Magnetic susceptibility of Gleysolic and Chernozemic soils in Saskatchewan

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de Jong, E. 2002. **Magnetic susceptibility of Gleysolic and Chernozemic soils in Saskatchewan.** Can. J. Soil Sci. **82**: 191–199. In Saskatchewan, Gleysolic and Chernozemic soils often are found close to each other in hummocky terrain. Magnetic susceptibility (χ) is known to be reduced in poorly drained soils compared to well-drained soils, and this study investigated the use of χ as an accessory criterion for identifying Gleysols. Archived soil samples from an area near Saskatoon were analyzed for χ and sand content, and where necessary for organic and inorganic C and oxalate (Feo) and dithionite (Fed) extractable iron. The lowest χ values were found in Humic Luvic Gleysols and the highest in Dark Brown Chernozems; Rego and Orthic Gleysols and Rego Humic Gleysols had χ values that overlapped those of the Dark Brown Chernozems. Within the upper 50 cm of the profile, all Gleysols except the Rego Humic Gleysol, had at least one horizon with χ less than 150×10^{-9} m^3 kg^{-1}. The χ of the A and B horizons was negatively correlated to their Feo/Fed ratios, and not correlated to their sand content. The χ of the deep tills was positively correlated to sand content, and not correlated to Feo/Fed ratio. It appears that χ may be as useful as the Feo/Fed ratio for assisting in classifying Gleysols.

Key words: Magnetic susceptibility, Gleysols, Chernozems, Feo, Fed, $CaCO_3$

de Jong, E. 2002. **Susceptibilité magnétique des gleysols et des tchernozioms de la Saskatchewan.** Can. J. Soil Sci. **82**: 191–199. Les gleysols et les tchernozioms se côtoient fréquemment dans les terrains mamelonnés de la Saskatchewan. On sait que les sols mal drainés ont une plus faible susceptibilité magnétique (χ) que les terrains qui le sont mieux. L'étude devait établir si on peut recourir à ce paramètre pour faciliter l'identification des gleysols. L'auteur a analysé les échantillons de sol venant d'une région près de Saskatoon pour en déterminer la susceptibilité magnétique et la teneur en sable. Le cas échéant, il a aussi dosé la concentration de carbone organique et inorganique, ainsi que celle de fer extractible à l'oxalate (Feo) et au dithionite (Fed). La valeur χ la plus faible a été relevée dans les gleysols humiques luviques et la plus élevée, dans les tchernozioms brun foncé. La valeur χ des gleysols rego et orthiques et celle des gleysols rego humiques chevauche celle des tchernozioms brun foncé. Dans les premiers 50 cm du profil, tous les gleysols sauf le gleysol rego humique présentent au moins un horizon dont la susceptibilité magnétique est inférieure à 150×10^{-9} m^3 kg^{-1}. La valeur χ des horizons A et B présente une corrélation négative avec le ratio Feo/Fed, mais elle n'est pas corrélée à la concentration de sable. La valeur χ des tills profonds est positivement corrélée à la teneur en sable, mais pas au ratio Feo/Fed. On en conclut que la susceptibilité magnétique pourrait s'avérer aussi utile que le ratio Feo/Fed pour la classification des gleysols.

Mots clés: Susceptibilité magnétique, gleysols, tchernozioms, Feo, Fed, $CaCO_3$

In knob-and-kettle topography, Gleysolic and Chernozemic soils occur in close proximity in Saskatchewan. Gleysols are defined [Soil Classification Working Group (SCWG) 1998] as soils that are saturated with water and under reducing conditions continuously or during part of the year as indicated by watertable and redox potential measurements. Since long-term watertable and/or redox potential measurements are usually unavailable, Gleysols are recognized in the field based on color criteria and mottling. Miller et al. (1989) found that color and mottling criteria were adequate for classifying **Humic Luvic Gleysols (HU.LG)** in the center of willow-ringed depressions in the Saskatoon, Saskatchewan, region, but that the color criteria were inadequate for classifying **Rego Humic Gleysols (R. HG)** and **Gleyed Dark Brown Chernozems (GL.DBC)** outside the willow ring.

McKeague and Day (1966) suggested that the ratio of **oxalate- to dithionite-extractable iron (Feo/Fed)** can be used to separate oxidized and reduced soils. High Feo/Fed ratios indicate poorly drained soils, and the Feo/Fed ratio may, perhaps, be useful as an accessory criterion for identifying Gleysolic soils. However, reports from Western Canada have been inconclusive (Michalyna 1971; Stonehouse and St. Arnaud 1971; Michalyna and Rust 1984a, b). The Feo and Fed reflect the long-term weathering and drainage of soils (Blume and Schwertmann 1969), but their measurement is time consuming. Recent studies (de Jong et al. 2000b) have suggested that the magnetic susceptibility of soils, which is more easily measured, is negatively correlated to the Feo/Fed ratio.

Magnetic susceptibility is defined as the ratio of the magnetization induced in a soil sample to the magnetic field inducing it (Mullins 1977) and in soil science is often expressed per unit mass. Mass magnetic susceptibility (χ) has units of m^3 kg^{-1}. The magnetic susceptibility of soils depends on the nature of the parent material, and the physical, chemical and biological weathering processes. Well-drained soils generally show increased χ in the A horizons

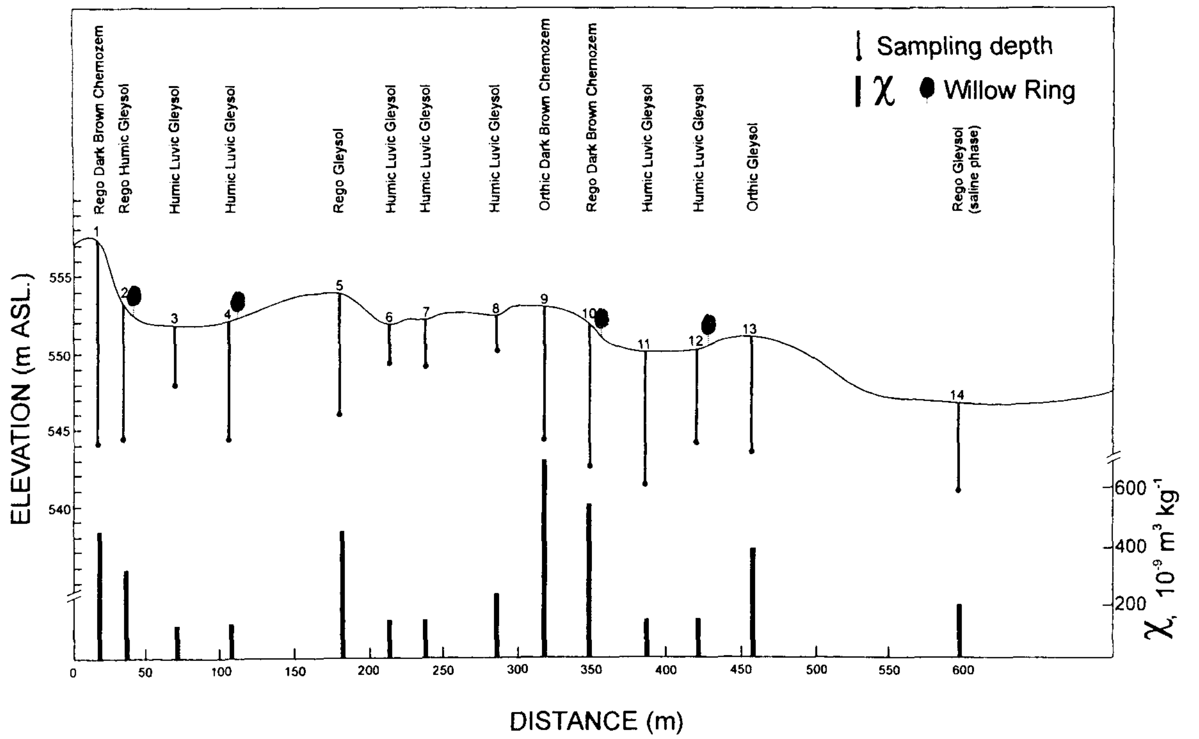

Fig. 1. Elevation, soil type, and solum magnetic susceptibility of the 14 sampling sites of the main transect.

(Dearing et al. 1985; Fine et al. 1989; Maher 1998; de Jong et al. 2000a), while the solum of poorly-drained soils has reduced χ (Dearing et al. 1985; Williams and Cooper 1990; de Jong et al. 1998; Maher 1998; Grimley and Vepraskas 2000). In Saskatchewan soils χ was found to increase with sand content (de Jong et al. 1998, 2000a, 2000b) and to decrease with increasing Feo/Fed ratio, but was not affected by total Fe content. Maher (1998) also found little correlation between χ and total iron content of soils.

The aim of this study was to investigate the use of χ as an accessory criterion for identifying soils of the Gleysolic order and of gleyed and non-gleyed subgroups of adjacent Chernozemic soils.

MATERIALS AND METHODS

Soils

Most of the samples came from the transect described by Miller et al. (1985). The transect, located north-east of Saskatoon, was in an area mapped as belonging to the Weyburn Association. The 14 cores (Fig. 1) represented seven HU.LG, two **Rego Gleysol (R.G.)**, one **Orthic Gleysol (O.G.)**, one R.HG., two **Rego Dark Brown Chernozem (R.DBC)** and one **Orthic Dark Brown Chernozem (O.DBC)** soil profiles. An additional core extracted from the same field, and classified as a R.DBC, was collected but not analyzed by Miller (1983). This core was added to the data set, as were five profiles [two HU.LG, two R.DBC and one **Solonetzic Dark Brown Chernozem (SZ.DBC)**] from a nearby similar location used by Letkeman (1993) and Bryce (1998). All cores were segmented by soil horizons, air dried, and ground to pass through a 2-mm sieve. The ground samples had been stored air-dry, which should not affect their χ (Oldfield et al. 1992). The topography, stratigraphy, salinity and typical groundwater levels for the Miller transect are shown in Miller et al. (1985).

Methods

From previous studies the following information was available for the upper 2 to 3 m of the Miller samples shown in Fig. 1: % $CaCO_3$ equivalent for sites nos. 1–5 and nos. 9–14 (Miller et al. 1985); Feo and Fed for site no. 1 (Miller 1983), nos. 2, 3 and 4 (Miller et al. 1989), no. 9 (Miller 1983), nos. 10, 11 and 12 (Miller et al. 1989) and no. 14 (Miller 1983); and organic C data for the A and upper B horizon for sites nos. 2, 3, 4, 10, 11,12 and 14 (Miller 1983). The data for the Letkeman-Bryce samples included sand content, and organic and inorganic C contents ($CaCO_3$ content was estimated as 8.33 × inorganic C content).

The following additional measurements were made on the archived air-dry < 2 mm soil:

Magnetic susceptibility of all samples was determined with a Bartington MS-2D meter at low (0.47 kH, χ_{lf}) and high (4.7 kH, χ_{hf}) frequency as described by de Jong et al. (2000a). Frequency dependence of the magnetic susceptibility was expressed as:

$$\% \chi_{fd} = 100 \times (\chi_{lf} - \chi_{hf}) / \chi_{lf}$$

Sand content of all samples from the 15 sites in the Miller field was estimated by washing a known amount of soil on a 53 μm sieve under a running tap while rubb ing the soil. Once the water draining through the sieve was clear, the retained material was dried overnight at 35°C.

Organic and total carbon were measured by combustion at 817 and 1100°C, respectively, in a LECO induction furnace (Wang and Anderson 1998) for all depths of sites nos. 6, 7 and 8 (Fig. 1) and additional samples for the Miller field.

Feo and Fed analysis (Sheldrick 1984) were completed on samples from depths of 2m or more of sites nos. 1, 2, 3, 9 and 14 in Fig. 1, and on the unanalyzed R.DBC of the Miller field.

Data Summary and Analysis

Magnetic susceptibility and sand data were measured on all soil horizons of the 20 cores. Organic C and $CaCO_3$ equivalent data were available for all A and B horizons, 15 (organic C) to 29 ($CaCO_3$ equivalent) IC horizons, and 59 (organic C) to 129 ($CaCO_3$ equivalent) deep till horizons. Feo and Fed data were available for the sola of cores nos. 1, 2, 3, 4, 9, 10, 11, 12, 14 (Fig. 1) and the additional core from the Miller field. As well Feo and Fed of 20 IC and 70 deep till horizons were measured.

The relationship between soil profile classification and χ was assessed by calculating a solum χ_{lf}:

$$\text{solum } \chi_{lf} = \frac{\Sigma \chi_i d_i}{\Sigma d_i}$$

where $\chi_i = \chi_{lf}$ (10^{-9} m^3 kg^{-1}) of the individual horizons and d_i = thickness (cm) of the individual horizons making up the solum.

Differences between properties of soil horizons were, in the first instance, assessed by box-and-whisker plots showing the median, interquartile range, etc., of the data. Box-and whisker plots were used as some properties did not have a normal distribution according to the Kolmogorov-Smirnov test. The possible relationships between χ and sand content, $CaCO_3$ equivalent, Feo, Fed and Feo/Fed were explored by Spearman correlation analysis for the A plus B horizons, and for the deep tills.

RESULTS AND DISCUSSION

Solum Magnetic Susceptibility

Along the main sampling transect, the solum χ_{lf} showed an inverse relationship with topography (Fig. 1). The HU.LG sites inside the large depressions (nos. 3 and 4, and 11 and 12) had a solum χ_{lf} of about 100 × 10^{-9} m^3 kg^{-1}, while the HU.LG profiles in the smaller depressions (nos. 6, 7 and 8) had a solum χ_{lf} from 100 to 200 × 10^{-9} m^3 kg^{-1}. All of these sites were locations of groundwater recharge (Miller et al. 1985) and had groundwater levels within 2 m or less of the soil surface in the spring. Site no. 14 (R.G., saline phase) also had groundwater levels as shallow as 2 m below the surface, but was characterized by both recharge and discharge of groundwater (Miller et al. 1985) and had a solum χ_{lf} of 150 × 10^{-9} m^3 kg^{-1}. Three more sites along the transects are classified as Gleysols (no. 2: R.HG, no. 5: R.G and no. 13: O.G) and have solum χ_{lf} values from 300 to 400 × 10^{-9} m^3 kg^{-1}. In sites nos. 2 and 13 the sand content decreases from the A to the C horizon (for site no. 2 see Fig. 2, data for site no. 13 not shown) and χ_{lf} drops correspondingly. This may indicate that these are sites where upperslope topsoil has been deposited as was evident in one of the two HU.LG of the Bryce-Letkeman field (Bryce 1998): one of these two HU.LG had a solum χ_{lf} of 165 × 10^{-9} m^3 kg^{-1}, but the second had a solum χ_{lf} of about 250 × 10^{-9} m^3 kg^{-1}. The latter site was in a cultivated depression, had a 40 cm thick Ap/Ah horizon (χ_{lf} of 350 × 10^{-9} m^3 kg^{-1}) over an Ae (χ_{lf} = 140 × 10^{-9}m ^{3}kg^{-1}) and Btg (χ_{lf} = 185 × 10^{-9} m^3 kg^{-1}) horizon, and ^{137}Cs data indicated deposition of upper slope soil (Bryce 1998). Site no. 5 (R.G) is on the crest of a small knoll and the field log (Miller 1983) describes the profile as Aph 0-8 cm, Cca 8-28 cm, IICkgl 28-50 cm, ...; it appears that the classification as a Gleysol is based on the IICkgl horizon.

The remaining profiles at the Miller and Bryce-Letkeman fields were all classified as Dark Brown Chernozems. Solum χ_{lf} ranged from 250 × 10^{-9} m^3 kg^{-1} for the SZ.DBC at the Letkeman-Bryce location (details not shown) to 650 × 10^{-9} m^3 kg^{-1} for the O.DBC in site no. 9 in Fig. 1 (for details see Fig. 3).

In summary, the solum χ_{lf} of HU.LG profiles all appeared to be less than 250 × 10^{-9} m^3 kg^{-1} while the DBC profiles had higher χ than this. Most HU.LG had a solum χ_{lf} of less than 150 × 10^{-9} m^3 kg^{-1} and some of the values close to 250 × 10^{-9} m^3 kg^{-1} could be due to deposition of eroded soil from upper slope positions. The R.G, O.G and R.HG profiles had solum χ_{lf} values that overlapped in range with those of DBC profiles. Miller et al. (1985) found that color criteria were adequate for classifying soils inside depressions, but were inadequate for soils outside the willow-ring. Color criteria for classifying Gleysols are generally applied to soil horizons (excluding the Ah, Ap and Ae) in the upper 50 cm of the mineral surface (SCWG 1998). Within that same depth all Gleysols, except the R.G at site no. 5 (Fig. 1), had at least one horizon with χ_{lf} less than 150 × 10^{-9} m^3 kg^{-1}; as mentioned before, the classification of site no. 5 as a Gleysol appears based on the IICkgl, which had many light gray (2.5Y 7/0, dry) mottles (Miller 1983) and an χ_{lf} of 310 × 10^{-9} m^3 kg^{-1}. Grimley and Vepraskas (2000) recently concluded that volumetric χ values of 20 to 30 × 10^{-5} SI units (corresponding to 150 to 230 × 10^{-9} m^3 kg^{-1} assuming a bulk density of 1300 kg m^{-3}) separated hydric and nonhydric soils in Illinois. They suggested that the critical χ value separating hydric and nonhydric soils is likely a function of parent material.

Variation of χ_{lf} and Selected Other Soil Properties with Depth

Figures 2, 3, and 4 show the variation in χ_{lf}, sand content, $CaCO_3$ content and Feo/Fed ratio in the upper 2 m of nine sites along the transect shown in Fig. 1. Past studies have shown relationships between χ_{lf} and both sand content and Feo/Fed ratio (de Jong et al. 2000b), and between magnetic horizonation and variations in $CaCO_3$ with depth (de Jong et al. 1998). Figure 2 shows the variation in

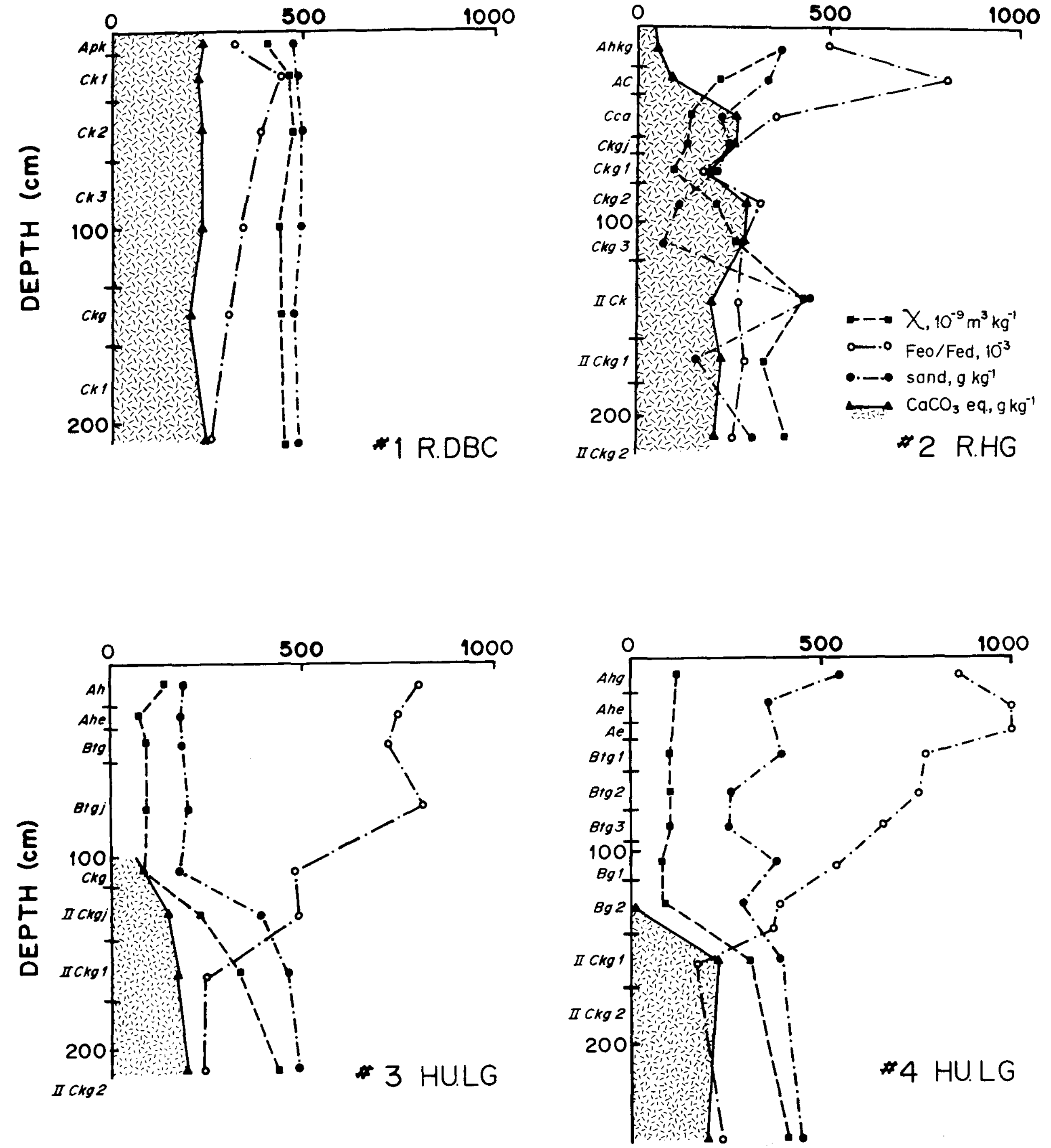

Fig. 2. Variation of χ_{lf}, sand content, $CaCO_3$ content and Feo/Fed ratio with depth at sites no. 1 (Rego Dark Brown Chernozem), no. 2 (Rego Humic Gleysol), no. 3 (Humic Luvic Gleysol) and no. 4 (Humic Luvic Gleysol) of the main transect.

χ_{lf} and the other soil properties for the catena consisting of sites nos. 1 to 4 in Fig. 1. Site no. 1 (R.DBC) shows little variation in χ_{lf}, sand content and $CaCO_3$ content with depth; the Feo/Fed ratio shows a weak maximum in the Ck1 horizon. Profile no. 1 has probably suffered erosion as the Ap horizon is thin and had only 8 g kg^{-1} organic C. Some of the eroded soil could have been deposited at site no. 2 (R.HG), which varies considerably in soil properties with depth. At site no. 2 the decrease in χ_{lf} from the surface to 70 cm depth parallels a drop in sand content, however in the 70 to 100 cm depth range χ_{lf} increases while sand content continues to decrease. The Feo/Fed ratio is fairly high in the Ahkg and AC horizons; the AC horizon has a similar Feo content, but a much lower Fed content than the horizons above and

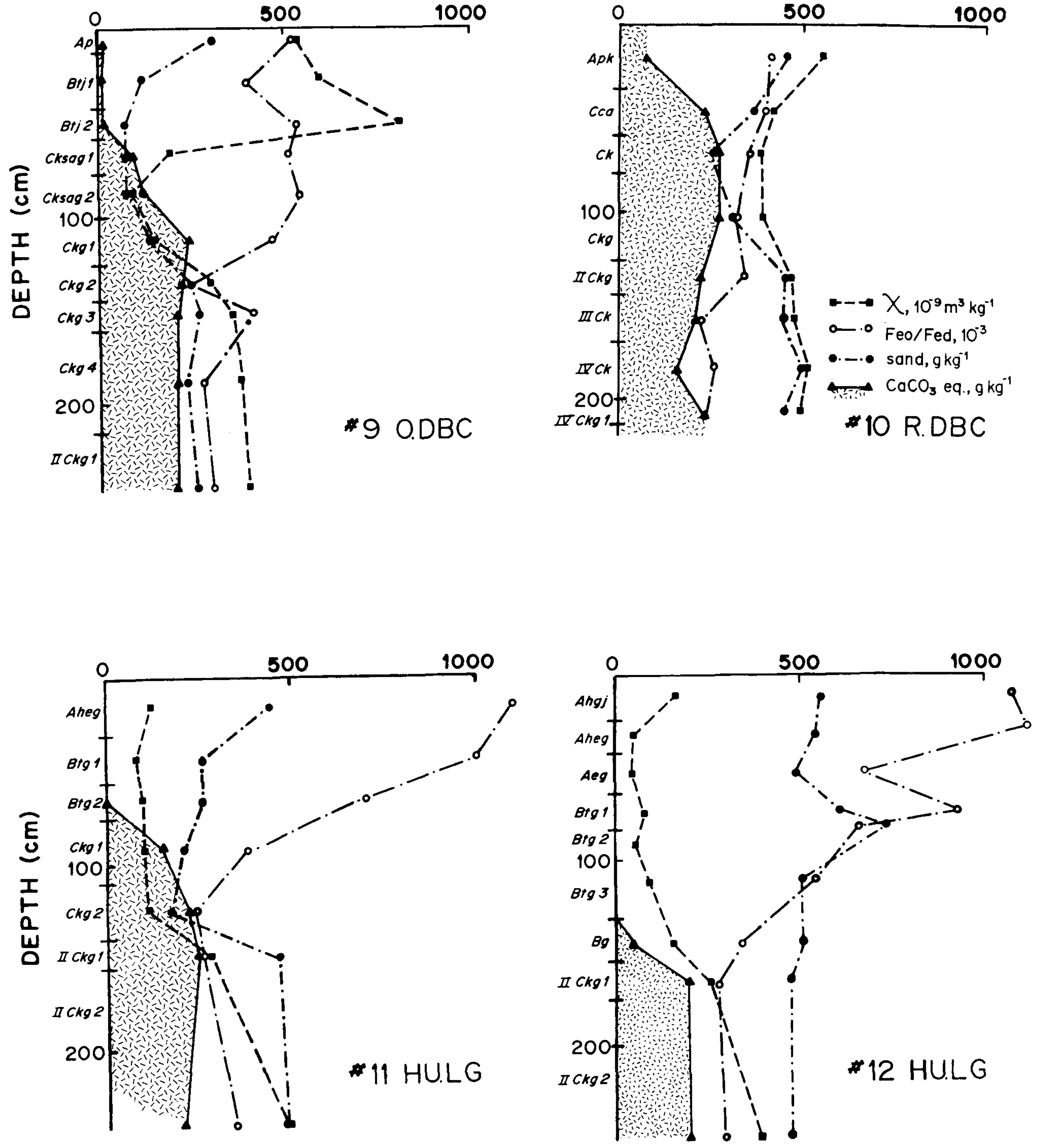

Fig. 3. Variation of χ_{lf}, sand content, $CaCO_3$ content and Feo/Fed ratio with depth at sites no. 9 (Orthic Dark Brown Chernozem), no. 10 (Gleyed Rego Dark Brown Chernozem), no. 11 (Humic Luvic Gleysol) and no. 12 (Humic Luvic Gleysol) of the main transect.

below it [for actual data see profile no. 3 in (Miller et al. 1989)]. Very low χ_{lf} values occur in the sola of sites nos. 3 and 4 (both HU.LG) while Feo/Fed ratios are high; χ_{lf} starts to increase in the IICkg horizons (Battleford till) where Feo/Fed ratios reach their lowest values. The values for χ_{lf}, sand content and Feo/Fed for the Ck horizons at site no. 1, where the Battleford till came to the surface, are similar to those for the IICkg horizons at sites nos. 2, 3 and 4. The variation in the sand content of the silty lacustrine overlay at sites nos. 2 to 4 is noteworthy.

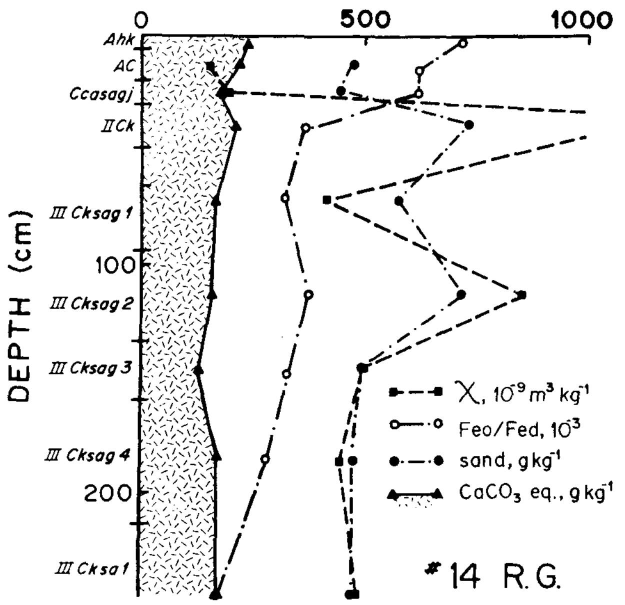

Fig. 4. Variation of χ_{lf}, sand content, $CaCO_3$ content and Feo/Fed ratio with depth at site no. 14 (Rego Gleysol, saline phase) of the main transect.

Although site no. 9 (O.DBC) shows as an upperslope slope on the cross-section in Fig. 1, it is in fact a toeslope (Miller 1983). The Btj horizons of site no. 9 have a high χ_{lf} despite relatively high Feo/Fed ratios and low sand contents (Fig. 3). Magnetic susceptibility is lowest in the Cksag1, Cksag2 and Ckg1 horizons. Site no. 10 (gleyed R.DBC) is in the "carbonated ring" around the depression in which sites no. 11 and 12 (both HU.LG) are located. In the "carbonated" ring carbonates are believed to have come to the surface by capillary rise from the groundwater mound that occurs in the spring (Miller et al. 1985). Site no. 2 (Fig. 2) is also in a "carbonated" ring. The χ_{lf} of the gleyed R.DBC (no. 10) profile in Fig. 3 is similar to that of the R.DBC in Fig. 2 (site no. 1), but more variable with depth. The soil at site no. 10 is developed in the silty lacustrine deposit overlying the Battleford till (IICkg). Possibly some soil deposition has occurred since cultivation started (the Apk horizon is 35 cm thick and has 25 g kg^{-1} organic C) at this site. The HU.LG profiles at sites nos. 11 and 12 are characterized by low χ_{lf} and high Feo/Fed ratios in the solum (Fig. 3), as was the case for those in Fig. 2.

Magnetic susceptibility and other properties of the saline R.G (site no. 14 in Fig. 1) are shown in Fig. 4. The solum has high Feo/Fed ratios and low χ_{lf}, similar to the HU.LG profiles in Figs. 2 and 3, but χ_{lf} increases in the Battleford (49–366 cm) and Floral (366–4549 cm, data not shown) tills. The highest χ_{lf} occurs in the IICk, which the field log (Miller 1983) describes as high in gravel. Compared to the other R.G (no. 5 in Fig. 1) the watertable at site no. 14 is shallower, resulting in slightly higher $CaCO_3$ and salt contents in the surface soil (Miller et al. 1985).

Relationships Between χ_{lf} and Other Soil Properties.

For the box-and-whisker plots of magnetic properties, C contents, Feo, Fed and Fed/Fed ratios, the data were sorted into nine categories: Gleysolic A, B and IC horizons, Chernozemic A, B and IC horizons, and the three underlying tills (Battleford, oxidized Floral and unoxidized Floral). Preliminary plotting had shown no significant differences in these properties between the deep tills under Gleysolic and Chernozemic profiles.

The box-and-whisker plots for sand content (Fig. 5) showed that on average the A, B and IC horizons of the Gleysols (and to a lesser degree the Chernozems) were somewhat less sandy than the deep tills. This reflects the silty lacustrine overlay on much of the lower areas [see Fig. 2 of Miller et al. (1985)]. All underlying deep tills were quite similar, but the Battleford till is most variable. Miller (1983) describes this till as stratified.

Organic C contents followed the expected trend in the sola of the soil profiles (Fig. 5). The high extreme values for organic C in the Battleford and unoxidized Floral till are associated with a shale layer below sites no. 1 and no. 2 in Fig. 1 (see Miller et al. 1985). The A and B horizons of the Gleysolic soils generally had low $CaCO_3$ contents; the three highest extremes in the A horizons are found in the two R.G profiles (nos. 5 and 14 in Fig. 1), which both have limited soil water recharge and upward capillary rise (Miller et al. 1985). The two high outliers in the Gleysolic B horizons are IIIBg horizons of site no. 7 (Fig. 1) occurring below 200 cm depth. Carbonate contents of the Chernozemic A horizons are fairly high, reflecting the predominance of Rego profiles. The $CaCO_3$ content of the IC horizons was similar to that of the deep tills (Fig. 5). The high $CaCO_3$ content extremes in the Battleford and unoxidized Floral tills are found at depths of 650 cm or greater at sites nos. 1 and 2 (Fig. 1), well below the depths shown in Fig. 2.

The median values suggest that Feo and Fed are higher in B horizons than in the A and IC horizons of Gleysolic and Chernozemic soils (Fig. 5). Feo of the A and IC horizons of Gleysolic and Chernozemic soils is comparable to that of the deep tills, but Fed seems to be lowest in the Gleysolic A horizons. Feo and Fed appear to be particularly variable in the sola of Gleysolic profiles. In the Gleysolic soils, the Feo/Fed ratio decreases markedly from the A to the IC horizons (Fig. 5); the median for the Gleysolic IC horizons is similar (about 0.5) to the median Feo/Fed ratio for the Chernozemic soils and deep tills.

The pattern of the χ_{lf} box-and-whisker plots (Fig. 5) is opposite to that for the Feo/Fed ratio (Fig. 5) for the A, B and IC Gleysolic horizons. The greatest variation in χ_{lf} was observed in the underlying Battleford till and appeared to be related to texture. For example, the highest and lowest outliers were associated with the gravelly IICk (29 to 49 cm depth, 750 g kg-1 sand, $\chi_{lf} = 1335 \times 10^{-9}\ m^3\ kg^{-1}$) of site no. 14 (Fig. 4) and the shale layer at 10 to 12 m depth (150 g kg^{-1} sand, $\chi_{lf} = 196 \times 10^{-9}\ m^3\ kg^{-1}$) of site no. 1 (Fig. 1), respectively. Frequency-dependant magnetic susceptibility was highest in the A and B horizons (Fig. 5), reflecting the pedogenetic formation of some of the ferrimagnetics.

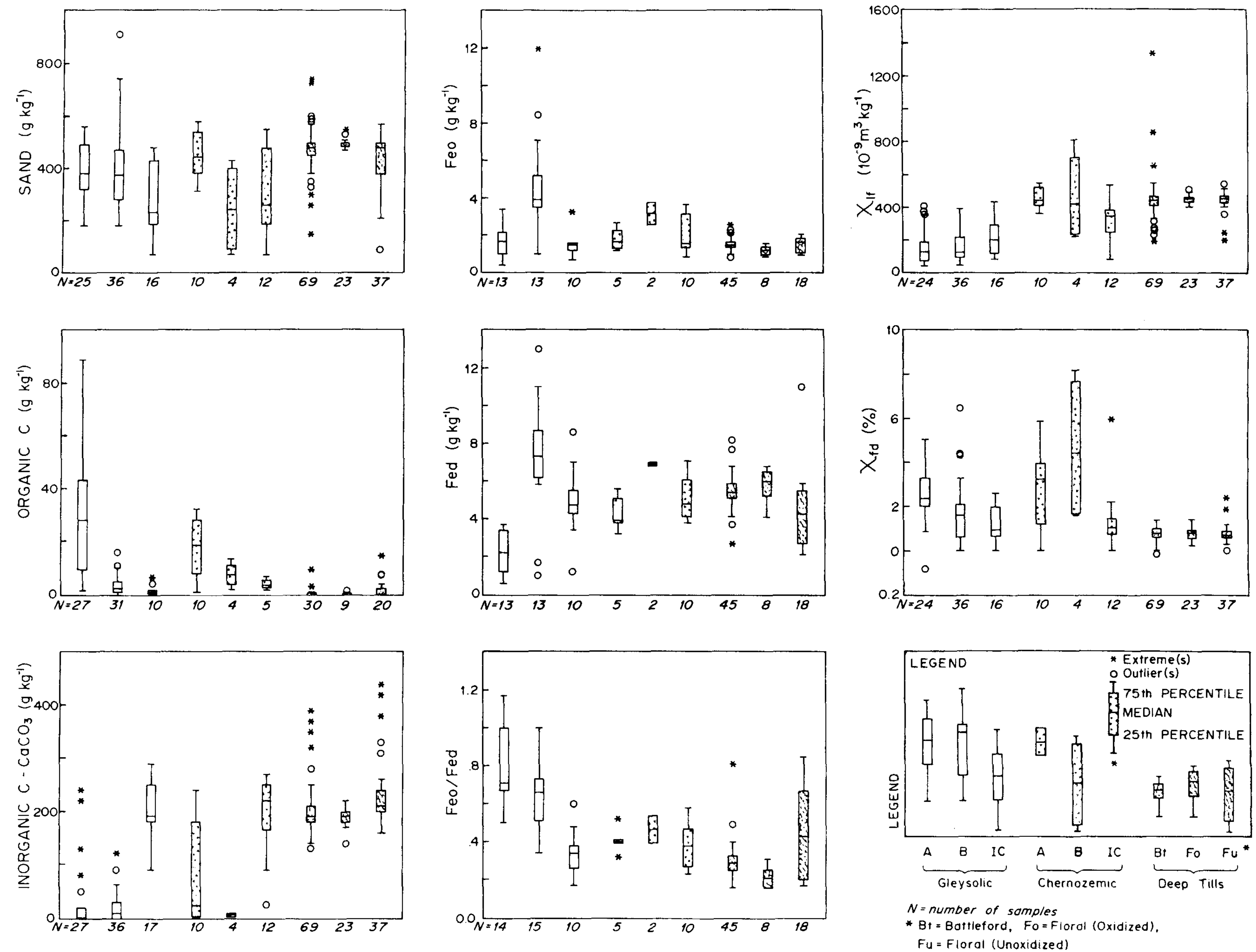

Fig. 5. Box-and-whisker plots for properties of the major horizons (A, B, and IC) of Gleysols and Chernozems, and of the deep tills.

Table 1. Spearman correlation matrices of magnetic susceptibility and selected soil properties for A and B horizons (bottom left) and deep tills (top right)

	χ_{lf} (196 – 1335)[z]	χ_{fd} (–0.2 – 2.4)	sand (90 – 740)	$CaCO_3$ (130 – 440)	Feo (0.9 – 2.6)	Fed (2.1 – 11.0)	Feo/Fed (0.16 – 0.85)
χ_{lf}, (10^{-9} m^3 kg^{-1}) (45 – 812)[z]		0.02	0.24**	0.20*	–0.25*	–0.17	–0.03
χ_{fd}, (%) (–0.8 – 8.2)	0.18		–0.22*	0.12	–0.04	0.25*	–0.22
sand, (g kg^{-1}) (70 – 910)	0.15	–0.04		–0.56***	–0.39***	0.13	–0.33**
$CaCO_3$, (g kg^{-1}) (0 – 240)	0.53***	–0.07	0.19		0.14	–0.28*	0.29*
Feo, (g kg^{-1}) (0.4 – 12.0)	–0.14	–0.06	–0.08	–0.34*		–0.07	0.77***
Fed, (g kg^{-1}) (0.6 – 13.0)	–0.01	–0.04	–0.07	–0.05	0.91***		–0.62***
Feo/Fed (0.32 – 1.17)	–0.53**	–0.14	0.11	–0.64***	–0.08	–0.38*	

[z]Range of each parameter in parentheses.
*, **, *** Significant at $P = 0.05$, $P = 0.01$ and $P = 0.001$, respectively.

The effect of pedogenesis on χ_{lf} and related soil properties was explored by comparing the Spearman correlation coefficients between soil properties of the A and B horizons to those of the deep tills (Table 1). The Spearman correlation was used as several of the variables (χ_{lf}, % χ_{fd}, and $CaCO_3$ equivalent of the A and B, and χ_{lf} , $CaCO_3$ equivalent, sand content and Feo/Fed ratio of the deep tills) had distributions that differed significantly ($P < 0.10$) from normal according to the Kolmogorov-Smirnov test. The deep tills are the likely source of the parent materials at the site and should show minimal alteration due to recent soil forming processes. The A and B horizons had a similar range of χ_{lf}, sand, and Fed content to the deep tills (Table 1, Fig. 5), but higher % χ_{fd}, Feo content and Feo/Fed ratios, and lower $CaCO_3$ content. As the sand content of the deep tills increased, their χ_{lf} increased but % χ_{fd}, $CaCO_3$ content, Feo content and Feo/Fed ratios decreased. In contrast, sand content was not correlated to any of the measured properties of the A and B horizons. The $CaCO_3$ content of the deep tills was negatively correlated to Fed content, possibly because $CaCO_3$ causes extracted Fed to precipitate (Stonehouse and St. Arnaud 1971), and positively correlated to Feo/Fed. In the A and B horizons, Fed was not correlated to $CaCO_3$ content, but Feo and Feo/Fed decreased as $CaCO_3$ content increased. The Feo content of the A and B horizons was strongly correlated to their Fed content, while there was no such relationship for the deep tills. There was no correlation between χ_{lf} of the deep tills and their Feo/Fed ratio, while χ_{lf} of the A and B horizons decreases as Feo/Fed increases (Table 1).

CONCLUSIONS

The sola of HU.LG profiles in the willow-ringed depressions were characterized by low magnetic susceptibility and high Feo/Fed ratios, whereas upper slope DBC profiles had high magnetic susceptibility and low Feo/Fed ratios. The sola of O.G, R.G, and R.HG profiles on the lower slope positions outside the willow rings had intermediate magnetic susceptibility values. At these positions the relationship between poor aeration and low magnetic susceptibility may be obscured by variations in texture and the deposition of eroded upper slope soil.

It appears that the magnetic susceptibility of A and B horizons is largely controlled by their Feo/Fed ratio and not by texture, whereas the reverse is true for the underlying deep tills. The strong negative correlation between χ_{lf} and Feo/Fed ratios of the A and B horizons suggests that magnetic susceptibility could be an alternative to Feo/Fed ratio as an accessory criterion in the classification of Gleysols. Further exploration of magnetic susceptibility is warranted, especially since it is easily determined.

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