

Photographic Key for the Microhistological Identification of some Arctic Vascular Plants

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ABSTRACT. Microhistological techniques are used in many studies of food habits in herbivores. A photographic key for the microhistological identification of 112 Arctic and Subarctic plant species is presented. Epidermal features used in the key are described and illustrated in a photographic glossary. Enough information is given on plant collection, fragment preparation, and feature identification to help users customize the key with additional Arctic plant species.

Key words: Arctic plants, Arctic herbivores, epidermis, food habit, key, microhistology, plant identification

RÉSUMÉ. L'analyse microhistologique est couramment utilisée lors d'études du régime alimentaire des herbivores. On présente un tableau photographique d'identification microhistologique de 112 espèces de plantes arctiques et subarctiques. Les caractéristiques épidermiques utilisées dans le tableau sont décrites et illustrées dans un glossaire photographique. L'article fournit assez de détails sur la collecte des plantes, la préparation des épidermes et l'identification des caractéristiques pour permettre aux utilisateurs d'adapter le tableau en y incluant d'autres espèces végétales.

Mots clés: plantes arctiques, herbivores arctiques, épiderme, régime alimentaire, clé, microhistologie, identification de plantes

INTRODUCTION

Microhistological techniques, used in many studies of food habits in herbivores (Owen, 1975; Holeček et al., 1982a; Black et al., 1994; Smith et al., 1998; Larter, 1999), are usually complemented by other methods, such as behavioural observations (e.g., Carrière et al., 1999), controlled feeding experiments, and macro-analysis of stomach or esophageal contents (see Kronfeld and Dayan, 1998). Microhistological techniques have well-documented shortcomings (Holeček and Vagra, 1981; Holeček et al., 1982a; Johnson et al., 1983b; Rosenberg and Cooper, 1990), such as low accuracy depending on herbivore and plant species studied (Caron et al., 1985), the sample preparation technique used (Holeček et al., 1982b; Johnson et al., 1983a), and observer training (Holeček and Gross, 1982). However, the absence of detailed reference material or prohibitive costs in time and effort to create reference material for a particular study species and area mostly hamper a better understanding and larger use of microhistological techniques.

Many Arctic plants have quasi-circumpolar distributions, and plant diversity is relatively low in the Arctic (Porsild and Cody, 1980; Cody, 1996). A reference key of Arctic plants based on microhistological features may be used by a large group of scientists interested in the feeding ecology of Arctic herbivores; for the most part, its use is independent of study sites and the species studied.

A key for the identification of 112 Arctic plant species is presented here. Enough information is included to allow users to customize the key with additional Arctic plant

species. A discussion of the microhistological technique itself (see Owen, 1975; Johnson, 1982) and of its advantages and pitfalls is beyond the scope of this paper. It is recommended, however, that the reader not already familiar with this technique review technical and methodological publications before using the key. Works cited in this paper, and the references therein, may form a good starting point.

COLLECTION AND PREPARATION OF REFERENCE PLANT FRAGMENTS

Two opposing principles can be applied to the preparation of reference material for microhistological identification (e.g., Lindström et al., 1998). The reference material could either (1) simulate the small and torn appearance of fragments found in samples following ingestion and digestion (e.g., Ellis et al., 1998), or (2) show as many identification features as possible (Johnson et al., 1983a; Carrière, 1996). I used the second principle because it provided a better opportunity for the identification not only of plant species, but also of plant parts. Identifying parts helps in determining the various arrangements of diagnostic features on plant epidermis, which in turn will provide valuable information for estimating correction factors for diets.

Whole plant specimens (see Appendix) were collected in June through August during studies on Arctic herbivores on the Kent Peninsula, Nunavut (goose research:

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1992–94, Carrière, 1996); on the Ungava Peninsula, Québec (study of introduced muskoxen: 1996); and near Bathurst Inlet, Nunavut and Inuvik, Northwest Territories (caribou studies: 1997). All plants were dried flat for transportation. In the laboratory, one epidermis (approx. 1 cm²) of different plant parts (i.e., leaf tip, leaf blade, stem) was carefully removed under a dissecting microscope. Plant parts were soaked for one day in water and then laid on a slide in a drop of household bleach. An epidermal fragment was then cleaned with a scalpel by scraping away the epidermis on one side, discarding it, and then carefully removing the inside tissue to reveal the reference epidermis, face down, on the other side. Bleach was used to clear pigments, and water, to soften dried tissue (Johnson et al., 1983a). The cleaned epidermis was laid in water and then mounted, the outside up, on a slide in a plastic medium for permanent storage and future reference.

All plant species were thoroughly investigated for different diagnostic features, and an epidermis was mounted for each distinctive plant part. These were photographed at 100× magnification, simulating how slides of fecal samples were to be observed (Figs. 1–11). A key for the identification of fragments was then developed using diagnostic features described below. Plant species not included in this key can be added using the method described above (see included species in the Appendix).

DESCRIPTION OF DIAGNOSTIC FEATURES

Diagnostic feature descriptions (Table 1) are from Metcalfe (1960), Johnson et al. (1983a), Blackmore and Tootill (1984), and Mady Dabo et al. (1986). The different variations of features useful during the identification of Arctic plant fragments are highlighted in a photographic glossary (symbols in Figs. 1–11).

Trichomes are defined as any outgrowths of an epidermal cell (Blackmore and Tootill, 1984). I assigned particular names to outgrowths that had specific shapes or functions (hair, gland, papillae, prickle) and described the shape of other trichomes. For example, star-shaped, V-shaped, and hook-shaped are all different aspects of the same category of outgrowth, called multi-branched trichomes.

For most species, fragments from both the abaxial (lower) and adaxial (upper) surface of the leaf (Blackmore and Tootill, 1984) were examined and included in the key if their features differed. Stem fragments were taken from twigs in trees and shrubs or from the stalk bearing the inflorescence in non-woody plants.

USING THE KEY

Species available when developing the key are listed alphabetically in the Appendix. Roots, rhizomes, and reproductive plant parts (such as seed and inflorescence) were not included in the key. Each plant part (leaves and

stem) of a single species usually possesses quite different diagnostic features. For this reason, microhistological keys cannot be purely dichotomous.

Microhistological keys help in the identification of fragments, not whole plants or plant species; and not all parts of a species are readily identifiable using epidermal features. Some species produced fragments that proved difficult to differentiate using microhistological features. These species were listed together at the species level at the ends of the key; i.e., these species were not systematically grouped into lower levels of identification. By listing all similarly featured fragments at the species level, the key may help researchers to identify these fragments to the species. For example, if only one of the similarly featured species listed in the key is known to be available to the studied herbivore, the observed fragment may be identified to species. If more than two such species are available, the researcher may want, for that fragment, to reduce the level of identification to genus, family, or plant group (e.g., forb) accordingly. In general, a higher diversity of available plants reduces the precision of diet identification. Rarely during microhistological analysis can all plant fragments be identified with confidence to the species level (e.g., Ellis et al., 1998; Carrière, 1999; Larter, 1999).

Some diagnostic features can be easily mistaken for others: short hairs for prickles (Figs. 4 and 8), small glands and druses for papillae (Figs. 2, 3, 4, 7), etc. When in doubt, try to key the fragment using both possible features and carefully examine the photographs. However, certain features of some species were included in the key, but are not apparent on the photographs. In addition, even the best photographs of epidermal features never truly represent the full appearance of fragments as seen under a microscope. The epidermis of most species has a single-cell layer, but it can have multiple layers of cells on some species. Furthermore, the different features are best examined by varying the focus of the microscope. Photographs capture only one thin plane of focus. Microhistological keys are at best simple guides (Mady Dabo et al., 1986).

Species scientific names follow Cody (1996), or Porsild and Cody (1980) for species not described in Cody (1996). Numbers and letters given in parentheses in the key (e.g., 1a; AD) refer to figure number and photograph letter, NS = no photograph shown, LF = any epidermal fragment of a leaf, AB = abaxial (lower) leaf epidermis, AD = adaxial (upper) leaf epidermis, and ST = stem fragment. The abbreviation *cf.* is given where a photograph of the keyed fragment is absent, but a photograph of a similar fragment can be consulted. Complementing this key, a searchable database that includes additional species and photographs, and all original microscopic slides are available upon request at the Wildlife and Fisheries Division, Department of Resources, Wildlife and Economic Development, Government of the Northwest Territories, 600, 5102 – 50th Avenue, Yellowknife, Northwest Territories X1A 3S8, Canada.

TABLE 1. Description of diagnostic features, reference to type variations, and codes to photographic glossary. Refer to Figures 1–11. Descriptions are from Metcalfe (1960), Johnson et al. (1983a), Blackmore and Tootill (1984), and Mady Dabo et al. (1986).

Feature	Description	Code	Reference to type variations (Figure; Photo)
Long-cells	Undifferentiated epidermal cells varying in length, width, and wall shape (synonymous with “general” cells or epidermal cells). Long-cells can be rectangular (r-c), spindle-shaped (sp-c), square (s-c), angular (an-c), or lobed (lob-c).	r-c sp-c sq-c an-c lob-c	1b 8b 3h 5d 2c
Cell walls	Walls of long-cells. Linear, sinuous, wavy.		
Hairs	Type of trichome resembling a hair. Macrohairs can usually be seen with the naked eye and are easily distinguished at magnification of 100×. Macrohairs can detach during digestion, but hair bases will suggest their presence. Microhairs, defined as hairs visible only at magnifications of 125× or more, are not used in the key. Hairs may be segmented (seg-h), ligulate (lig-h) or flattened.	seg-h lig-h	4k 5e
Hair bases	Basal cells or group of cells attaching hair to other epidermal cells. Basal cells can be single or segmented (seg-b).	seg-b	5m
Multi-branched trichomes	Multi-branched trichomes are other protrusions of the epidermis that are shaped like stars or branched. They are typically found on dicot species.	mt	1l
Crystals	Non-living cellular inclusion of calcium compounds, starch or silica. Typical shapes are square (cr), slate-needle (raphides), globular (druses; dr).	cr dr	7n 4a; 7n
Stomata	Epidermal pores to provide for gaseous exchanges between internal tissues and the atmosphere. Stomata (st) are typically, but not exclusively, aligned in monocot species and dispersed in dicot species. The shape of the pore and the guard cells are also good diagnostic features. Stomata are usually more numerous on the abaxial (lower) surface of leaves than on the adaxial (upper) surface.	st	1e
Papillae	Variously shaped protrusions appearing as swollen waxy bubbles on epidermal cells. They often involve large amounts of cutin and may serve as water loss protection.	pa	2a; 3i; 3m; 3n
Silica bodies	Differentiated epidermal cells completely or partially filled with silicon. Silica bodies are typical of monocot species.	sb	1c
Prickles	A rigid and short-pointed protrusion resembling a tooth. Prickles vary little in appearance among species, but some differences exist in length and thickness. They can be present on leaf margins, on veins, or generally dispersed. Prickles are quite robust to digestion and their presence offers an additional diagnostic feature.	pr	8e; 8g; 8n
Glands	Group of one (rare) or more cells secreting specific chemical substances on the plant surface. Some species of plants are named after these features (e.g., <i>Betula glandulosa</i>). Glands can resemble hairs with a bulbous extremity or complex papilli.	gl	2k; 2o; 2p

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FRAGMENT IDENTIFICATION KEY OF SOME ARCTIC PLANT SPECIES

- Ia** Silica bodies present, epidermal long-cells generally rectangular, elongated; walls may be sinuous, no multi-branched trichomes present, stomata if present arranged in rows, with subsidiary cells and guard cells present (Monocots only) (Fig. 1) **Group A**
- Ib** Silica bodies absent, multi-branched trichomes may be present, epidermal long-cells irregularly shaped, lobed, rectangular or squarish, stomata if present of variable shape **II**
- II** Multi-branched trichomes present, numerous stomata (Dicots only) (Fig. 1) **Group B**
- II** Multi-branched trichomes absent, stomata may be present
- III** Glands present (Dicots only) (Figs. 2 and 3) **Group C**
- III** Glands absent **IV**
- IV** Papillae present (Figs. 3 and 4) **Group D**
- IV** Papillae absent **V**
- V** Hairs present and segmented (Dicots only) (Fig. 4) **Group E**
- V** Hairs if present, not segmented **VI**
- VI** Hairs present and ligulate or flattened (Figs. 5–7) **Group F**
- VI** Hairs absent **VII**
- VII** Druses or crystals present (Fig. 7) **Group G**
- VII** Druses or crystals absent **VIII**
- VII** Prickles present (Fig. 8) **Group H**
- VIII** Prickles absent (Figs. 9–11) **Group I**

Group A (Silica bodies present)

- a** Prickles present
- b** Papillae near or on silica bodies *Puccinellia phryganodes* (1a; AD).
- b** Papillae absent *Poa pratensis* (1b; AB).
- a** Prickles absent
- c** Stomata present, numerous *Festuca brachyphylla* (1d; ST), *Alopecurus alpinus* (1e; AB), *Dupontia fisheri* (1f; AB), *Hierochloë pauciflora* (1g; ST), *Puccinellia phryganodes* (1h; AD), *Poa pratensis* (1c; AB), *Poa arctica* (1i; AB), *Leymus mollis* (1j; AB), *Festuca rubra* (1k; AB), *Puccinellia phryganodes* (ignore stomata cf. 1a; AB).
- c** Stomata absent

Group B (Multi-branched trichomes present, no silica bodies)

- a** Hairs present *Draba aurea* (1o; LF), *Draba longipes* (1m; LF), *Arabis alpina* (1n; LF).
- a** Hairs absent *Draba alpina* (1l; LF), *Ranunculus pedatifidus* (5o; LF).

Group C (Glands present, no trichomes, no silica bodies)

- a** Hairs present; stomata present, may be numerous
- b** Hairs segmented,
- c** Papillae present, druses absent *Pedicularis labradorica* (2a; LF),
Pedicularis lapponica (2b; AB).
- c** Papillae absent, druses may be present *Cerastium alpinum* (2c; AB), *Rhinantus* spp. (2d; LF),
Veronica wormskjoldii (2e; ST).
- b** Hairs ligulate or flattened
- d** Hair base segmented
- e** Crystals or druses present *Cerastium beeringianum* (2f; AB).
- e** Crystals or druses absent *Ledum decumbens* (2g; LF).
- d** Hair base not segmented
- f** Crystals present *Empetrum nigrum* (2h; ST),
Oxytropis nigrescens (2i; LF).
- f** Crystals absent
- g** Prickles present *Euphrasia subarctica* (2j; FL)(glands not visible).
- g** Prickles absent *Oxytropis nigrescens* (cf. 2i),
Petasites sagittatus (2m; ST), *Salix arctica* (cf. 5n),
Linnaea borealis (2k; AB) (2l; ST).
- a** Hairs absent; stomata variable
- h** Druses present *Betula glandulosa* (2p; ST), *Primula incana* (2n; ST),
Rhododendron lapponicum (2o; LF)
- h** Druses absent
- i** Prickles present; stomata variable
- j** Stomata present *Betula glandulosa* (3a; ST),
Vaccinium vitis-idaea (3b; LF)
- j** Stomata absent *Betula glandulosa* (cf. 3a),
Phyllodoce coerulea (3c; LF, 3g; LF).
- i** Prickles absent, stomata present *Betula glandulosa* (cf. 3a),
Cerastium beeringianum (cf. 4e; ST) (4f; ST),
Hippuris vulgaris (3d; LF),
Saxifraga tricuspidata (3e; LF) (3f; LF)

Group D (Papillae present, no glands, no multi-branched trichomes, no silica bodies)

- a** Long-cells squarish, linear cell walls *Carex Bigelowii* (cf. 3h),
Carex subspathacea (3i; AD tip section).
- a** Long-cells not squarish, but may be rectangular, spindle-shaped or angular, cell walls variable
- b** Long-cells rectangular
- c** Crystals present *Equisetum arvense* (3j; LF)
- c** Crystals absent *Carex* sp. [*C. aquatilis* (3k; LF), *C. Bigelowii* (3h; LF),
C. glareosa (3l; ST), *C. subspathacea* (3m; AD)],
Arctophila fulva (3n; AB),
Puccinellia arctica (3o; AD) (3p; AB)
- b** Long-cells angular or lobed
- d** Hairs present ligulate or filiforme, stomata absent *Cassiope tetragona* (4a; LF)(4.b; LF)
- d** Hairs absent, stomata present and numerous *Saxifraga aizoides* (4c; AD), *Castilleja* sp.(4d; LF)

Group E (Segmented hairs, no papillae, no glands, no multi-branched trichomes, no silica bodies)

- a** Long-cells rectangular, stomata present
b Prickles present; stomata variable
Cerastium alpinum (cf. 2c),
Cerastium beeringianum (4e; AD),
Pedicularis flammea (4g; LF),
Rhinanthus sp. (4h; LF),
Veronica wormskjoldii (4i; LF).
- b** Prickles absent, stomata present
Pedicularis sudetica (4j; ST), *Pedicularis lanata* (NS),
Senecio confusa (4k; LF), *Saxifraga cernua* (4l; ST),
Veronica wormskjoldii (4m; ST),
Solidago multiradiata (4n; ST),
Myosotis alpestris (4o; ST).
- a** Long-cells angular or lobed, stomata present
c Prickles present
c Prickles absent
Cerastium sp. (NS), *C. alpinum* (4p; AB).
Arnica angustifolia (5a; AB),
Senecio confusa (cf. 4k), *Pedicularis sudetica* (cf. 4j),
Saxifraga cernua (5b; LF).

Group F (Hairs ligulate or filiform or flattened, not segmented, no papillae, no glands, no multi-branched trichomes, no silica bodies)

- a** Crystal or druses present (or druse-like hair bases)
b Long-cells lobed
c Hair base segmented
c Hair base not segmented
Cerastium beeringianum (cf. 4e).
Linnaea borealis (5c; AD).
- b** Long-cells angular
Dryas sp. (5d; AD), *Salix lanata* (5e; LF).
- a** Crystals absent
d Prickles present
e Hair base segmented, long-cells sinous
e Hair base not segmented, long-cells variable
Cerastium sp. (NS).
Rubus arcticus (5f; LF), *Salix arctophila* (5g; LF),
Alnus crispa (5h; AD), *Euphrasia subarctica* (cf. 2j).
- d** Prickles absent
f Stomata present
g Long-cells spindle-shaped
g Long-cells rectangular, lobed or angular
Festuca rubra (cf. 1k).
- h** Long-cells angular or lobed
i Long-cells angular
j Hair base segmented
j Hair base not segmented
Achillea millefolium (5m; AB).
Antennaria sp. (5i; AD), *Potentilla palustris* (5j; AB),
Potentilla norvegica (5k; LF),
Rubus chamaemorus (5l; AB),
Solidago multiradiata (NS), *Salix arctica* (5n; LF),
Rubus arcticus (cf. 5f),
Ranunculus pedatifidus (cf. 5o),
Potentilla nivea (6a; AD),
Oxytropis nigrescens (cf. 6e),
Hedysarum boreale (cf. 6i),
Epilobium palustre (6b; AB),
Epilobium latifolium (NS).
- i** Long-cells lobed
k Hair base segmented
Achillea millefolium (cf. 5m),
Arnica angustifolia (cf. 5a).

k Hair base not segmented	<i>Oxytropis maydelliana</i> (6c; LF), <i>Hedysarum boreale</i> (cf. 6i), <i>Empetrum nigrum</i> (6d; LF).
h Long-cells rectangular	<i>Oxytropis nigrescens</i> (6e; LF), <i>Taraxacum</i> sp. (6f; ST), <i>Ranunculus pedatifidus</i> (6g; ST), <i>Potentilla nivea</i> (6h; AB), <i>Hedysarum boreale</i> (6i; ST), <i>Anemone parviflora</i> (6j; AB).
f Stomata absent	
l Long-cells rectangular or squarish	<i>Ledum decumbens</i> (cf. 7c), <i>Alnus crispa</i> (6p; AD), <i>Epilobium latifolium</i> (6k; ST), <i>Oxytropis nigrescens</i> (6l; ST), <i>Salix glauca</i> (6m–n; AD), <i>Salix planifolia</i> (6o; LF).
l Long-cells angular or lobed	<i>Astragalus alpinus</i> (7a; LF), <i>Dryas integrifolia</i> (7b; AD), <i>Ledum decumbens</i> (7c; AB, stomata not visible, under hair), <i>Linnaea borealis</i> (cf. 5c), <i>Oxytropis nigrescens</i> (7d; ST), <i>Potentilla palustris</i> (cf. 5j), <i>Salix arctica</i> (cf. 5n), <i>Salix arctophila</i> (cf. 5g), <i>Salix planifolia</i> (cf. 6o).

Group G (Druses or crystals present, no hairs, no papillae, no glands, no multi-branched trichomes, no silica bodies)

a Prickles present	<i>Silene acaulis</i> (7e; LF), <i>Ledum decumbens</i> (7f; AD).
a Prickles absent	
b Stomata present	
c Long-cells lobed	<i>Silene acaulis</i> (7g; ST), <i>Woodsia iivensis</i> (7h; LF), <i>Arenaria longipedunculata</i> (7i; AB).
c Long-cells angular	<i>Pyrola minor</i> (7j; AB, crystals not shown), <i>Arctostaphylos alpina</i> (7k; AB)
b Stomata absent	<i>Ledum decumbens</i> (7l; ST), <i>Salix lanata</i> (7m; LF), <i>Salix uva-ursi</i> (7n; LF), <i>Potentilla palustris</i> (7o; LF)

Group H (Prickles present, no crystals, no hairs, no papillae, no glands, no multi-branched trichomes, no silica bodies)

a Prickles segmented	<i>Silene acaulis</i> (cf. 7e), <i>Loiseleuria procumbens</i> (cf. 8a).
a Prickles not segmented	
b Prickles not on veins, mostly numerous	
c Stomata present, numerous, long-cells variable	
d Long-cells rectangular or spindle-shaped	<i>Loiseleuria procumbens</i> (8a; LF), <i>Silene acaulis</i> (cf. 7e), <i>Poa pratensis</i> (8b; AD), <i>Poa arctica</i> (8c; AB), <i>Saxifraga tricuspidata</i> (cf. 3e, 3f), <i>Festuca brachyphylla</i> (cf. 1d), <i>Elymus trachycaulum</i> (8d; AD), <i>Alopecurus alpinus</i> (8e; AD), <i>Arctophila fulva</i> (8f; AD), <i>Carex glareosa</i> (cf. 3l), <i>Carex nardina</i> (8g; AD), <i>Carex scirpodea</i> (8h; AD), <i>Eriophorum vaginatum</i> (8i; ST).
d Long-cells angular or lobed or squarish	<i>Saxifraga tricuspidata</i> (cf. 3e, 3f), <i>Loiseleuria procumbens</i> (cf. 8a).

- c** Stomata rare or absent,
long-cells rectangular or spindle-shaped
- b** Prickles on veins only, numerous or rare,
stomata numerous
- e** Long-cells rectangular
or spindle-shaped
- e** Long-cells angular or lobed
- Calamagrostis stricta* (8j; AB),
Carex scirpodea (cf. 8h), *Dupontia fisheri* (8k; AB),
Festuca rubra (8l; AB), *Poa pratensis* (8m; AB).
- Calamagrostis stricta* (8n; AD),
Carex subspathacea (8o; AD),
Leymus mollis (8p; AD),
Saxifraga tricuspidata (cf. 3e, 3f).
Arctostaphylos alpina (NS),
Saxifraga tricuspidata (cf. 3e, 3f), *Viola adunca* (NS).

Group I (No prickles, no crystals, no hairs, no papillae, no glands, no trichomes, no silica bodies)

- a** Stomata present
- b** Long-cells lobed or angular
- c** Long-cells lobed
- c** Long-cells angular
- b** Long-cells spindle-shaped or rectangular
- d** Long-cells spindle-shaped
- d** Long-cells rectangular
- Stellaria humifusa* (9a; LF),
Stellaria longipes (9b; AB),
Parnassia kotzebuei (9c; LF),
Pyrola asarifolia (9d; AB),
Senecio pauciflorus (9e; LF), *Taraxacum* sp. (9f; AD),
Viola adunca (9g; AB), *Cardamine digitata* (9h; LF),
Pedicularis sp. (NS), *Primula incana* (9i; AB).
Arctostaphylos alpina (9j; AB),
Arenaria longipedunculata (9l; AD),
Diapensia lapponica (9m; AB),
Hedysarum alpinum (9n; AB),
Hedysarum boreale (cf. 10j),
Mertensia maritima (9o; AB),
Oxyria digyna (9p; AD), *Petasites sagittatus* (NS),
Polygonum viviparum (10a; LF),
Primula incana (10b; ST), *Pyrola minor* (10c; AD),
Ranunculus lapponica (10d; AB),
Salix arctica (10e; LF), *Salix reticulata* (10f; LF),
Saxifraga aizoon (10g; AD),
Taraxacum sp. (10h; AD),
Pyrola asarifolia (10i; AD),
Carex Bigelowii (cf. 11k),
Eriophorum angustifolium (cf. 11k),
Eriophorum scheuchzeri (cf. 11k),
Potamogeton filiformis (NS), *Silene acaulis* (cf. 7e)
- Dupontia fisheri* (9k; AD), *Puccinellia arctica* (NS)
Arctostaphylos alpina (11a; ST),
Artemisia campestris (11b; ST),
Cardamine digitata (cf. 9h),
Diapensia lapponica (11c; ST),
Mertensia maritima (cf. 9o),
Myosotis alpestris (11d; AD),
Parnassia kotzebuei (11e; ST), *Pedicularis* sp. (NS),
Primula incana (cf. 2n), *Saxifraga aizoides* (11f; AD),
Senecio pauciflorus (11g; ST),
Stellaria humifusa (cf. 9a), *Stellaria longipes* (cf. 9b),
Taraxacum sp. (cf. 9f), *Viola adunca* (11h; ST),
Woodsia iivensis (NS), *Petasites sagittatus* (11i; AD),

Carex aquatilis (cf. 11j; LF), *Carex Bigelowii* (cf. 11k),
Carex glareosa (cf. 11k),
Carex membranaceae (cf. 11k),
Carex subspathacea (cf. 11k),
Carex saxatilis (11k; LF), *Carex scirpodea* (cf. 11k),
Carex nardina (cf. 11k), *Dupontia fisheri* (NS),
Hierochloë pauciflora (NS), *Larix laricina* (NS),
Poa pratensis (NS), *Puccinellia arctica* (NS),
Ranunculus flammula (NS),
Triglochin maritimum (11i; AB),
Eriophorum angustifolium (cf. 11m),
Eriophorum scheuchzeri (11m; ST),
Luzula confusa (11n; AB).

a Stomata absent**e** Long-cells angular or lobed**f** Long-cells angular

Hedysarum boreale (10j; ST),
Potamogeton filiformis (10k; ST),
Potentilla palustris (cf. 7o),
Saxifraga Aizoon (cf. 10g),
Vaccinium uliginosum (10i; AD),
Vaccinium vitis-idea (NS)
Andromeda polifolia (10m; AD),
Diapensia lapponica (cf. 9m),
Parnassia kotzebuei (10n; AB).

f Long-cells lobed**e** Long-cells rectangular or spindle-shaped**g** Long-cells spindle-shaped**g** Long-cells rectangular

Poa pratensis (10o; AD, below node).
Arctophila fulva (NS), *Carex Bigelowii* (NS),
Carex nardina (NS), *Carex salina* (NS),
Carex scirpodea (NS), *Diapensia lapponica* (NS),
Festuca rubra (NS), *Hedysarum alpinum* (NS),
Luzula confusa (NS), *Oxyria digyna* (NS),
Poa pratensis (11o; AD, basal), *Poa arctica* (NS),
Polygonum viviparum (NS),
Potamogeton filiformis (NS),
Puccinellia arctica (11p; AD, old),
Saxifraga Aizoon (NS), *Triglochin maritimum* (NS).

APPENDIX: NOTES

¹ UP = Ungava Peninsula, Rivière Caniapiscou (areas near 58° N, 70° W), muskox study 1996, collector: R. Pilote; KP = Kent Peninsula, Walker Bay Research Station (68° 21' N, 108° 04' W), goose study 1992–94, collector: S. Carrière; CM = central mainland Arctic, Bathurst Inlet (67° 39' N, 106° 23' W) and near Inuvik (69° 25' N, 122° 03' W), caribou study 1997, collector: F. Mueller.

² All specimens are available at Wildlife and Fisheries Division, Department of Resources, Wildlife and Economic Development, Government of the Northwest Territories, 600, 5102–50th Ave., Yellowknife, Northwest Territories X1A 3S8, Canada. p = whole dried plant(s); f = plant fragments; s = original microscopic slide.

³ Refers to figure number and photograph letter in Figs. 1–11. NS = no photographs are shown, but plant species is described in key.

⁴ Follows Porsild and Cody (1980) for synonymous names, or for main names if the species is not described in Cody (1996).

⁵ *C. Bigelowii* Torr. (Amphi-Atlantic distribution) was collected. *Carex consimilis* Holm (Amphi-Beringian distribution), a distinct species (Porsild and Cody, 1980), is listed here as a species with possibly similar microhistological characteristics.

APPENDIX

List of plant species included in the microhistological key, study area, specimen availability, and photographic reference. Names follow Cody (1996), except where noted. Wherever names in Porsild and Cody (1980) differ from Cody (1996), they are provided as a cross-reference.

Species	Study area ¹	Specimen Availability ²	Photo. Ref. ³	Species	Study area ¹	Specimen Availability ²	Photo. Ref. ³
1 <i>Achillea millefolium</i> L.	UP	f, s	5m	54 <i>Linnaea borealis</i> L.	UP	f, s	2k, 2l, 5c
2 <i>Alnus crispa</i> (Dryander ex Ait.) Pursh	UP	s	5h, 6p	55 <i>Loiseleuria procumbens</i> (L.) Desv.	UP	s	8a
3 <i>Alopecurus alpinus</i> J.E. Smith	KP	p, s	1e, 8e	56 <i>Luzula confusa</i> Lindebl.	KP	p, s	11n
4 <i>Andromeda polifolia</i> L.	CM	p, s	10m	57 <i>Mertensia maritima</i> (L.) S.F. Gray	UP	f, s	9o
5 <i>Anemone parviflora</i> Michx.	UP	s	6j	58 <i>Myosotis alpestris</i> Schm.	UP	f, s	11d, 4o
6 <i>Antennaria</i> sp. Gaertn.	CM	p, s	5i	59 <i>Oxyria digyna</i> (L.) J. Hill	UP	s	9p
7 <i>Arabis alpina</i> L. ⁴	UP	s	1n	60 <i>Oxytropis maydelliana</i> Trautv.	KP	p, s	6c
8 <i>Arctophila fulva</i> (Trin.) Rupr.	KP	p, s	8f, 3n	61 <i>Oxytropis nigrescens</i> (Fisch.)	KP	p, s	2i, 6e, 6l, 7d
9 <i>Arctostaphylos alpina</i> (L.) Spreng.	CM	p, s	7k, 9j, 11a	62 <i>Parnassia kotzebuei</i> Cham. & Schlecht.	CM	p, s	9c, 11e, 10n
10 <i>Arenaria longipedunculata</i> Hultén	UP	f, s	7i, 9l	63 <i>Pedicularis flammea</i> L. ⁴	UP	s	4g
<i>A. humifusa</i> Wahlenb. ⁴				64 <i>Pedicularis labradorica</i> Wirsing	UP	s	2a
11 <i>Arnica angustifolia</i> Vahl	UP	f, s	5a	65 <i>Pedicularis lanata</i> Cham. & Schlecht.	UP	s	NS
<i>A. alpina</i> (L.) Olin ⁴				66 <i>Pedicularis lapponica</i> L.	UP	s	2b
12 <i>Artemisia campestris</i> L. s.l.	UP	f, s	11b	67 <i>Pedicularis sudetica</i> Willd.	KP	p, s	4j
<i>A. canadensis</i> Michx. ⁴				68 <i>Petasites sagittatus</i> (Banks ex Pursh) Gray	UP	f, s	2m, 11i
13 <i>Astragalus alpinus</i> L.	KP	p, s	7a	69 <i>Phylodoce coerulea</i> (L.) Bab. ⁴	UP	s	3c, 3g
14 <i>Betula glandulosa</i> Michx.	UP	s	2p, 3a	70 <i>Poa pratensis</i> L.	KP	p, s	1b, 1c, 8b, 8m, 10o, 11o
15 <i>Calamagrostis stricta</i> (Timm) Koeler	KP	p, s	8j, 8n	<i>P. alpigena</i> (Fr.) Lindm. ⁴			
<i>C. neglecta</i> (Ehrh.) Gaertn., Mey. & Scherb. ⁴				71 <i>Poa arctica</i> R. Br. S.l.	KP	p, s	1i, 8c
16 <i>Cardamine digitata</i> Richards.	KP	s	9h	72 <i>Polygonum viviparum</i> L.	UP	s	10a
17 <i>Carex aquatilis</i> Wahlenb.	CM	p, s	3k	73 <i>Potamogeton filiformis</i> Pers.	KP	p, s	10k
18 <i>Carex Bigelowii</i> Torr. ⁴	KP	p, s	3h	74 <i>Potentilla nivea</i> L.	KP	p, s	6a, 6n
? <i>C. consimilis</i> Holm ⁵				75 <i>Potentilla norvegica</i> L.	UP	s	5k
19 <i>Carex glareosa</i> Wahlenb.	KP	p, s	3l	76 <i>Potentilla palustris</i> (L.) Scop.	UP	s	5j, 7o
20 <i>Carex membranacea</i> Hook.	CM	p, s	c.f. 11k	77 <i>Primula incana</i> M.E. Jones	KP	f, s	2n, 9i, 10b
21 <i>Carex nardina</i> Fries	KP	p, s	8g	78 <i>Puccinellia arctica</i> (Hook.) Fern. & Weath.	KP	p, s	3o, 3p
22 <i>Carex subspatheacea</i> Wormskj.	KP	p, s	3i, 3m, 8o	79 <i>Puccinellia phryganodes</i> (Trin.) Scribn. & Merr.	KP	p, s	1a, 1h
23 <i>Carex saxatilis</i> L.	UP	s	11k	80 <i>Pyrola asarifolia</i> Michx.	CM	p, s	9d, 10i
24 <i>Carex scirpodea</i> Michx.	KP	p, s	8h, 11j	81 <i>Pyrola minor</i> L.	CM	p, s	7j, 10c
25 <i>Cassiope tetragona</i> (L.) Moench	UP	s	4a, 4b	82 <i>Ranunculus flammula</i> L.	CM	p, s	NS
26 <i>Castilleja</i> sp. Mutis	UP	s	4d	83 <i>Ranunculus lapponicus</i> L.	UP	s	10d
27 <i>Cerastium alpinum</i> L. s. lat. ⁴	UP	f, s	2c	84 <i>Ranunculus pedatifidus</i> Sm.	KP	p, s	5o, 6g
28 <i>Cerastium beeringianum</i> Cham. & Schlecht.	CM	p, s	2f, 4e, 4f	85 <i>Rhinanthus</i> sp. L.	UP	s	4h
29 <i>Diapensia lapponica</i> L.	CM	p, s	9m, 11c, 10n	86 <i>Rhododendron lapponicum</i> (L.) Wahlenb.	UP	s	2o
30 <i>Draba alpina</i> L.	UP	s	1l	87 <i>Rubus arcticus</i> L.	UP	s	5f
31 <i>Draba aurea</i> M. Vahl	KP	p, s	1o	<i>R. acaulis</i> Michx. ⁴			
32 <i>Draba longipes</i> Raup	UP	s	1m	88 <i>Rubus chamaemorus</i> L.	UP	s	5l
33 <i>Dryas integrifolia</i> M. Vahl	UP	f, s	7b	89 <i>Salix arctica</i> Pall.	KP	p, s	5n, 10e
34 <i>Dryas</i> sp. L.	CM	p, s	5d	90 <i>Salix arctophila</i> Cockerell	UP	s	5g
35 <i>Dupontia fisheri</i> R. Br. s. l.	KP	p, s	1f, 8k, 9k,	91 <i>Salix glauca</i> L. s. l.	UP	s	6m-n
36 <i>Elymus trachycaulus</i> (Link) Gould ex Shinnars	KP	p, s	8d	92 <i>Salix lanata</i> L.	KP	p, s	5e, 7m
<i>Agropyron trachycaulum</i> (Link) Malte ⁴				93 <i>Salix planifolia</i> Pursh	UP	s	6o
37 <i>Empetrum nigrum</i> L.	CM	p, s	2h, 6d	94 <i>Salix reticulata</i> L.	UP	s	10f
38 <i>Epilobium latifolium</i> L.	UP	f, s	6k	95 <i>Salix uva-ursi</i> Pursh	UP	s	7n
39 <i>Epilobium palustre</i> L.	CM	p, s	6b	96 <i>Saxifraga aizoides</i> L.	UP	s	4c, 11f
40 <i>Equisetum arvense</i> L.	UP	f, s	3j	97 <i>Saxifraga aizoon</i> Jacq. ⁴	UP	f, s	10g
41 <i>Eriophorum angustifolium</i> Honckn.	KP	p, s	c.f. 11k	98 <i>Saxifraga cernua</i> L.	UP	f, s	4l, 5b
42 <i>Eriophorum scheuchzeri</i> Hoppe	CM	p, s	11m	99 <i>Saxifraga tricuspidata</i> Rottb.	UP	s	3e, 3f
43 <i>Eriophorum vaginatum</i> L.	CM	p, s	8j	100 <i>Senecio congestus</i> (R. Br.) DC.	KP	p, s	4k
44 <i>Euphrasia subarctica</i> Raup	UP	s	2j	101 <i>Senecio pauciflorus</i> Pursh	UP	f, s	9e, 11g
<i>E. arctica</i> Lange ⁴				102 <i>Silene acaulis</i> L.	CM	p, s	7e, 7g
45 <i>Festuca brachyphylla</i> Schultes & Schultes fil.	KP	p, s	1d	103 <i>Solidago multiradiata</i> Ait.	UP	f, s	4n
46 <i>Festuca rubra</i> L. s.l.	KP	p, s	1k, 8l	104 <i>Stellaria humifusa</i> Rottb.	KP	p, s	9a
47 <i>Hedysarum alpinum</i> L.	CM	p, s	9n	105 <i>Stellaria longipes</i> Goldie s.l.	UP	f, s	9b
48 <i>Hedysarum boreale</i> Nutt.	KP	p, s	8i, 10j	106 <i>Taraxacum</i> sp. Wiggers	UP	f, s	6f, 9f, 10h
<i>H. mackenzii</i> Richards. ⁴				107 <i>Triglochin maritimum</i> L.	UP	f, s	11l
49 <i>Hierochloë pauciflora</i> R. Br.	KP	p, s	1g	108 <i>Vaccinium uliginosum</i> L. s.l.	UP	s	10l
50 <i>Hippuris vulgaris</i> L.	KP	p, s	3d	109 <i>Vaccinium vitis-idaea</i> L.	UP	s	3b
51 <i>Larix laricina</i> (Du Roi) K. Koch	UP	s	NS	110 <i>Veronica wormskjoldii</i> Roem. & Schult.	UP	s	2e, 4i, 4m
52 <i>Ledum decumbens</i> (Ait.) Lodd.	UP	s	2g, 7c, 7f, 7l	111 <i>Viola adunca</i> J.E. Smith	UP	f, s	9g, 11h
53 <i>Leymus mollis</i> (Trin.) Pilger	KP	p, s	1j, 8p	112 <i>Woodsia iivensis</i> (L.) R. Br.	UP	s	7h
<i>Elymus arenarius</i> L. ⁴							

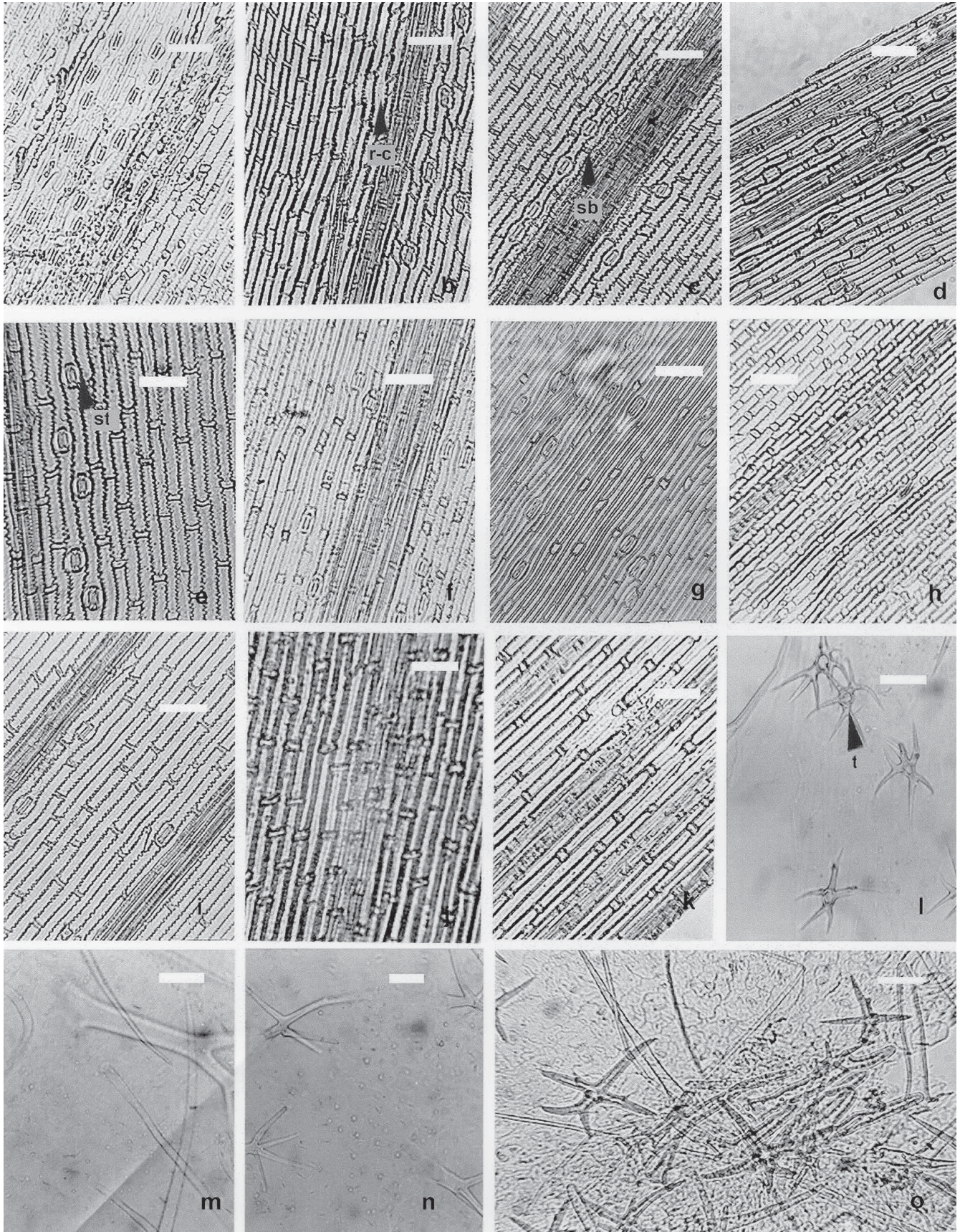


FIG. 1. *Puccinellia phryganodes* (a), *Poa pratensis* (b, c), *Festuca brachyphylla* (d), *Alopecurus alpinus* (e), *Dupontia fisheri* (f), *Hierochloë pauciflora* (g), *Puccinellia phryganodes* (h), *Poa arctica* (i), *Leymus mollis* (j), *Festuca rubra* (k), *Draba alpina* (l), *Draba longipes* (m), *Arabis alpina* (n), *Draba aurea* (o). White bars are 100 μm long.

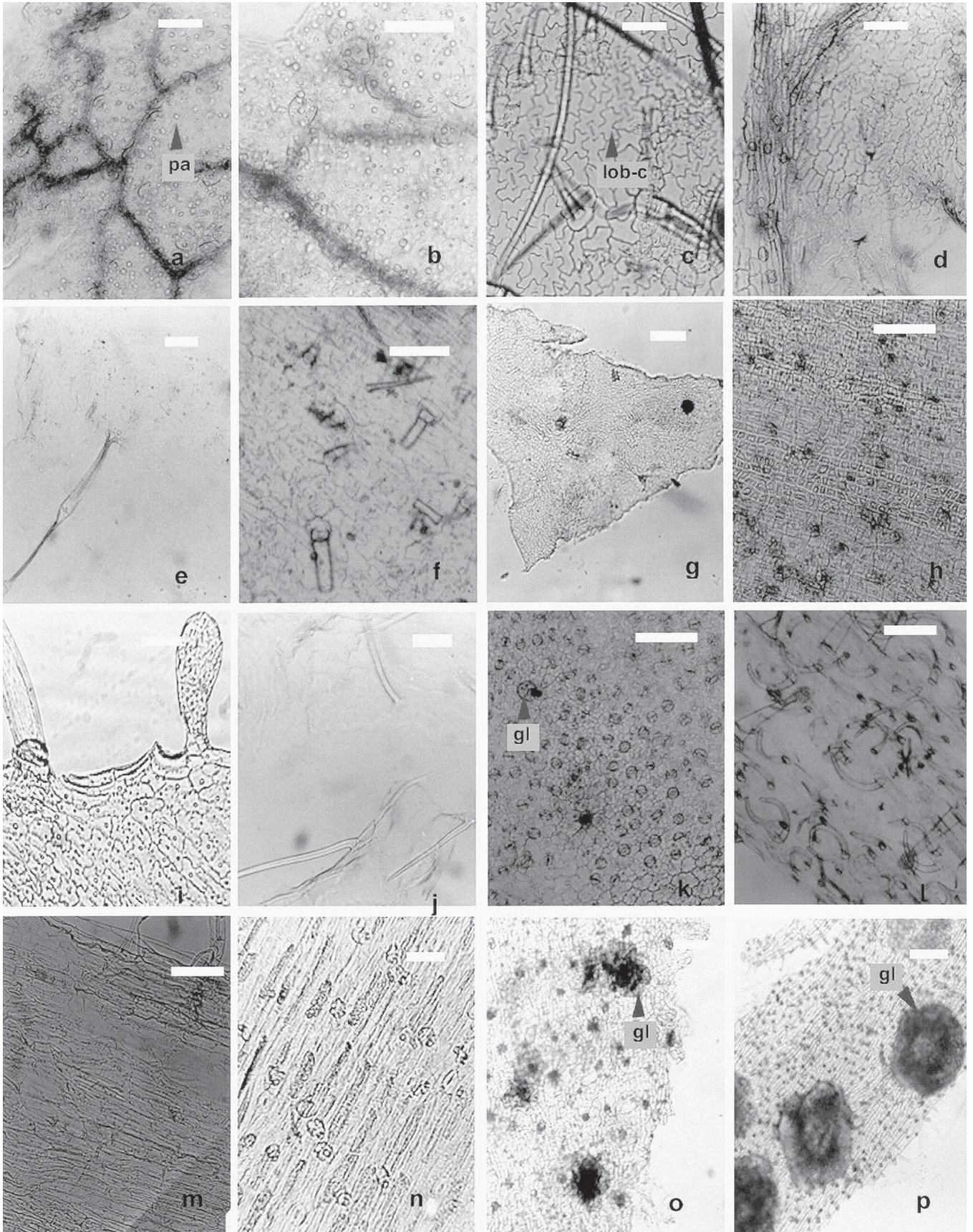


FIG. 2. *Pedicularis labradorica* (a), *Pedicularis lapponica* (b), *Cerastium alpinum* (c), *Rhinantus* spp. (d), *Veronica wormskjoldii* (e), *Cerastium beeringianum* (f), *Ledum decumbens* (g), *Empetrum nigrum* (h), *Oxytropis nigrescens* (i), *Euphrasia subarctica* (j), *Linnaea borealis* (k,l), *Petasites sagittatus* (m), *Primula incana* (n), *Rhododendron lapponicum* (o), *Betula glandulosa* (p). White bars are 100 μm long.

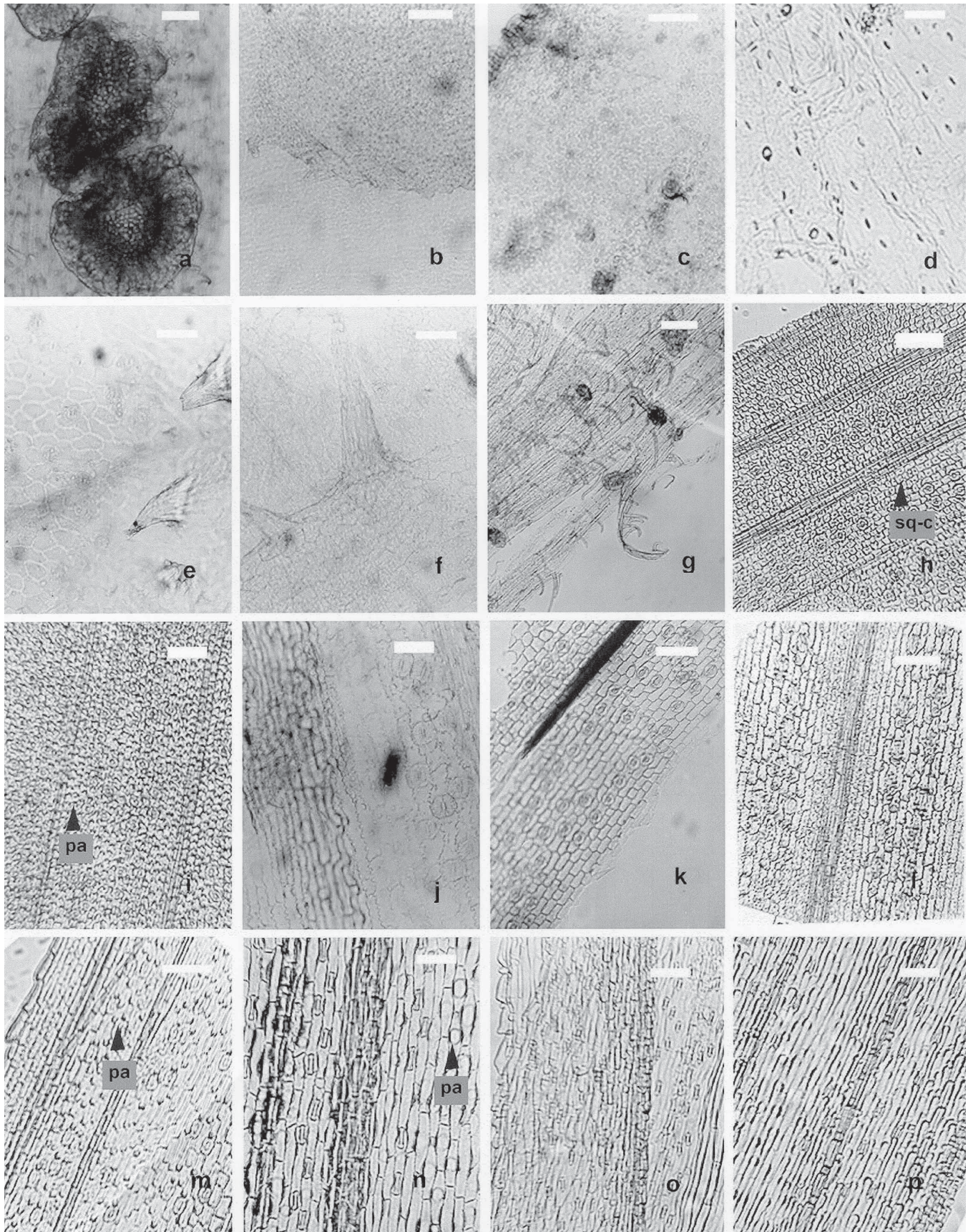


FIG. 3. *Betula glandulosa* (a), *Vaccinium vitis-idaea* (b), *Phyllococe coerulea* (c, g), *Hippuris vulgaris* (d), *Saxifraga tricuspidata* (e, f), *Carex Bigelowii* (h), *Carex subspathacea* (i), *Equisetum arvense* (j), *Carex aquatilis* (k), *Carex glareosa* (l), *Carex subspathacea* (m), *Arctophila fulva* (n), *Puccinellia arctica* (o, p). White bars are 100 μ m long.

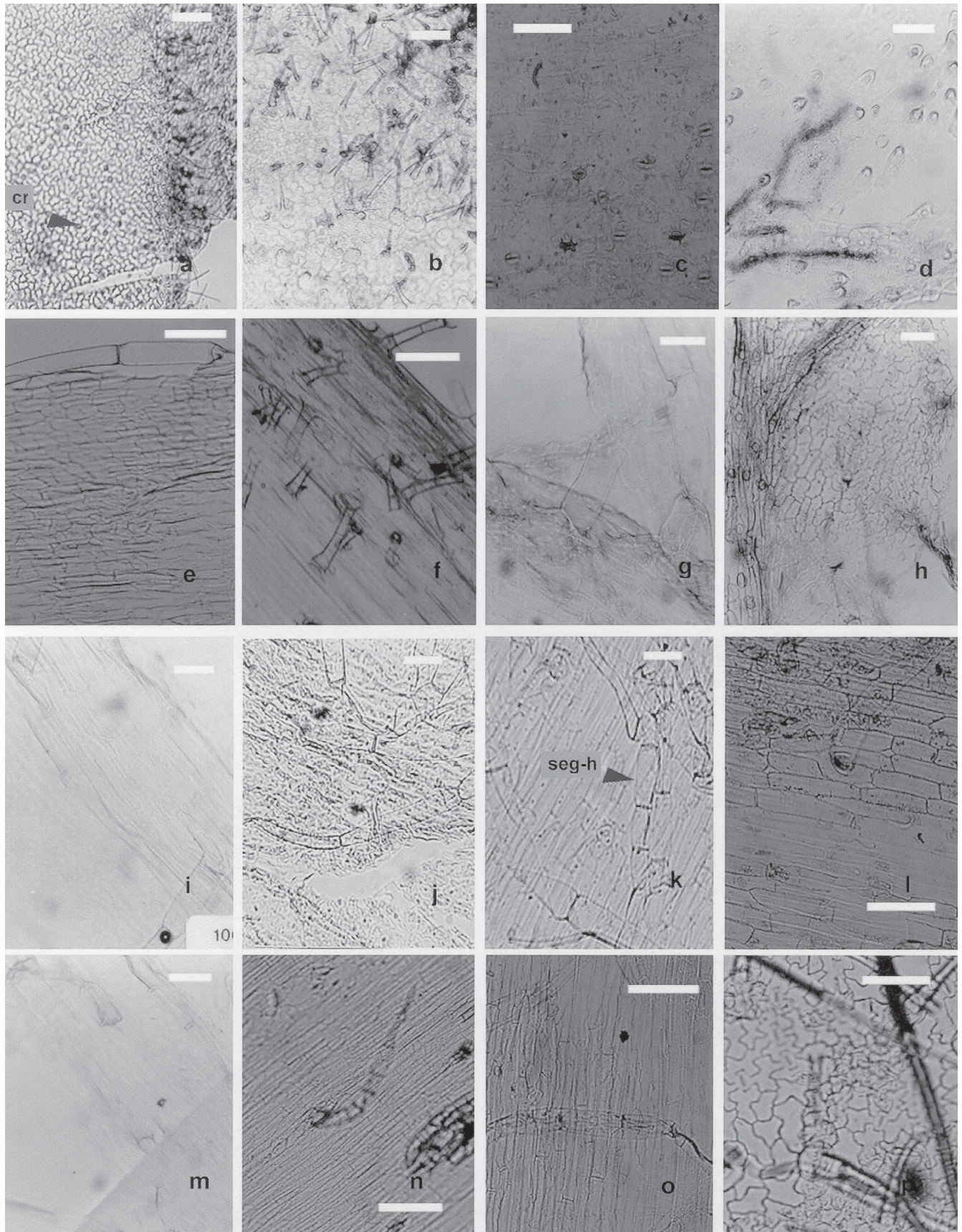


FIG. 4. *Cassiope tetragona* (a, b), *Saxifraga aizoides* (c), *Castilleja* sp.(d), *Cerastium beeringianum* (e, f), *Pedicularis flammea* (g), *Rhinanthus* sp. (h), *Veronica wormskjoldii* (i), *Pedicularis sudetica* (j), *Senecio congestus* (k), *Saxifraga cernua* (l), *Veronica wormskjoldii* (m), *Solidago multiradiata* (n), *Myosotis alpestris* (o), *C. alpinum* (p). White bars are 100 μ m long.

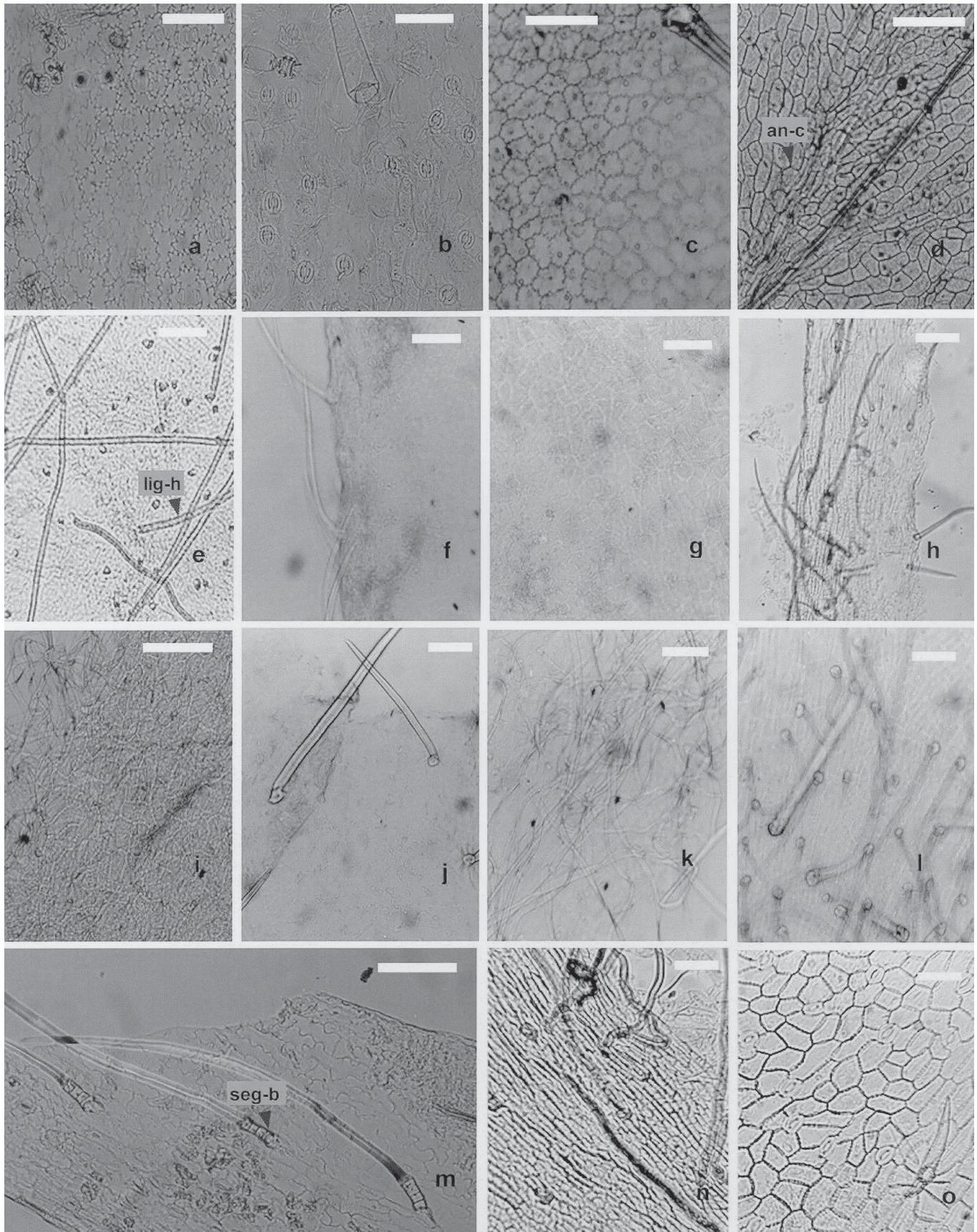


FIG. 5. *Arnica angustifolia* (a), *Saxifraga cernua* (b), *Linnaea borealis* (c), *Dryas* sp. (d), *Salix lanata* (e), *Rubus arcticus* (f), *Salix arctophila* (g), *Alnus crispa* (h), *Antennaria* sp. (i), *Potentilla palustris* (j), *Potentilla norvegica* (k), *Rubus chamaemorus* (l), *Achillea millefolium* (m), *Salix arctica* (n), *Ranunculus pedatifidus* (o). White bars are 100 μm long.

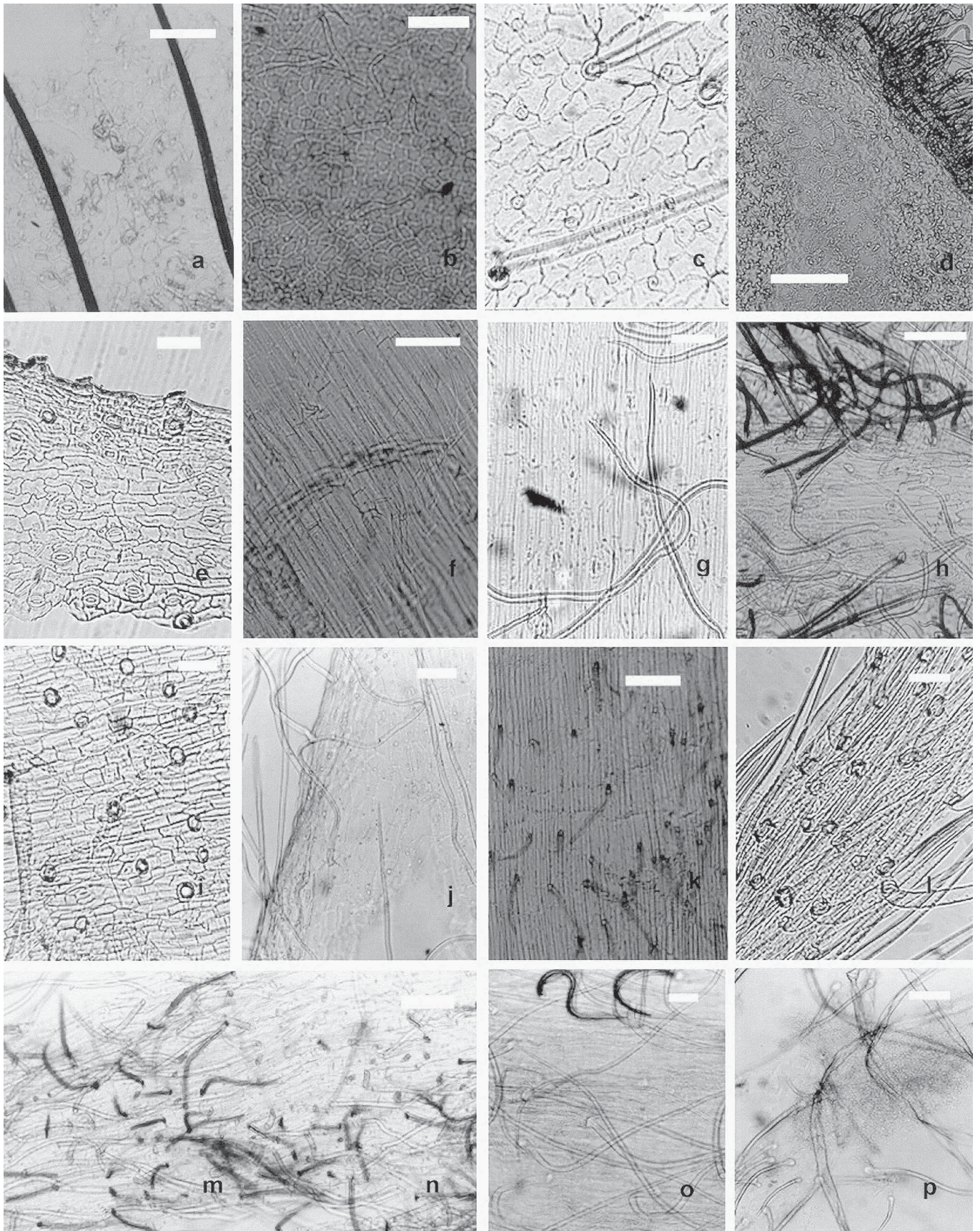


FIG. 6. *Potentilla nivea* (a), *Epilobium palustre* (b), *Oxytropis maydelliana* (c), *Empetrum nigrum* (d), *Oxytropis nigrescens* (e), *Taraxacum* sp. (f), *Ranunculus pedatifidus* (g), *Potentilla nivea* (h), *Hedysarum boreale* (i), *Anemone parviflora* (j), *Epilobium latifolium* (k), *Oxytropis nigrescens* (l), *Salix glauca* (m, n), *Salix planifolia* (o), *Alnus crispa* (p). White bars are 100 μ m long.

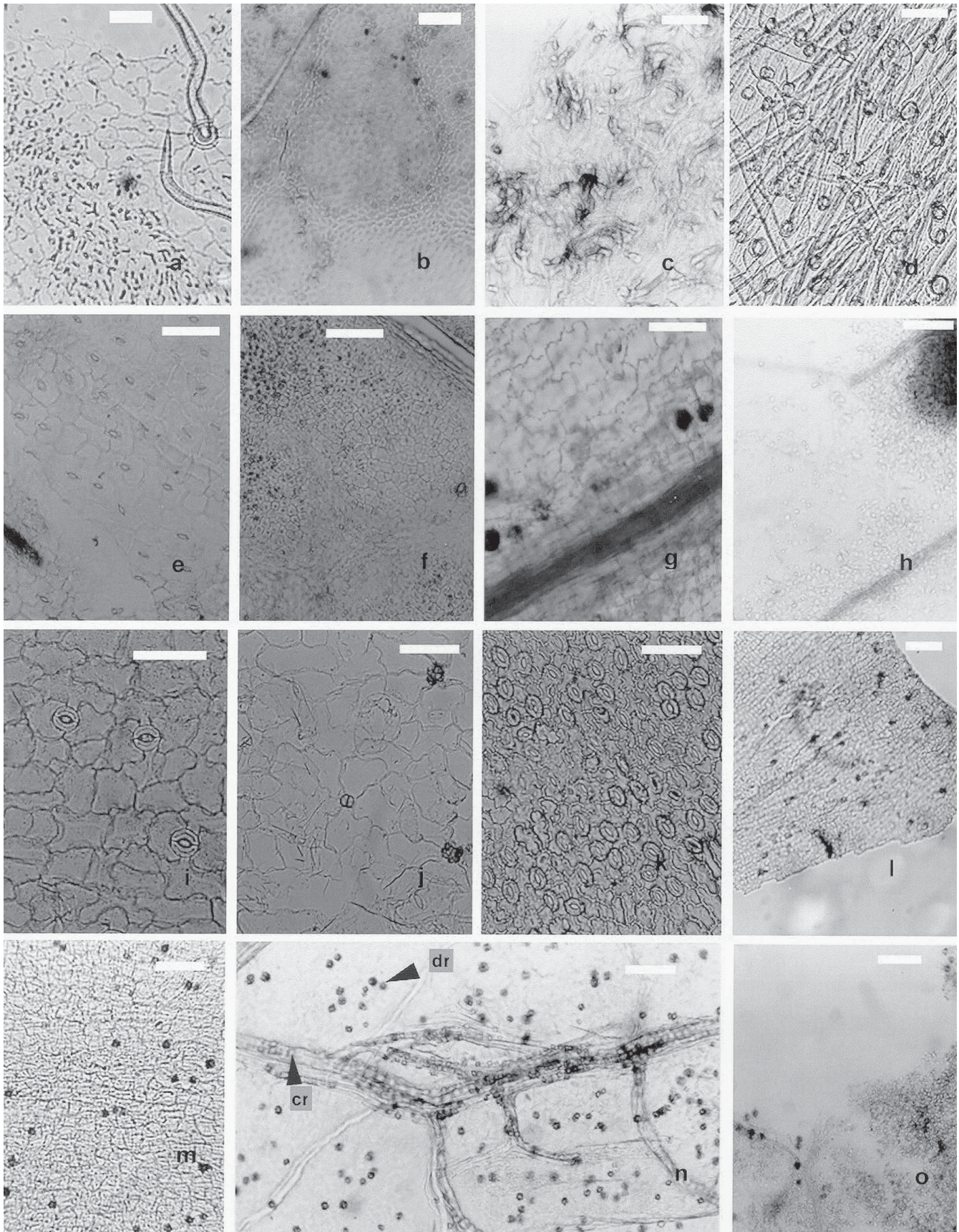


FIG. 7. *Astragalus alpinus* (a), *Dryas integrifolia* (b), *Ledum decumbens* (c), *Oxytropis nigrescens* (d), *Silene acaulis* (e), *Ledum decumbens* (f), *Silene acaulis* (g), *Woodsia iivensis* (h), *Arenaria longipedunculata* (i), *Pyrola minor* (j), *Arctostaphylos alpina* (k), *Ledum decumbens* (l), *Salix lanata* (m), *Salix uva-ursi* (n), *Potentilla palustris* (o). White bars are 100 μm long.

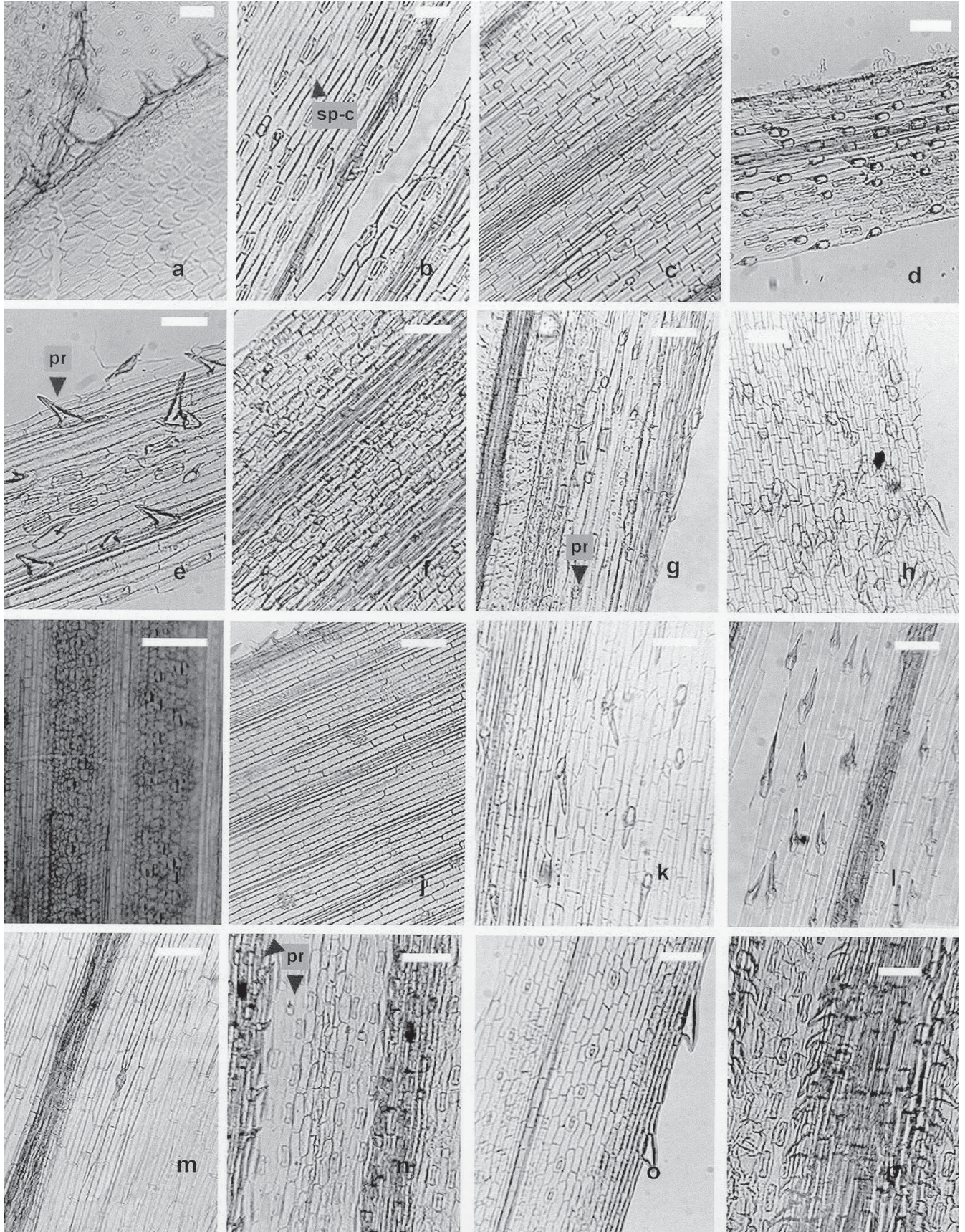


FIG. 8. *Loiseleuria procumbens* (a), *Poa pratensis* (b), *Poa arctica* (c), *Elymus trachycaulum* (d), *Alopecurus alpinus* (e), *Arctophila fulva* (f), *Carex nardina* (g), *Carex scirpodea* (h), *Eriophorum vaginatum* (i), *Calamagrostis stricta* (j), *Dupontia fisheri* (k), *Festuca rubra* (l), *Poa pratensis* (m), *Calamagrostis stricta* (n), *Carex subspathacea* (o), *Leymus mollis* (p). White bars are 100 μ m long.

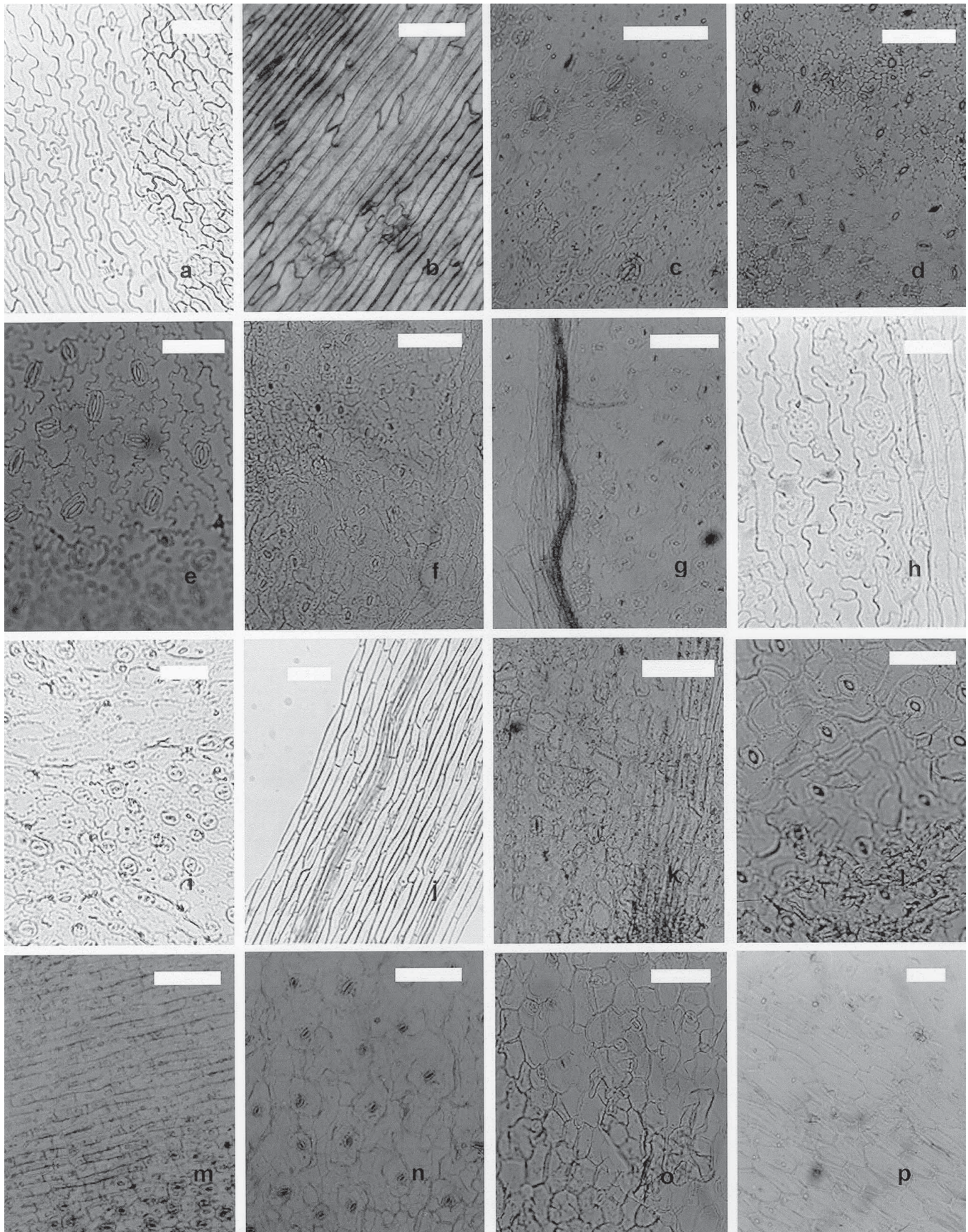


FIG. 9. *Stellaria humifusa* (a), *Stellaria longipes* (b), *Parnassia kotzebuei* (c), *Pyrola asarifolia* (d), *Senecio pauciflorus* (e), *Taraxacum* sp. (f), *Viola adunca* (g), *Cardamine digitata* (h), *Primula incana* (i), *Arctostaphylos alpina* (j), *Dupontia fisheri* (k), *Arenaria longipedunculata* (l), *Diapensia lapponica* (m), *Hedysarum alpinum* (n), *Mertensia maritima* (o), *Oxyria digyna* (p). White bars are 100 μ m long.

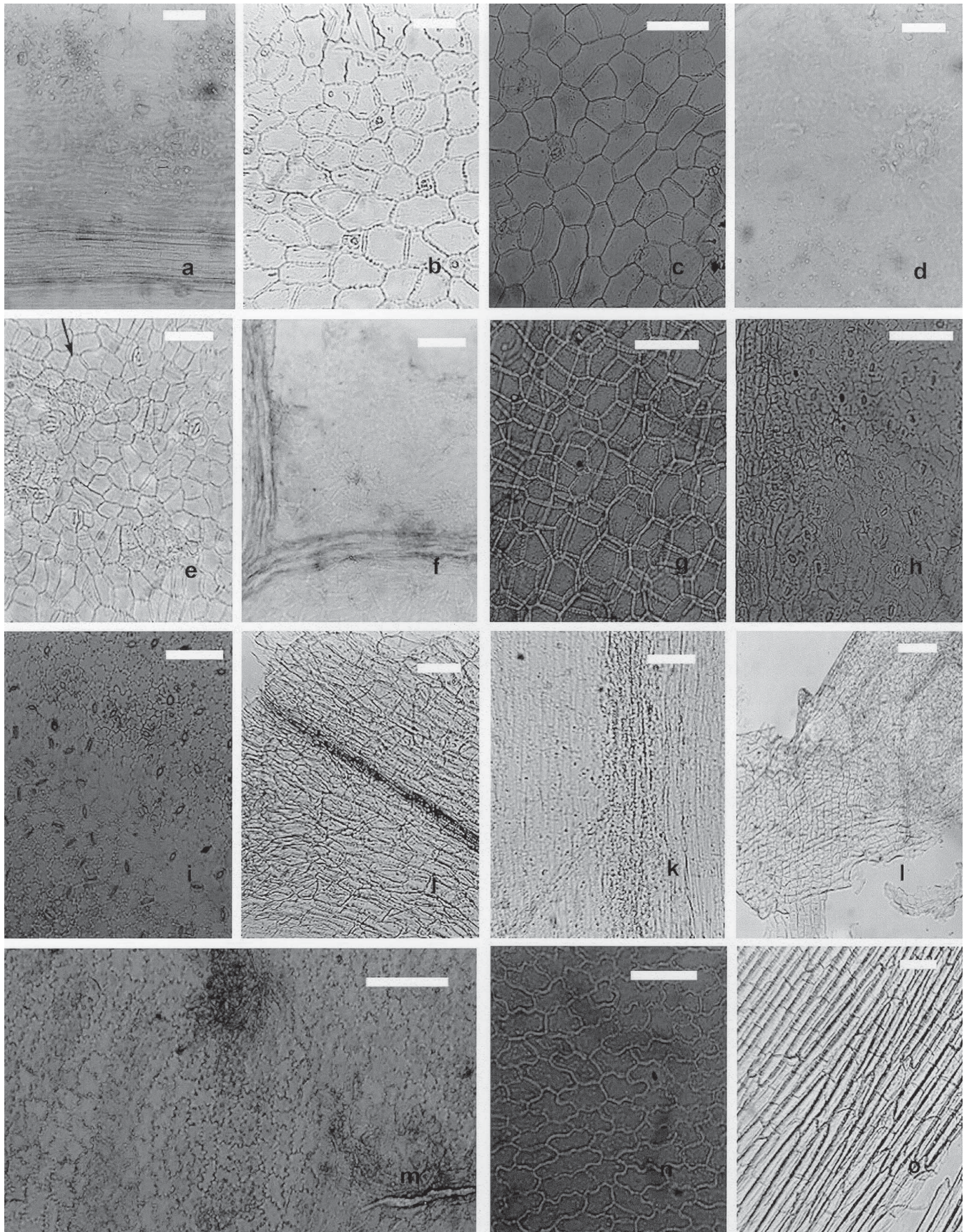


FIG. 10. *Polygonum viviparum* (a), *Primula incana* (b), *Pyrola minor* (c), *Ranunculus lapponica* (d), *Salix arctica* (e), *Salix reticulata* (f), *Saxifraga aizoon* (g), *Taraxacum* sp. (h), *Pyrola asarifolia* (i), *Hedysarum boreale* (j), *Potamogeton filiformis* (k), *Vaccinium uliginosum* (l), *Andromeda polifolia* (m), *Parnassia kotzebuei* (n) *Poa pratensis* (o). White bars are 100 μ m long.

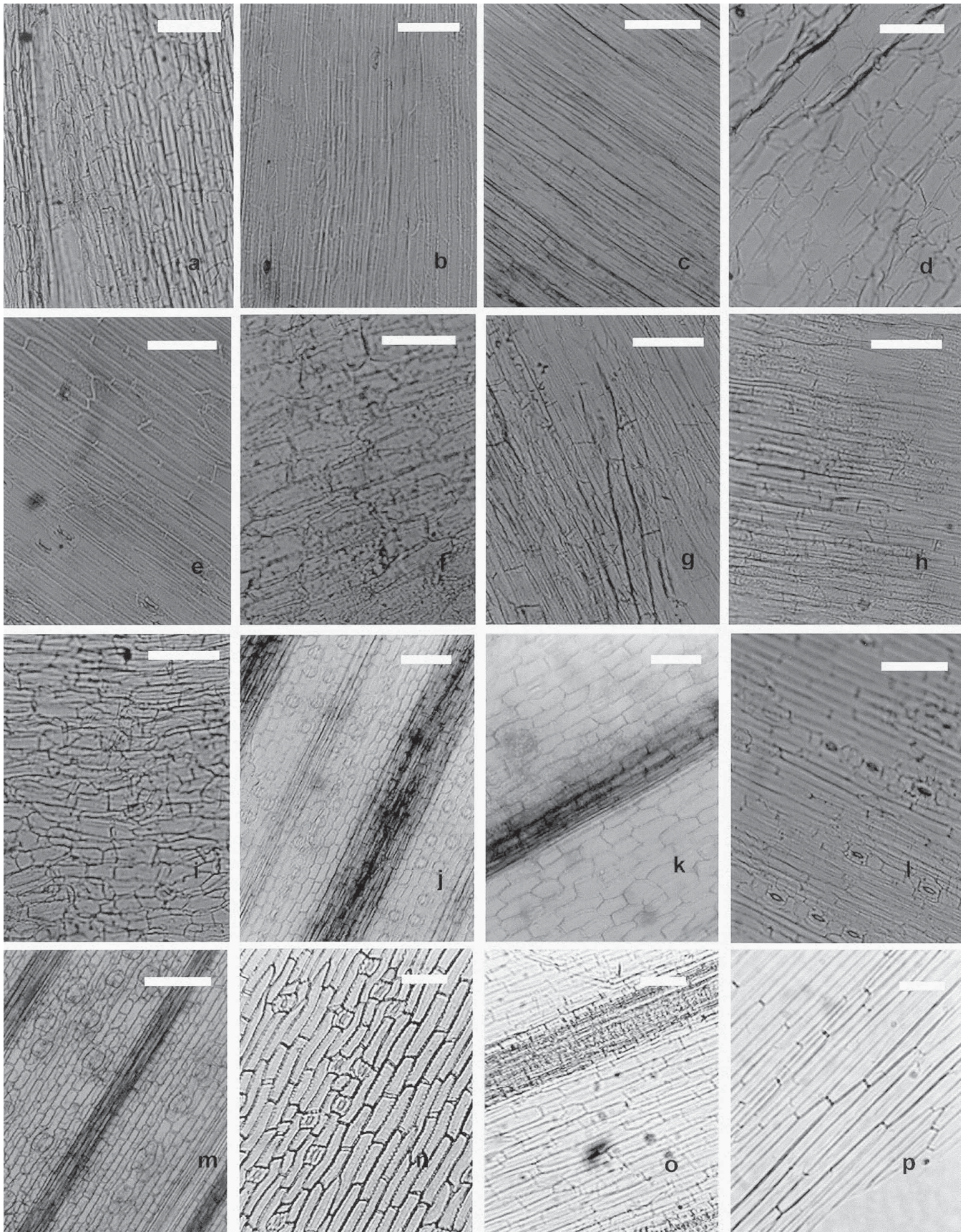


FIG. 11. *Arctostaphylos alpina* (a), *Artemisia campestris* (b), *Diapensia lapponica* (c), *Myosotis alpestris* (d), *Parnassia kotzebuei* (e), *Saxifraga aizoides* (f), *Senecio pauciflorus* (g), *Viola adunca* (h), *Petasites sagittatus* (i), *Carex scirpodea* (j), *Carex* sp. (k), *Triglochin maritimum* (l), *Eriophorum* sp. (m), *Luzula confusa* (n), *Poa pratensis* (o), *Puccinellia arctica* (p). White bars are 100 μ m long.