Plasmic fabric analysis of glacial sediments using quantitative image analysis methods and GIS techniques

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3. PLASMIC FABRIC DIAGNOSTICS

3.1 Introduction

The main purpose of this thesis is to create a quantitative - image analysis based - method for analysis of plasmic fabrics in glacial sediments. One objective of the thesis should be the creation of a set of diagnostic criteria for plasmic fabric recognition. These criteria should be based on an established and proven set of descriptive characteristics.

It is the main aim of this chapter to define just such a set of plasmic fabric diagnostic criteria. The first step to be undertaken is the selection of the plasmic fabric patterns currently studied in glacial micromorphology and the identification of their diagnostic features. In addition, each form of plasmic fabric will also be described in terms of sedimentary or deformational conditions, processes and diagenetic conditions with which it is known to be associated.

The system of classification used in this thesis will use some previously established terminology - such as plasmic fabric names - but it will avoid the use of terms which might have a different meaning or connotations in glacial studies (e.g. striations). It is hoped that the new classification will simply build on the experience of the previous research in soil science. At the same time the objective for this chapter calls for a clearly stated set of diagnostic characteristics of plasmic fabrics in glacial sediments creating a need for some revision and clarification of the current classification methods. A short note about the various classification methods can also be found in section 2.2.1.

Although descriptive and based on previous plasmic fabric interpretations, the subjective component of the new classification system is necessary before any objective description criteria can be identified. The necessity is derived from the fact that the current subjective studies of sedimentary facies in thin sections are based on subjective classification methods. Therefore, the current interpretations of sedimentary processes or conditions are associated with, and based on, a number of established subjective criteria such as plasmic fabric patterns. In the future it may be possible to move away from the subjective terminology and use quantified characteristics of micromorphic features as means of descriptions. Currently it is necessary to seek compromise by quantifying the qualitative.

If a high degree of accuracy in pattern identification is to be achieved it is necessary
that each description of individual types of plasmic patterns must be as complete as is currently possible and should encompass the maximum number of possible permutations of the given fabric patterns. This does not mean that the quantitative analysis will be all encompassing but only that the data extracted will be more likely to be significant. The summary of diagnostic features will include characteristics which make identification and differentiation of plasmic fabrics possible. This list will then be used in subsequent chapters to create a set of objective criteria to be used in image analysis.

Before the work of studying plasmic fabrics can begin there are several additional comments to be made. Some issues, such as the methodology of observation, should be discussed before proceeding any further.

When studying plasmic fabric in thin sections preference should be given to the use of circularly polarized light rather than cross-polarized. The use of cross-polarized illumination automatically implies a degree of subjectivity in terms of colour intensity and possibly areal extent of plasma separations. This is mostly because each individual image only captures one stage orientation angle. Depending on the stage position objects possessing preferred orientations may or may not show until the stage is rotated - forcing the need to take a number of images at different stage positions. The use of cross-polarized light may be preferred when looking at some plasmic fabrics such as bimasepic or trimasepic where the dominant preferred orientation direction may be more easily identified and measured individually. For some examples of plasmic fabric patterns the choice of circularly polarized light may be entirely inappropriate. For example, kinking plasmic fabric (see section 3.4) would not be distinguishable from omnisepic plasmic fabric. Whenever appropriate, a comment will be made as to the expected differences between these viewing options for a plasmic fabric type.

Another point of note is the plasmic fabric forms definitions and nomenclature in general. Essentially there are two main plasmic fabric aspects to be looked at: the strength and direction of plasma arrangement (basic orientation) and the overall pattern of the plasmic fabric (preferred orientation). Jim (1990) defines the basic and preferred orientations as:

Basic orientation - formation of plasma separations by clay mineral stacking.

Preferred orientation - alignment of plasma separations with respect to each other.

The definitions differentiate between the degree of plasmic fabric development and the pattern, or shape, of the development. In this part of the thesis, the emphasis will be on the preferred orientation aspect of plasmic fabrics while the concept of basic orientation and its measurement will be considered in the methodology and the results sections. The separation
is necessary since the strength of basic orientation (optical anisotropism) has little effect on the preferred orientation patterns and then only as far as making them more or less visible. Since the strength of basic orientation may be indicative of specific genetic conditions it should and will not be ignored. The strength can be thought of as the product of the physical size of a domain, its area, and the clarity (uniformity) and brightness of the visible anisotropism. However, the analysis of basic orientation (plasmic fabric strength) falls outside the scope of this part of the thesis section and can be found in section 5.3.

3.2 Plasmic Fabric

Plasma is defined by Brewer (1976) to be all material of colloidal size, i.e. smaller than 2 microns in diameter, which is not bound up in skeleton grains but can be "soluble". The term "soluble" indicates any material which is not consolidated but does not necessarily dissolve in water. Plasma may contain both amorphous and/or crystalline material as well as organic matter. Plasmic fabric is the form, or the arrangement of plasma. Similar units of plasma can be referred to as domains. Some domains show high degrees of anisotropism due to particles of anisotropic plasma having a highly uniform basic orientation. Anisotropic domains can also be referred to as plasma separations and are always associated with crystalline anisotropic clay minerals. Strongly birefringent plasmic material generally shows a much higher degree of uniformity in basic orientation. This is not always true since some masking agents (isotropic materials) can affect anisotropism without changing the actual basic orientation of the material (Diagram 3.1). Although some anisotropism can be the result of sedimentation, it is generally accepted that the strength of development of anisotropic plasma separations is a direct result of the amount of available clay and the stresses acting on the sediment (van der Meer, 1993a,b). Furthermore, the direction of the stress fields is also thought to be reflected in the direction of the plasma separations. (Greene-Kelly and Mackney, 1970; van der Meer, 1993a,b).

3.3 Glacial Plasmic Fabric Types

Van der Meer (1993a) uses Brewer's (1976) classification of plasmic fabric in order to describe some of the plasmic fabric patterns known to be associated with glacial sediments. Although devised for soil science, Brewer's nomenclature uses terminology based on shapes, patterns and relationships of plasmic fabric and soil features. Presuming that the same conditions can be observed in glacial sediments nothing prevents this classification system
Diagram 3.1. This diagram illustrates the effects of clay mineral stacking and masking agents on plasmic fabric strength. Under cross-polarizers situation A would show highest birefringence intensity. In case B the stacking is not nearly as uniform resulting in weakening of the optical anisotropism of the plasma. Case C presents a situation where isotropic minerals mix with anisotropic clay platelets and act as a masking agent. This would also result in weakening or even complete blocking of birefringence. Case D presents a situation where an opaque object completely blocks illumination resulting in plasma appearing black (asepic). Voids inherit the optical characteristics of the impregnating medium used to create the thin section - most often translucent and isotropic.

from being used in glacial sedimentology. Based on review of literature in glacial micromorphology it seems that at least some of the plasmic fabrics mentioned by Brewer appear to play little role in glacial sediments. These will only be mentioned briefly in the last section of this chapter but will not be discussed in any detail. In addition, some new types of plasmic fabrics may have already been added to the growing body of glacial sedimentology features. For this reason it is important to identify and work only with plasmic fabric patterns relevant to the type of thin sections analysed.

A summary of known plasmic fabric patterns can be found in Table 3.1. The table lists plasmic fabrics according to Brewer's (1976) classification and includes main points of the general descriptions as given in Brewer, (1976), FitzPatrick, (1984) and Bullock, et al. (1985). In addition to the three main soil micromorphology classification systems, a few additional references to some of the plasmic fabrics were added when these were initially described in the context of glacial sedimentology (Korina and Faustova, 1964).

Currently at least one other type of plasmic fabric, not described by Brewer (1976) is known to exist in glacial sediments. Kinking plasmic fabric, although not mentioned in Brewer (1976) was described by FitzPatrick (1984) and is therefore listed in the Table 3.1. It was first observed and reported by van der Meer (1982) in glacial sediments. Since then several other papers in glacial micromorphology describe this form of plasma orientation.
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<tr>
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<tbody>
<tr>
<td>Argillasepic</td>
<td>random extinction pattern, recognizable plasma domains, mostly clay sized</td>
<td>isotropic matrix</td>
<td>stipple-speckled*</td>
<td></td>
</tr>
<tr>
<td>Silasepic</td>
<td>random extinction pattern, no clay aggregates</td>
<td>isotropic matrix</td>
<td>stipple-speckled*</td>
<td></td>
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<tr>
<td>Insepic</td>
<td>clusters of preferred (&quot;striated&quot;) orientation within randomly oriented matrix</td>
<td>small and discontinuous anisotropic flecks</td>
<td>stipple-speckled</td>
<td>scaly microstructure (Korina &amp; Faustova, 1964)</td>
</tr>
<tr>
<td>Mosepic</td>
<td>well developed insepic plasmic fabric</td>
<td>larger anisotropic flecks</td>
<td>mosaic-speckled</td>
<td>conchoidal texture (Korina &amp; Faustova, 1964)</td>
</tr>
<tr>
<td>Vosepic</td>
<td>preferred orientation of striated plasma parallel to voids</td>
<td>anisotropic aureoles</td>
<td>porostriated b-fabric</td>
<td>conchoidal texture (Korina &amp; Faustova, 1964); microfoliation (Sitler &amp; Chapman, 1955); haloes (Wisniewski, 1965)</td>
</tr>
<tr>
<td>Skelsepic</td>
<td>preferred orientation of striated plasma parallel to skeleton grains</td>
<td>anisotropic aureoles</td>
<td>granostrated b-fabric, birefringent halo</td>
<td></td>
</tr>
<tr>
<td>Masepic</td>
<td>plasma separation zones consisting of &quot;striated&quot; orientations parallel to the general orientation of the zones, continuous anisotropic zones or a set of anisotropic lines</td>
<td>monostrated, parallel striated</td>
<td></td>
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<td>Masepic - Multisepic</td>
<td>plasma separations aligned in two or more dominant preferred orientation directions</td>
<td>variegated anisotropic zones, irregular set of oriented zones of plasma</td>
<td>cross-striated b-fabric, sets of birefringent streaks, not perpendicular to each other, intersecting</td>
<td>perpendicularly fibrous reticulate (Korina &amp; Faustova, 1964); lattice (Wisniewski, 1965)</td>
</tr>
<tr>
<td>Lattisepic</td>
<td>elongated, short, discontinuous domains, oriented at about right angle to each other</td>
<td>reticulate anisotropic zones</td>
<td>reticulate striated, must be right angled</td>
<td></td>
</tr>
<tr>
<td>Omnisepic</td>
<td>no single predominant preferred orientation direction but all plasma is oriented</td>
<td>variegated anisotropic zones</td>
<td>random striated b-fabric</td>
<td></td>
</tr>
<tr>
<td>Unistrial</td>
<td>masepic fabric but longer domains. Discussed only in terms of consolidated material.</td>
<td>anisotropic lines</td>
<td>unistrial plasmic fabric of Brewer, (1976)</td>
<td></td>
</tr>
<tr>
<td>Kinking</td>
<td>not described</td>
<td>zigzag or herring bone pattern, related to argillan coating fabrics</td>
<td>not described</td>
<td></td>
</tr>
</tbody>
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Table 3.1. A summary of the known plasmic fabric patterns and some of the original classifications references.

*Note: Asepic plasmic fabrics should not be identified as identical to insepic plasmic fabrics. This appears to be the case for Bullock et al. 1985 classification system.
Several terms used in soil micromorphology and plasmic fabric classification systems may not be appropriate when used in glacial sedimentological studies. For example, Brewer (1976) refers to "striated orientation" when describing preferred orientation in plasma separations. The terms striation and striated refer to a very specific set of glacial features and processes. The appearance of plasmic fabric "striations" and elast striations may be similar but the genetic processes involved are not at all same. For this reason term "striated" should not be used when referring to plasmic fabric patterns. Similarly, the term "domains" as used in Menzies and Maltman (1992) refers to individual visually different units of sediment often found in thin sections. Brewer (1976) used this term to describe zones of similarly oriented plasma. The ambiguous use of the term "domain" may lead to confusion in understanding verbal descriptions. In this work the terms "zones" "sub-units and "units" will be used to refer to visually different zones of thin sections. The term "domain" will only be used in reference to previous plasmic fabric pattern descriptions.

3.4 Diagnostic Characteristics of Plasmic Fabric Patterns

This section of the chapter concerns the summary of the known visual aspects of plasmic fabric patterns and a listing of their "diagnostic" features. Diagnostic features represent not just the shape, size or orientation of plasma separations but also their relationship to other sedimentary features to be found in glacial sediment thin sections. It is important to state that the recognition of certain plasmic fabrics patterns may only be possible when a strong and unique relationship between orientated plasma and other features can be established. A good example of this relationship would be skelsepic plasmic fabric and skeleton grains. Before any computer work can begin it is vitally important to identify the most important recognition characteristics of each type of plasmic fabric.

The subsequent set of descriptions will aim to create just such a list of unique qualities for each of the described plasmic fabric patterns. The application of confirmed diagnostic characteristics listed should be applied following a positive identification of oriented plasma separations in thin sections and will be explained in the subsequent chapters. The patterns analysed will coincide with the list defined in Table 3.1.
3.4.1 Argillasepic Plasmic Fabric

This type of fabric can be simply described as lacking any visible plasma separations. The plasma of this type of fabric consists mostly of clay sized material. Random extinction pattern (or flecked matrix pattern) and recognizable plasma domains should also be observed (Brewer, 1976).

FitzPatrick (1984) simply refers to this type of plasmic fabric as "isotropic matrix" without being more specific.

Bullock et al. (1985) "stipple-speckled" classification must be put to question since argillasepic plasmic fabric can not show anisotropism while at the same time "speckles" are defined as small equant bodies of birefringent plasma domains.

Argillasepic plasmic fabric pattern may be found in undisturbed marine sediments, not affected by iceberg scour (Lagerlund and van der Meer, 1990; Hiemstra, 1999). Flow tills (van der Meer, 1987; Menzies and Zaniewski, in prep) have also exhibited this type of plasmic fabric. The lack of plasmic fabric pattern may be the result of relatively low stress depositional conditions but a possibility of visible anisotropism masking by amorphous agents (ex. calcium carbonate) should not be excluded unless chemical testing indicates otherwise.

When identifying argillasepic plasmic fabric, the lack of plasma separations is an important characteristic. The matrix may show some domains but there should be no evidence of anisotropism when viewed under cross- or circular-polarizers. This is an idealized situation of course. It does not account for a highly variable nature of plasma where asepic plasma often closely coexists with sepic domains. This may result in some image overlap. To account for this it is best to accept that a small percentage of anisotropic domains may be present even in an otherwise asepic plasma. FitzPatrick (1993) defined 'rare anisotropic areas' where anisotropism frequency drops below 2 %. ‘Very rare anisotropism’ value was listed as less than 0.5 % ). In this thesis, optical anisotropism frequency of less than 2% and the predominantly clayey matrix (more than 50% clay sized material) should be treated as diagnostic in argillasepic fabric recognition. (Colour plate 1)

3.4.2 Silasepic Plasmic Fabric

This type of plasmic fabric also lacks visible plasma separations. The matrix should
consist mostly of silt sized material and must have a random extinction pattern (Brewer, 1976).

Both of the asepic plasmic fabrics are referred to as "stipple-speckled" plasmic fabrics by Bullock et al. (1985) but this, as explained above, must be considered as inaccurate.

FitzPatrick (1984) did not differentiate between asepic plasmic fabrics.

Silasepic plasmic fabric can be found in undisturbed glacial marine sediments (Lagerlund and van der Meer, 1990) and flow tills (van der Meer, 1987; Menzies and Zaniewski, in prep.). The conditions for this type of plasmic fabric formation are generally the same as those of argillasepic plasmic fabric.

There is very little difference between argill- and silasepic plasmic fabrics. If most of the matrix material contained in a sedimentary unit appears to be silt (more than 50% of the matrix consists of silt sized material) and plasma separations are rare or very rare (less than 2% optical anisotropism frequency of the matrix) then the fabric should be classified as silasepic. (Colour plate 2)

3.4.3 Insepic Plasmic Fabric

Insepic plasmic fabric differs from the asepic plasmic fabrics in that plasma separations can be observed within the matrix. These domains of preferred orientation or "striated orientation" appear as individual clusters within a randomly oriented matrix (Brewer, 1976). When viewed under cross-polarized conditions this type of fabric will likely increase in frequency but the distribution pattern should remain largely the same.

FitzPatrick (1984) refers to this type of fabric as anisotropic flecks. Flecks (or domains) should be small and discontinuous with diffuse or sharp boundaries. There should be no preferred orientation pattern for the domains.

Bullock et al. (1985) calls this type of plasma arrangement "stipple-speckled" plasmic fabric. Here, also, plasmic fabric definition refers to small bodies of oriented plasma, "equidimensional or slightly prolate" in shape.

This type of plasmic fabric was found to be present in "ground moraine" material by Korina and Faustova (1964) and was referred to as scaly microstructure.
Based on these descriptions insepic plasmic fabric can be described as essentially the simplest type of a sepic plasmic fabric. The development of plasma separations is only minimal in terms of areal extent. The critical value is tentatively set at 125 μm² based on 5 pixel minimum (at 25 μm²/pixel) used to define oriented shapes (see chapter 5.4). Matrix appears speckled with small clusters of orientated plasma. The individual clusters should not have any general preferred orientation direction nor should there be any overall pattern for the plasma separations. (Colour plate 3)

3.4.4 Mosepic Plasmic Fabric

According to Brewer (1976) this type of plasmic fabric appears to be a very well developed example of insepic plasmic fabric. Domains of "striated" plasma separations often appear to nearly overlap but do not have a general overall orientation or pattern. Thin zones of flecked plasma separate these individual domains of oriented clay minerals.

This type of fabric can also be classified as large anisotropic flecks (FitzPatrick, 1984). FitzPatrick (1984) therefore distinguishes between mosepic and insepic plasmic fabrics based only on the size of the plasma separations. Here again no preferred orientation pattern can be distinguished, nor is there a relationship between the domains and any other soil material.

Bullock et al. (1985) calls this type of fabric "mosaic-speckled" plasmic fabric. Here the difference appears to be the fact that individual domains of plasma must be in contact with each other. This is different from Brewer's (1976) classification in being much more explicit about the difference between the two types of plasmic fabrics.

This type of plasmic fabric pattern can be described as a variant of insepic plasmic fabric. Since the size of the orientated domains is a measure of plasmic fabric development it can be said that the mosepic plasmic fabric is essentially a well developed insepic plasmic fabric. This type of description is not well suited towards quantitative description or identification. It is therefore necessary to clarify and synthesize the various definitions into a more logical and rigid set of diagnostics that even a computer would understand.

A mosepic plasmic fabric is as a set of equidimensional unorientated anisotropic plasma domains. It differs from the insepic plasmic fabric in two ways: the individual clusters of plasma may occasionally be found in contact with each other forming a "checker board" pattern within a visibly isotropic matrix; individual domains appear larger in size. Although in current studies the size difference appears poorly defined, presumably due
to the infinite range of potential sizes, a single finite value must be stated explicitly. Presently this author chooses to use a value of \textbf{125 $\mu$m or more in area} for each anisotropic domain as the defining quality for mosepic plasmic fabric (see insepic p.f.).

One final note. The fact that mosepic plasmic fabric domains are often in contact with each other will not significantly affect the computer based diagnostics. If such situation arises the combined domains will be treated as a single domain of a size larger than 20 $\mu$m and, presumably, of no defined overall direction. Even if a slight preferred orientation is established for the whole combined unit, its shape characteristics and size will likely exclude it from being classified as any of the “orientated” plasmic fabrics.

\subsection*{3.4.5 Vosepic Plasmic Fabric}

This type of plasmic fabric is closely associated with void spaces within sediments. Although matrix appears predominantly flecked some striated plasma separations should be observed in relation to the sides of the voids. The orientation of the striated plasma is predominantly parallel to the voids (Brewer, 1976). This type of fabric along with the skelsepic plasmic fabric are also known as “surface related” fabrics (Blokhuis et al., 1990).

In FitzPatrick (1984) this arrangement of plasma domains is known as anisotropic aureoles. In this case the diagnostic features appear to be the shape of the overall pattern and its relation to voids. Individual domains forming the aureoles can be both, continuous and "striated", they can vary in thickness around the void and they can either surround the void only partially or completely.

Bullock et al. (1985) calls this type of fabric "porostriated b-fabric" and describes it as a birefringent fabric formed as a result of plasma separations being orientated parallel to the surface of the void.

Korina and Faustova (1964) identify this type of plasmic fabric as "conchoidal texture" when found in “ground moraine” sediments.

In clayey soils this type of plasmic fabric appears closely related to swelling. In fact the frequency of occurrence appeared to increase with depth in vertisols (Blokhuis et al. 1990). The same authors also indicated a temporal factor with an increase in the frequency of vosepic domains with time. Retallack (1997) indicated that although often associated with pedogenic processes, vosepic plasmic fabric can also be a result of filling in of voids during burial.
In this case the relationship between orientated domains and the voids is the key
diagnostic. Plasma separations must be located in the immediate vicinity (subcutanic) of the
void and must represent at least 40% of all the domains. The domains may be continuous or
discontinuous around the void. They should however be oriented parallel to the surface of
the void. There should also be a limit in terms of the distance that an orientated plasma
domain may extend away from the surface of the void. This is tentatively set at 25 μm. It
should be indicated that the method does not differentiate between argillans (diagenetic
structures) and plasma in general. Argillans often exhibit strong birefringence and would be
classified as birefringent plasma. To exclude argillans from the vosepic plasmic fabric
evaluation procedure would require an a priori knowledge of their existence and of the
location of the void walls. The division between matrix and argillan based anisotropism will
not be attempted in this thesis. (Colour plate 4)

3.4.6 Skelsepic Plasmic Fabric

Brewer (1976) describes this type of plasmic fabric as evidenced by plasma separations
occurring subcutanically - aligned parallel - to the surfaces of skeleton grains. The remainder
of the plasma, further away from the core skeleton grain, should be randomly oriented. Plasma
separation orientation appears predominantly parallel to the surface of the skeleton grain.

FitzPatrick (1984) also calls them anisotropic aureoles without making any
differentiation between the surface related plasmic fabrics.

Bullock et al.(1985) refers to skelsepic plasmic fabric as "granostriated b-fabric". This
type of fabric can be associated with any resistant fabric unit such as mineral grains or nodules.
Bullock et al.(1985) also describe this type of fabric as a birefringent halo around individual
grains.

This type of plasmic fabric was also referred to as conchoidal texture, when first
identified in glacial sediments by Korina and Faustova (1964), and haloes by Wisniewski
(1965).

It is generally thought that the skelsepic plasmic fabric is a result of rotational
movement sediments - especially rolling skeleton grains within a clay dominated matrix (van
der Meer, 1987, 1996; Retallack, 1997). Laboratory studies appear to confirm these findings
(Hiemstra and Rijnsdijk, in press). Subsequent alignment of plasma parallel to the surface of the
rotating skeleton grains results in the skelsepic pattern. This explanation also finds support in the common combination of turbate structures and skelsepic plasmic fabric in glacial sediments. Basal tills frequently contain examples of skelsepic plasmic fabric (van der Meer, 1987, 1990, 1996; van der Meer and Laban, 1990; van der Meer et al., 1983).

It should be noted that Jim (1990), Dalrymple and Jim (1984) and Retallack (1997) point to isotropic stresses due to wetting/drying cycles as capable of creating skelsepic plasmic fabrics. This direct relationship between clay swelling, depth and the development of skelsepic plasmic fabric is also supported by Blokhuis et al., (1990). The same authors also indicate an increase in the presence of skelsepic plasmic fabric domains with time - possibly linked to the number of shrink-swell cycles. The issue of swelling cycles is important as water removal by air drying, while causing some shrinking, also happens to be a very common method of sample preparation in glacial micromorphology. Retallack (1997) also indicates that the movement of grains during thin section preparation may be responsible for some skelsepic domains. Greene-Kelly and Mackney (1970) however found no evidence that consecutive wetting/drying cycles have any effect on the overall plasma anisotropism in clays. Their studies showed preexisting skelsepic and unistrial domains which were not enhanced, enlarged or modified due to wetting/drying cycles. Hiemstra and Rijsdijk (in press) indicate that thin skelsepic domains around irregular grains should not be treated as indicative of rotational movement.

Skelsepic plasmic fabric can be described as either, continuous to discontinuous plasma domains surrounding skeleton grains. Domains should appear parallel to the surfaces of the skeleton grains. A limit as to the distance away from the edge of the core grain that the plasma separations may extend while remaining identified as skelsepic in nature is set to 25 μm. For a fabric to be classified as skelsepic at least 40% of all the domains should fit within the 25 μm zones. As the critical value selected is based on visual thin section description experience it may undergo future modifications if necessary. The defining aspect of this type of fabric is predominantly its proximity to the core grain. However, since only domains which fit completely within each critical zone are considered they will act as a de facto filter (see section 5.5.2). (Colour Plate 5)

3.4.7 Masepic Plasmic Fabric

Streaks of uniformly oriented plasma domains. Domains are often discontinuous and dispersed uniformly. The appearance of streaking can be explained by the alignment of smaller plasma domains or flecks. Some or all of these flecks can be at least partially elongated. Their
longest axis orientation when combined with their general linear alignment results in the appearance of unidirectional orientation of plasma. The length (or size) of the flecks seems to vary without affecting the identification.

Brewer (1976) describes masepic plasmic fabric as a zone or zones of "striated" plasmic fabric. Plasma separations are independent of any soil features such as skeleton grains or pore spaces. There can be a number of zones of uniform basic orientation but the relationship between zone orientation may be random.

FitzPatrick’s (1984) classification generally refers to strial fabrics as anisotropic lines. When a number of similarly oriented zones of plasma can be observed the plasmic fabric pattern is described as a continuous zone. The masepic plasmic fabric as defined by Brewer (1976) would fit somewhere in between the two definitions.

Bullock et al. (1985) refers to this plasmic fabric as monostriated where plasma separations occur in distinct individual streak patterns but parallel striated where a number of similarly oriented streaks of birefringent plasma occur in sets of parallel lineations.

Where plasma domains appear orientated in one direction, such as masepic plasmic fabric or unistrial plasmic fabric, the direction tends to indicate shearing displacement in the sediment. In masepic plasmic fabrics this tends to appear in form of shear bands or zones (van der Meer, 1993).

For this type of fabric to be recognised, a pattern of orientated plasma separations must be observed. Plasma separations may occur in continuous or discontinuous zones which should be fairly large so that an idea of the preferred orientation direction may be gained. Furthermore, the orientation direction should be very similar for most of the observed domains. At least **15%** of the non-skelsepic/vosepic domains should be measured for orientation. These domains must then be evaluated for preferred orientation. One way to establish the nature of the plasmic fabric pattern is by way of visual examination of the rose diagram. This approach may prove misleading unless the rose diagram used is drawn with extreme care and using appropriate techniques (Wells, 2000). In addition, visual examination moves away from the objective principles of this thesis. Instead the decision regarding the preferred orientation direction is based on the orientation frequency distribution of the domains. Masepic fabric can be identified when orientation measurements cluster in one dominant direction. This can be recognized when one (and only one) of the following conditions has been detected:
a) 25% of all the measured orientations fit within a single 30° class interval or,
b) 20% of all the measured orientation fit within a single 20° class interval or,
c) 15% of all the measured orientations fit within a single 10° class interval.

The diagnostic values are explained in more detail in section 6.5.5. The critical values are based on testing experience but like the other critical values is tentative only and may undergo change when tested in practice. (Colour plate 6)

3.4.8 Bimasepic/Trimasepic Plasmic Fabrics

These types of plasmic fabrics are essentially a variation of masepic plasmic fabric. If plasma separations within zones of oriented matrix align in two distinct directions the plasmic fabric is known as bi-masepic or two directional masepic plasmic fabric. Trimasepic plasmic fabric involves three dominant preferred orientation directions (Brewer, 1976). These types of fabric are sometimes referred to as subcutanic types of plasmic fabric (Blokhuis et al., 1990). Subcutanic fabrics also include masepic and unistrial patterns.

Bullock et al. (1985) calls this type of fabric "cross-striated b-fabric". It can be defined by "two sets of birefringent streaks, not perpendicular to each other, intersecting". It is important to note that only one set of streaks at a time can be seen under cross-polarizers at any given stage orientation. The stage must be rotated before the second set of streaks can be observed.

These types of plasmic fabric pattern are referred to as variegated anisotropic zones in FitzPatrick (1984). Variegated anisotropic zones are essentially a set of individual multidirectional zones of orientated plasma. FitzPatrick (1984) does not apparently consider the number of unique orientation directions as significant and subsequently no specific names were given to each type.

For diagnostic recognition purposes bimasepic or trimasepic plasmic fabrics should be treated as a combination of two or more masepic plasmic fabrics. Essentially a zone of matrix may be described as bi/trimasepic if more than one dominant direction of preferred orientation may be found. Bimasepic or trimasepic plasmic fabric can be identified if conditions described in masepic plasmic fabric definition (see above) are found true in more than one preferred direction. (Colour plate 7)
3.4.9 Lattisepic Plasmic Fabric

This is a variation of the bimasepic plasmic fabric. Here the plasma appears mostly unoriented. However, some plasma separations can be observed. These are elongated, short and discontinuous while their domains appear oriented in two distinct directions at an approximately right angle to each other. This results in a lattice like appearance of the matrix (Brewer, 1976).

This type of plasmic fabric is known as reticulate striated under Bullock et al. (1985) classification. Here, also, the difference between cross-striated and reticulate striated lays in the angle at which the streaks intersect but in this case the definition clearly indicates 90 degrees as diagnostic.

FitzPatrick (1984) refers to lattisepic plasmic fabric as reticulate anisotropic zones. These are defined as zones of oriented plasma orientated in two dominant directions normal to each other.

Korina and Faustova (1964) refer to examples of this type of plasmic fabric to be found in “ground moraine” sediments as perpendicularly fibrous reticulate plasmic fabric.

Jim (1990) generally described the process of lattisepic plasmic fabric formation as a rotational in nature. The rotation of skeleton grains tended toward ellipsoid and resulted in the box like arrangement of plasma.

Lattisepic plasmic fabric is commonly found in basal tills (van der Meer, 1990; van der Meer et al., 1983). Menzies and Maltman (1992) have also found lattisepic fabric in subglacial sediments.

Based on these descriptions and definitions it should be reasonable to accept that the major diagnostic characteristic to be used in the recognition of lattisepic plasmic fabric should be the relationship between the two dominant preferred orientation directions. In other words, plasma should be organized into zones of bimasepic plasmic fabric. The angle of intersection between the two dominant direction should be 90° (+/-10°). In practice the value may range away from the perfect value stated. (Colour plate 8)
3.4.10 Omnisepic Plasmic Fabric

This type of plasmic fabric exhibits a very complex pattern of striated plasma separations. No single predominant preferred orientation can be observed but all of the plasma shows some orientation (Brewer, 1976).

This is similar to Bullock's et al. (1985) random striated b-fabric. This type of plasmic fabric can be described as an irregular pattern of discontinuous streaks of birefringent plasma. The streaks frequently intersect each other at various angles and show successive extinction with stage rotation.

Variegated anisotropic zones of FitzPatrick (1984) fit the description of omnisepic plasmic fabrics closest. This type of plasmic fabric can be described as a number of domains of plasma strongly orientated but lacking a predominant preferred orientation pattern.

Diagnostic recognition of this type of plasmic fabric should be based on the nearly infinite range of preferred orientation directions for the zones of plasma separations. As in case of masepic plasmic fabric, a minimum of 15% of oriented domains should be present (exclusive of vo/skelsepic domains). If no obvious preferred orientation pattern is found (masepic, bimasepic, trimasepic) then orientation pattern should be tested further. When tested for directional frequency at each 5° class centre, no values should fall below:

a) 10% of all the measured orientations for the 30° class intervals or,
b) 4% of all the measured orientations for the 20° class intervals or,
c) 1% of all the measured orientations for the 10° class intervals.

The critical diagnostic values used are tentative only. They are based on observed frequencies found during the preliminary testing procedures of known omnisepic plasmic patterns. (Colour plate 9)

3.4.11 Unistrial Plasmic Fabric

This type of plasma arrangement occurs most commonly in clay rich sediments. It is also referred to as discrete shears (Maltman, 1987; Menzies, 1990; Menzies and Maltman, 1992). Discrete shears appear in cross-polarized light as strongly anisotropic streaks of oriented clay. Unlike masepic plasmic fabric, unistrial fabric streaks appear to have a very well defined length and be continuous. Since discrete shears can be attributed to a slip along a plane
of weakness, theoretically at least they are of only a very limited width. In practice discrete shears' widths can be measured in tens of microns. The preferred orientation of the unistrial plasmic fabric appears to vary from shear to shear. Discrete shears can be straight or curvilinear. Discrete shears can cross cut each other at any angle.

Brewer (1976) did not exclusively mention the unistrial plasmic fabric but its description would place it under masepic plasmic fabric category.

FitzPatrick (1984) refers to unistrial plasmic fabrics as anisotropic lines. Anisotropic lines generally occur in the matrix as a set of thin layers of sheared clay plasma. In glacial sediments they are generally found within matrix.

Unistrial plasmic fabrics are generally thought to be a result of shearing, as shown in experimental studies (Foster and De, 1971; Maltman, 1977, 1987; Tovey and Wong, 1980; Smart and Tovey, 1981). They have been found in basal tills (van der Meer, 1987, 1990, 1996; van der Meer and Laban, 1990; van der Meer et al., 1983) and in glaciotectonized sediments (van der Meer et al., 1994).

Blokhuis et al. (1990) linked their existence in some young clayey soils to swelling under confined volume conditions - resulting in unistrial plasmic fabric orientation angle of approximately 45 degrees. In glacial sediments angles other than 45 degrees may reflect the effects of horizontal shearing induced by the overriding ice sheet. In an earlier study, Greene-Kelly and Mackney (1970) observed no apparent link between wetting and drying and unistrial domain formation.

For the sake of diagnostic recognition it may be necessary to differentiate mathematically between masepic, bimasepic or lattisepic plasmic fabrics and unistrials. The unistrial plasmic fabrics should have a much higher L:W axis ratio (tentatively 20:1) for their plasma separation zones as they are generally continuous and thin. Also important to note is the fact that unistrial plasmic fabrics generally appear as strongly anisotropic, indicating strong basic orientation, as well as having well defined boundaries. The shape characteristics of the plasma domains must be considered critical since differentiation based purely on a preferred orientation may result in misidentification as other subcutanic plasmic fabrics. (Colour plate 10)
3.4.12 Kinking Plasmic Fabric

This type of fabric was observed in glacial sediments (van der Meer, 1982, 1987, Menzies and Maltman, 1992; Bordonau and van der Meer, 1994) but was not described in Brewer (1976) or Bullock et al. (1985). FitzPatrick (1984) briefly mentioned this type of plasma arrangement.

Kinking plasmic fabric can be described as consisting of a "herring bone" or "tiger skin" pattern of extinction bands in clay rich sediments. Kink bands appear very highly anisotropic. The extinction bands are oriented to each other at high angles. This type of plasmic fabric is often restricted to individual lenses of clay rich material within coarser matrix.

Kinking plasmic fabric is generally associated with very strongly sheared, compressive, zones within clay rich bands found in glacial tills (van der Meer, 1985, 1993). Examples of this type of plasmic fabric found in glacial sediments can be found in van der Meer (1982, 1987), Menzies and Maltman (1992) and Bordonau and van der Meer (1994). Experimental testing on strongly sheared clays also resulted in kinking plasmic fabrics (Tchalenko, 1968; Foster and De, 1971; Maltman, 1977; Smart and Tovey, 1981).

This type of fabric should be recognized by the strength of anisotropism and the high frequency and width of the extinction bands. Also, the dominant preferred orientation direction between the extinction bands should be at a near right angle (Colour plate 11). It is possible that under circularly polarized light settings this type of plasmic fabric would be undistinguishable from a strongly developed masepic plasmic fabric.

3.5 Other Types of Plasmic Fabric

3.5.1 Undulic, Isotic and Crystic Plasmic Fabrics of Brewer, (1976)

These rare types of plasmic fabrics appear to have little relevance to glacial sediments. Undulic and isotic plasmic fabrics both appear isotropic at low magnifications (isotic plasmic fabric is a true isotropic plasmic fabric). Crystic plasmic fabric, Bullock's et al. (1985) crystallytic b-fabric, appears unique in that it consists of visible crystal of soluble plasma fractions. An example of this type of fabric has been observed in the Lund diamicton in Varpinge, Sweden (van der Meer, pers. comm.) Its significance remains questionable as the fabric described can also be treated as omnisepic.
None of the three fabrics will be considered by this thesis. Low magnifications used in glacial micromorphology make proper identification of these three types of plasmic fabric difficult. At the same time their relevance to glacial sediment studies is dubious.