4	6	2.12	5.8
Hf	6	2.8	2.6	3.5	3.34	4.6	3.09	1.95	4.7	8
Th	13.5	8	6.1	9.4	8.9	6.7	8.6	7	13	18.3

Sample No.	BB*23*	BB*24*	BB*25*	BB*26*	BB*27*	BB*28*	BB*29*	BB*30*	BB*31*	BB32
Str. sect.	CG	CG	CG	CG	CG	CG	CG	CG	CG	CG
Str. unit	LN	LN	NTZ	NTZ	NTZ	UN	UN	UN	UN	GREY
La	24.5	22.5	23.8	26.8	53.5	19.3	284	31	26.2	53.6
Ce	49.7	47.1	51.5	54.4	120	38.6	59	66	58.2	112.9
Sm	4.36	3.98	4.61	5.7	9.70	3.79	5.59	5.97	4.86	9.42
Eu	0.61	0.62	0.7	0.81	0.56	0.52	0.88	0.86	0.62	1.35
Tb	0.44	0.46	0.47	0.69	1.01	0.41	0.63	0.62	0.53	1.11
Yb	1.8	1.85	1.65	2.45	3.8	1.5	2.45	2.56	1.95	4.5
Lu	0.23	0.25	0.25	0.4	0.55	0.19	0.44	0.39	0.29	0.7
Co	6.4	8.1	6	5.8	1.18	4.54	7.4	4.15	4	0.9
Hf	2.35	2.13	2.85	3	3.8	1.59	2.7	5.2	2.26	6.5
Th	9.5	8	8.3	8	16	5.8	9	9.3	8.8	16.5

TABLE I (*continued*)

Sample No.	BB*33*	BB*34*	BB*35*	BB*36*	BB*37*	BB*38*	BB*39*	BB*40*	BB*41*	BB*42*
Str. sect.	DC	DC	DC	DC	DC	DC	DC	DC	DC	DC
Str. unit	LN	LN	LN	LN	LN	LN	LN	LN	LN	LN
La	22.3	18.3	25.7	22.4	25	26.4	15.9	17.7	18	20.8
Ce	49.4	39.2	59	50.6	52	52	34.1	37.4	39.6	45
Sm	3.72	3.21	3.84	3.59	3.94	4.19	2.71	2.87	3.04	3.67
Eu	0.59	0.51	0.64	0.56	0.56	0.69	0.47	0.46	0.51	0.66
Tb	0.38	0.35	0.45	0.4	0.39	0.49	0.32	0.34	0.33	0.46
Yb	1.44	1.24	1.24	1.4	1.38	1.5	1.1	1.2	1.1	1.6
Lu	0.19	0.19	0.17	0.23	0.16	0.23	0.18	0.16	0.17	0.24
Co	6.18	6.22	4.31	8.34	3.51	3.48	4.47	2.71	3.5	2.9
Hf	2.15	1.86	1.79	2.56	1.87	1.7	1.3	1.48	1.25	1.96
Th	6.7	5.9	8.1	7.3	7.9	7.6	5	5.5	5.6	6.4

Sample No.	BB*43*	BB*44*	BB*45*	BB*46*	BB*47*	BB*48*	BB*49*	BB*50*	BB*51*	BB*52*
Str. sect.	DC	DC	DC	DC	DC	DC	DC	DC	DC	DC
Str. unit	NTZ	NTZ	NTZ	NTZ	NTZ	NTZ	NTZ	UN	UN	UN
La	24.9	18.5	25.2	21.9	26.3	17.2	74.5	24.7	32.2	27.5
Ce	55.5	40.1	54	45.3	57.7	40.3	184	59.5	75	60
Sm	5.19	3.64	5.17	3.98	5.33	3.33	13.62	4.69	5.63	4.82
Eu	0.63	0.71	0.8	0.7	0.7	0.43	1.25	0.75	0.9	0.74
Tb	0.78	0.48	0.7	0.5	0.7	0.49	1.55	0.59	0.65	0.6
Yb	2.88	1.65	2.8	1.7	2.4	1.9	6.7	1.9	2.6	2.17
Lu	0.35	0.22	0.4	0.22	0.33	0.29	0.92	0.33	04	0.32
Co	1.9	4.76	3.85	4.06	5.85	8.46	1.31	4.67	7.96	5.86
Hf	3.55	2.28	3.9	2.57	4.52	4.91	12.2	3.18	4.5	2.78
Th	9.2	5.7	8.7	6.8	9.4	14.9	35	7.4	9.7	7.1

Sample No.	BB*53*	BB*54*	BB*55*	BB*56*	BB*57*	BB*58*	BB*59*
Str. sect.	DC	DC	DC	DC	DC	DC	DC
Str. unit	UN	UN	UN	UN	UN	GREY	GREY
La	28.9	42.1	35.7	33.6	19.3	45	40
Ce	63	97	80	72.9	44	99	95
Sm	5.02	7.33	5.93	5.11	3.69	8.87	7.66
Eu	0.8	1.3	0.95	0.64	0.65	1.41	1.27
Tb	0.64	0.95	0.78	0.61	0.5	1.25	1.02
Yb	2.6	3.4	3.16	2.8	1.5	4.7	4.1
Lu	0.47	0.57	0.51	0.4	0.24	0.69	0.61
Co	5.77	3.15	0.79	3.13	2.5	1.42	3.8
Hf	5.12	5.64	6.28	4.76	1.59	7.8	5.73
Th	9.5	12.6	11.5	12.3	4.2	13.8	10.6

LH = LaHood samples, BB = Big Belt samples, Str. sect. = stratigraphic section, Str. unit = stratigraphic unit, LN = Lower Newland, NTZ = Newland Transition Zone, UN = Upper Newland, GREY = Greyson Shale, TC = Trout Creek, AC = Avalanche Creek, CG = Confederate Gulch, DC = Deep Creek.

graphic sections (Fig. 1) were analysed from the Big Belt Mountains (Table I). The samples show the same range of La/Th ratios and Co/Hf ratios as observed in the Little Belt Mountains (Schieber, 1986a; Fig. 4). the "lower Newland" is characterized by flat and ramp-shaped REE patterns, whereas in the "NTZ" and "upper Newland" patterns with negative Eu anomalies are common in addition to flat and ramp-shaped patterns (Figs. 3 and 5). Five samples from the Greyson Shale were analysed to see if there is a contrast in REE patterns between "upper Newland" and Greyson Shale. Figs. 3 and 5 show that the Greyson Shale is characterized by negative Eu anomalies, just like "NTZ" and "upper Newland".

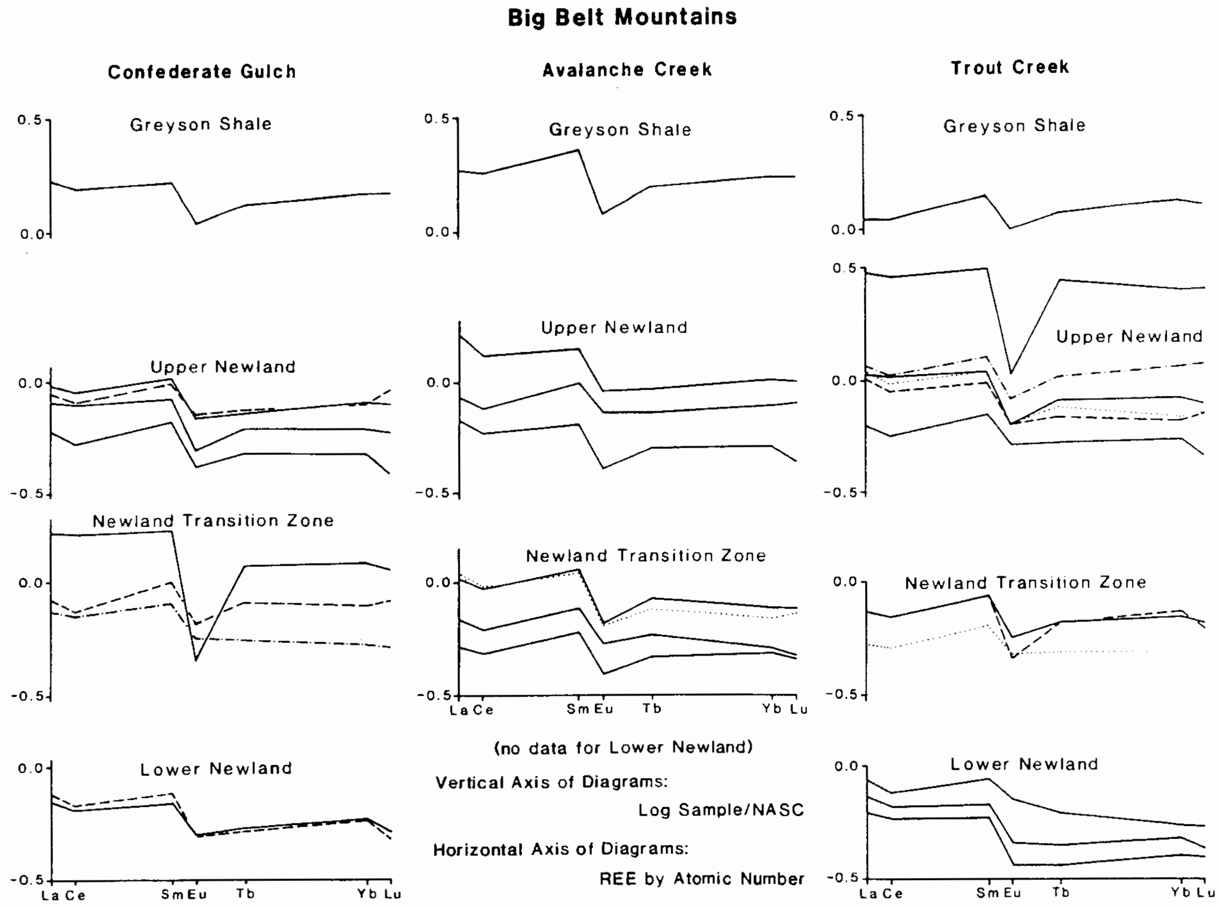

Fig. 5. REE pattern distribution in stratigraphic units of the northern Big Belt Mountains (Trout Creek, Avalanche Creek, Confederate Gulch). Distribution of pattern types is the same as encountered in the southern Big Belt Mountains and the Little Belt Mountains.

3.3. The LaHood Formation

The LaHood Formation (McMannis, 1963) contains arkoses, conglomerates and fine clastic intervals, and is exposed in scattered outcrops in the southern portion of the Helena embayment (Fig. 1). Shale facies types within fine-grained intervals of the LaHood Formation are equivalent to those distinguished in sediments of the central and northern Helena embayment (Schieber, 1984, 1989). Eight shale samples that represent stratigraphic positions from the bottom to the top of the LaHood sequence were analysed. The ranges of La/Th and Co/Hf ratios displayed by these samples are the same as found in the sediments of the Big Belt and Little belt Mountains (Fig. 4). Applying the Kolmogorov–Smirnov two-sample test (Till, 1974) to the La/Th and Co/Hf ratios of LaHood Formation and Newland Formation also indicates that the two data sets do not differ significantly with respect to La/Th and Co/Hf ratios. REE pattern types are the same as observed in shales of the Newland Formation to the north (Fig. 3) with negative Eu anomalies being dominant.

4. Discussion

4.1. Newland Formation REE *stratigraphy*

Continuity of lithofacies between Big Belt and Little Belt Mountains, as well as abundances of La, Th, Hf and Co, indicate that the Newland Formation in both areas was derived from a source area of similar composition (Fig. 4). It is therefore not surprising that the stratigraphic distribution of REE patterns is identical in both areas (Figs. 3 and 5). The "NTZ", at the base of which the change of REE pattern types occurs, was deposited due to uplift in the hinterland that caused a regression in the Helena embayment (Schieber, 1985), and was accompanied by enhanced sediment supply and increased sedimentation rates. In outcrops along the fringe of the present basin margin nearshore deposits are found in the position of the "NTZ", but in the remainder of the Newland outcrop area the "NTZ" typically consists of shales with interbedded sandstones. These sandstones contain hummocky cross-stratification and other indications of storm deposition, and proximality trends and sandstone distribution patterns are comparable with sandstone distribution found in modern storm-dominated shelf seas (Schieber, 1987). The shales that are interbedded with these sandstones also contain abundant evidence for storm activity during deposition (Schieber, 1987), such as graded silt/mud couplets with sharp basal contacts and graded rhythmites. In modern shelf seas, sediment redistribution by storms causes the deposition of sediment layers that are traceable over wide areas (Reineck et al., 1967, 1968), and the identification of abundant storm deposits in the "NTZ" implies by comparison that many of the sediment layers in the "NTZ" are "event layers" and probably of large lateral extent. Considerations of sediment accumulation rates in the Helena embayment (Schieber, 1985, 1987) and the small thickness of the "NTZ" (Fig. 2) suggest that this unit was deposited within a time span of ~0.5–1 Ma. Deposition by storms that probably distributed sediment over large areas, as well as the small thickness of the "NTZ" suggest that this unit should have been spread across the embayment in a relatively short time span. Thus, any diachroneity at the base of the "NTZ" should be quite small. Because Belt sedimentation spans ~600 Ma (Harrison, 1972), the contact between "NTZ" and the "lower Newland" can be considered an approximate time-line for all practical purposes of Precambrian stratigraphy.

A basic consideration for REE stratigraphy is that clays, the main carriers of REE in sediments, can travel large distances in suspension. Provenance-related changes in REE patterns of shales should therefore show up in basin marginal as well as in basin central stratigraphic sections at essentially the same time (Schieber, 1986a, fig. 7).

The new data from the Big Belt Mountains show the same stratigraphic distribution of REE patterns as in the Little Belt Mountains. The "lower Newland" is characterized by flat to ramp-shaped patterns, whereas samples from "NTZ" and "upper Newland" show patterns with negative Eu anomalies in addition to the pattern types found in the "lower Newland" (Fig. 3). The first appearance of REE patterns with negative Eu anomalies at the base of the "NTZ" in all stratigraphic sections demonstrates that a REE-based stratigraphic marker (Schieber, 1986a) extends over the whole outcrop area of the Newland Formation, an area four times as large as the original study area (Fig. 1). Because the base of the "NTZ" can be considered an approximate time line (see preceding two paragraphs), the new data help to confirm the previously proposed (Schieber, 1986a) concept of REE stratigraphy.

4.2. Relationships between LaHood and Newland Formations

McMannis (1963) stated that the LaHood Formation rests nonconformably on crystalline basement, and is a lateral equivalent of all Belt units in the north, from the Neihart Quartzite through the Greyson Shale (this view is not expressed in Fig. 2). In a later study, Boyce (1975) questioned several of McMannis' earlier interpretations and concluded: (1) at no place does the LaHood Formation rest on basement rocks (instead, fault contact is the rule); and (2) the LaHood Formation interfingers with Newland and Greyson type rocks as they occur in the Big Belt Mountains to the north. Neither McMannis nor Boyce specified if they saw "upper" or "lower Newland" lithologies interfinger with the LaHood Formation. Both authors state that an active-basin-bounding fault existed along the southern margin of the basin, and that the LaHood Formation was deposited north of that fault (or fault zone).

Examination of LaHood outcrops by Schieber (1985) revealed that carbonate-bearing intervals in the LaHood Formation commonly show lithologic features typical of the "NTZ" and the "upper Newland" in the Big Belt Mountains. Several tongues of sandstone and scattered sandstone beds occur in the Newland/Greyson sequence of the southern Big Belt Mountains. These sandstones contain metamorphic rock fragments and feldspars of the same type as found in the LaHood Formation, and sedimentary features indicate derivation from a southern source (Schieber, 1987). These sandstones are probably lateral equivalents of the LaHood Formation and occur only in the "NTZ" and younger stratigraphic units ("upper Newland" and Greyson). No sandstones of any kind were found in the "lower Newland". Thus, petrographic and sedimentological observations suggest that the LaHood Formation is possibly a lithostratigraphic lateral equivalent of "NTZ", "upper Newland" and Greyson, but not of the "lower Newland".

Comparison of REE patterns from the Newland and LaHood Formations (Fig. 3) also suggests that the LaHood Formation is more likely a lateral equivalent of "NTZ"/"upper Newland"/Greyson than of the "lower Newland". Basically there are three scenarios of correlation between the LaHood Formation and the Belt sequence in the northern part of the Helena embayment: (1) the LaHood Formation is a lateral equivalent of the "lower Newland"; (2) the LaHood Formation is a lateral equivalent of "NTZ", "upper Newland" and Greyson Shale; and (3) the LaHood Formation is a lateral equivalent of the whole sequence from Neihart Quartzite through Greyson Shale. In the case of scenario (3), we should expect to find only flat and ramp-shaped REE patterns and no patterns with negative Eu anomalies in the lower portions of the LaHood Formation (Fig. 3). However, even though only a small number of samples were analysed from the LaHood Formation, one sample with a well-developed negative Eu anomaly (LH*1*) comes from a lower portion of the LaHood Formation which McMannis (1963) correlated with the "lower Newland"/Chamberlain Shale interval of the northern Helena embayment. Thus, scenario (3) appears not very likely. Scenario (1), implying that shales of the LaHood Formation should only show flat and ramp-shaped REE patterns, is clearly in conflict with the presence of negative Eu anomalies in five of the samples (Fig. 3). This leaves us with scenario (2), lateral equivalency of LaHood Formation and "NTZ", "upper Newland" and Greyson Shale. In that case one should expect to find REE patterns that are flat to ramp-shaped as well as patterns with negative Eu anomalies, an expectation that is borne out by the data presented in Fig. 3.

Thus, whereas petrographic features as well as REE pattern distributions are consistent with a lithologic equivalency between LaHood Formation and the "NTZ", "upper Newland" and Greyson Shale sequence, lithologic dissimilarities as well as the absence of sandstones and REE patterns with negative Eu anomalies appear to refute the possibility of an equivalency between "lower Newland" and LaHood Formation.

Recent Sm/Nd isotope studies on the Belt Series suggest that the LaHood Formation was derived from source rocks of Archean age, whereas the remainder of the Belt Series has source rocks of Early Proterozoic age (Frost and Winston, 1987). These data suggest on first thought that REE-based correlations between LaHood and Newland Formation may not be very meaningful. However, the observation that the LaHood Formation has a Sm/Nd source age that differs from the rest of the Belt Supergroup does not imply that the source-rock types are different as well. This is so because Sm/Nd source age determinations rely only on isotopic ratios and not on the overall relative abundances of other REE. Sm and Nd isotopic ratios depend on the source age of a rock, whereas the REE patterns depend on the type of source rock. In other words, the weathering of an Archean vs. a Proterozoic granite will most likely lead to shales with similar REE patterns as long as the weathering conditions are the same for both granites. Studies of the LaHood Formation (McMannis, 1963; Boyce, 1975) as well as of pre-Belt basement rocks north and south of the Helena embayment (Witkind, 1971; Keefer, 1972; Cohenour and Kopp, 1980; Mueller et al., 1982; Wooden et al., 1982) indicate that the LaHood Formation and the Newland Formation were both derived from a source area that was dominated by granitoid gneisses, migmatites and granites. Considering the relatively small size of the Helena embayment it is reasonable to assume that climatic conditions to the north and south of it were about the same. It follows from the above-mentioned considerations that the LaHood and Newland Formations had comparable source rocks and climate conditions. Therefore, at any given time, we should expect similar REE patterns for both formations, even though their source rocks are of different age.

4.3. Basin evolution

Two radically different views of basin evolution are implicit in the controversy over correlation between LaHood Formation and the Beltian sequence to the north. McMannis (1963), by correlating the LaHood Formation with the northern sequence as a whole, implied that Belt sedimentation in the Helena embayment commenced with the formation of a half-graben (Fig. 6; view *1*). Schieber (1985, 1986a), by correlating the Lahood Formation only with "NTZ", "upper Newland" and Greyson Shale (as suggested on p.94), implies on the other hand that the "lower Newland" was deposited prior to faulting and LaHood sedimentation (Fig. 6; view *2*). In addition, the Neihart Quartzite and most of the Chamberlain Shale (Fig. 2) should also predate LaHood deposition.

According to view *2* (Fig. 6), deposition of the LaHood Formation did not start with the onset of Belt sedimentation. Sediments that were deposited between the Neihart Quartzite and the "NTZ" consist essentially of 100% shales (Schieber, 1985). The preponderance of shales, a complete absence of sandstones, and the considerable thickness and uniform appearance of the "lower Newland"/Chamberlain Shale sequence suggest a hinterland of low relief and tectonic quiescence during its deposition. Reynolds (1984) concluded that the shales above the Neihart Quartzite most likely accumulated far from the basin edge, and suggested that similar strata may have covered much of northwestern Montana and southern Alberta during early Belt time.

The above-mentioned considerations of the stratigraphic record are in conflict with McMannis' (1963) view of basin evolution, because the tectonic quiescence indicated by "lower Newland" shales is incompatible with deposition of the LaHood Formation during initial stages of basin evolution (Fig. 6; view *1*). Instead, the rock record lends credence to the second view of basin evolution (Fig. 6, view *2*), suggesting that a widespread cratonic sediment blanket or an extensive smooth sediment-filled depression formed at the beginning of Belt time. Only at some later time did major rejuvenation of the hinterland initiate the coarse clastic sedimentation that is marked by the LaHood For-

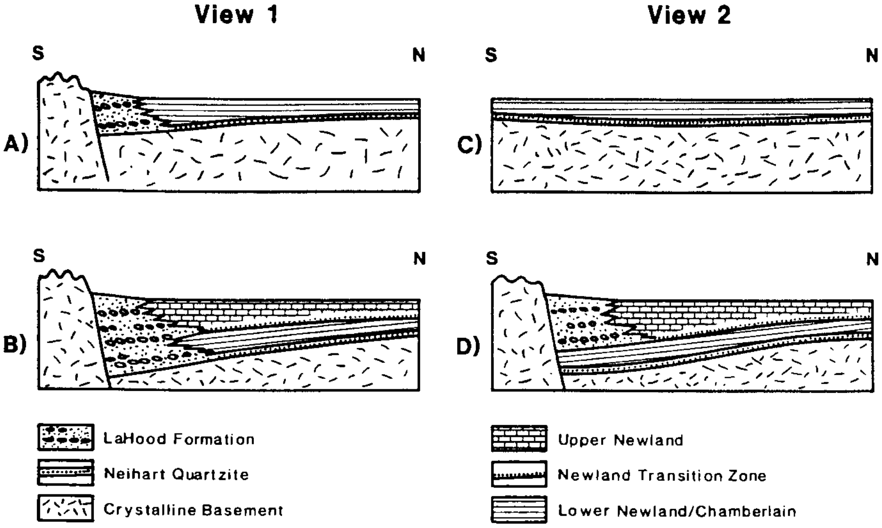

Fig. 6. Depicts the two basic view points concerning the evolution of the Helena embayment. View *1* (McMannis, 1963) suggests that initial deposits in the Little Belt Mountains were deposited at the same time as faulting and LaHood deposition occurred in the south of the embayment (A), and that LaHood deposition continued as "NTZ" and "Upper Newland" were deposited (B). View *2* (Schieber, 1985, 1986a) holds that initial deposits of in the embayment area were laid down on the craton without development of active faults (C), and that the beginning of LaHood deposition coincides with the onset of faulting in the south and deposition of the "NTZ" in the north (D).

mation and "NTZ". At that time tectonic movements appear to have changed the basin configuration to an east-west-trending half-graben, with an active growth fault along the southern margin and a gentle flexure in the north.

5. Conclusions

A stratigraphically controlled change in shale REE pattern types of the Belt sequence (Schieber, 1986a) has now been traced over a much larger area than originally investigated. REE pattern changes are interpreted to reflect changes in weathering intensity and tectonic regime in the source area of the shales. Stratigraphic and sedimentologic considerations indicate that the break in REE pattern types that has been traced through the Newland Formation of the Helena embayment does follow an approximate time-line.

In addition to supporting the predictions of Schieber (1986a), the new data have helped us to refine stratigraphic correlations in the Helena embayment and to improve our understanding of basin history in that area. It seems quite likely that widespread sedimentation occurred on a gradually subsiding craton during early stages of basin history. Only after deposition of a considerable thickness of sediment (Fig. 6; view *2*) did tectonic forces cause uplift in the hinterland and faulting along the southern margin of the present Helena embayment. It is possible that a thick shale sequence, the southern equivalent of the "lower Newland" shales, lies hidden below the present exposures of the LaHood Formation (Fig. 6; view *2*).

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