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Crystals in North American Commercial Woods of *Abies* Species

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북미산 주요 전나무속 수종 목재에 있어서의 결정

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ABSTRACT

Crystal-bearing cells are rarely encountered in the softwoods and their regular occurrence, e.g., in species of *Abies, Picea, Ginkgo*, and *Pinus*, is of considerable diagnostic significance. Thus, this study discusses the distribution and types of crystals in North American *Abies* species to provide additional information for wood anatomy and identification through light and scanning electron microscopies. Prismatic crystals, elongate crystals, and styloids are identified, in descending order of frequency, in *Abies concolor, A. grandis* and *A. magnifica, A. nobilis* (=*A. procera*), *A. lasiocarpa*, and *A. amabilis* but not in *A. balsamea* and *A. fraseri*. Differently from the other species, *A. lasiocarpa* shows the tendency of more elongate crystals and styloids than prismatic crystals. *A. concolor* contains crystal sands, prismatic crystals, elongate crystals, and styloids both in the axial and ray parenchyma cells, whereas the other species show prismatic crystals, elongate crystals, and styloids only in the ray parenchyma cells. Ray parenchyma cells containing crystal sand and axial parenchyma cells having crystal sand, prismatic crystals, elongate crystals, and styloids are probably reported here for the first time in *A. concolor*. In conclusion, the presence or absence of crystals appears to be the most powerful diagnostic character for separating *A. concolor, A. grandis*, and *A. magnifica* from *A. nobilis* (=*A. procera*), *A. lasiocarpa, A. amabilis, A. balsamea*, and *A. fraseri*.

Keywords : Axial and ray parenchyma cells, Crystals, North American *Abies* species, Wood identification

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INTRODUCTION

Crystals in softwoods have been known to occur rarely, being limited to the species of *Abies, Cedrus, Ginkgo, Keteleeria, Picea, Pinus*, and *Pseudolarix*. Sudo (1968) found crystals in the ray parenchyma cells of *Picea sitchensis*, and Core et al. (1979) reported rhomboidal and rectangular crystals were rather common in some species of *Abies*. Panshin and de Zeeuw (1980) stated that crystals were present only in the ray parenchyma of some North American softwoods and are also found even in the longitudinal tracheids of Eastern Asian, monotypic genus *Pseudolarix*. Kellogg et al. (1982) and Baas et al. (1986) found styloids in the resin canal complexes of *Pinus flexilis* and *Pinus longaeva*, respectively. Wheeler et al. (1986) reported crystals in ray cells of *Abies, Cedrus, Keteleeria, Picea*, and *Pseudolarix*. Lee and Eom (1987) and Lee et al. (1988) reported that druses are present in the idioblasts formed by metamorphosis of strands of axial parenchyma of *Ginkgo biloba* and polyhedral crystals, styloids, and aciculars in ray parenchyma cells of *Abies holophylla*.

IAWA Committee (2004) commented that crystals in softwoods appeared to occur only in a single cell type in a given taxon, prismatic crystals were more or less common in marginal and submarginal ray cells in some species of Pinaceae, and that those cells containing one or more crystals were not subdivided.

Panshin and de Zeeuw (1980) felt that these crystals in softwoods were of no diagnostic significance because of their rare encounter, but Core et al. (1979) and IAWA Committee (1989) concluded that their regular occurrence was of considerable diagnostic value in *Abies, Picea*, and *Ginkgo biloba*. Wiedenhoeft et al. (2003) found small elongate crystals in the subsidiary parenchyma of resin canal complexes of *Pinus contorta* but not in those of *Pinus ponderosa* and insisted that their presence or absence appeared to be the most powerful diagnostic character for separating these woods.

Especially in the North American genus *Abies*, Kukachka (1960) concluded that crystals were absent in ray parenchyma cells of *A. balsamea, A. fraseri*, and *A. lasiocarpa* but present in *A. amabilis, A. concolor, A. grandis, A. magnifica, A. bracteata*, and *A. procera*. Kennedy et al. (1968) noted the regular occurrence of crystals of rhomboidal and elongated forms in *A. concolor, A. grandis, A. magnifica, A. bracteata*, and *A. procera* but regular absence in *A. amabilis, A. balsamea, A. fraseri*, and *A. lasiocarpa*. They also found that crystals were deposited predominantly in the marginal ray parenchyma cells which died prematurely within a critical zone of sapwood and a pattern of very infrequent crystal distribution was found in association with immature wood in *A. grandis* and in seedlings or saplings of several species. In the earlier studies, however, Wiesehugel (1932) reported their regular occurrence only in *A. concolor, A. magnifica*, and *A. bracteata*.

This study discusses the distribution and types of crystals in North American *Abies* species to provide additional information for wood anatomy and identification through light and scanning electron microscopies.

MATERIALS AND METHODS

Wood samples of genus *Abies* (Table 1) were obtained from the H.P. Brown Memorial Wood Collection of the Faculty of Construction Management and Wood Products Engineering, College of Environmental Science and Forestry, State University of New York, Syracuse, NY 13210, U.S.A.

Small cubes of about 10 mm per side were prepared and softened in water in an autoclave. For light microscopy, radial and tangential sections 25 to 30 μm thick were cut with a sliding microtome, followed by staining with safranin O and dehydration in an ethanol and xylene series. Finally, permanent slides were prepared with Permount mounting media in accordance with

general laboratory techniques (Japan Wood Research Society, 1985; Eom and Butterfield, 1997). For photography, a Spot-RT digital camera was used with a Nikon Optiphot light microscope equipped with DIC (Nomarski) optics. For scanning electron microscopy, clean cut and split surfaces for observation were made in the radial surface of the above softened small cubes. After removal of unwanted wood, the specimens were oven-dried at 100°C, glued to specimen stubs with conductive carbon paint, sputter-coated with gold-palladium to a thickness of 30 nm using a Denton Desk II Cold Sputter Unit (Exley et al., 1974, 1977; Eom and Butterfield, 1997), and photographed in a JSM-5800LV Scanning Microscope, JEOL, at 15 to 20 kV.

Table 1. Woods of *Abies* species used in this study

Sample No.[1]	Origin	Species
8800	Canada	*A. amabilis*
8446	U.S.A.	*A. amabilis*
8660	U.S.A.	*A. balsamea*
8540	U.S.A.	*A. concolor*
8662	U.S.A.	*A. fraseri*
8366	Canada	*A. grandis*
8041	U.S.A.	*A. lasiocarpa*
8328	U.S.A.	*A. magnifica*
8237	U.S.A.	*A. nobilis* (=*Abies procera*)

[1]H.P. Brown Memorial Wood Collection accession number

RESULTS AND DISCUSSION

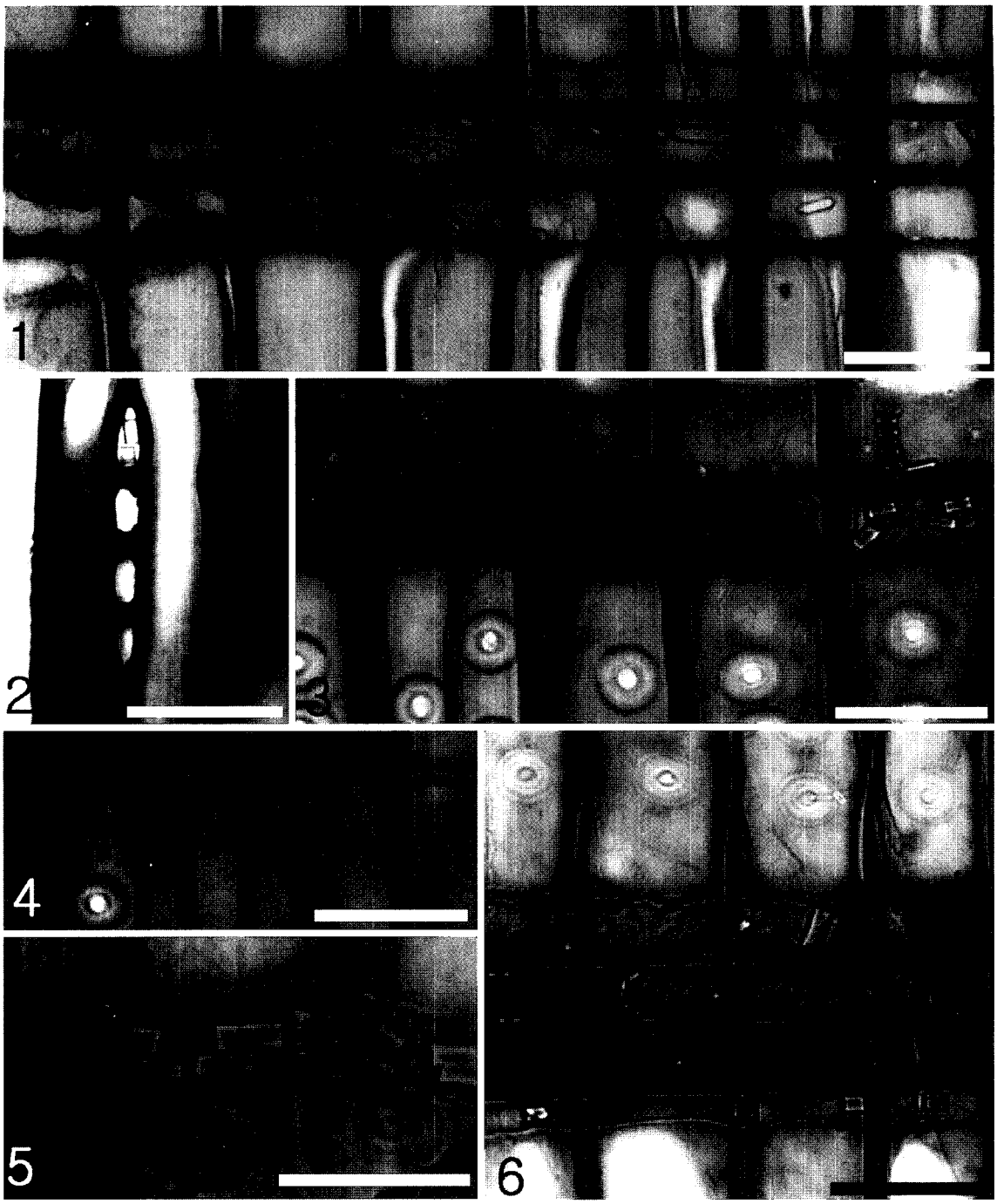
Elongate crystals and styloids as well as prismatic crystals (IAWA Committee, 1989, 2004) were identified, in descending order of frequency, in *Abies concolor, A. grandis* and *A. magnifica, A. nobilis* (=*A. procera*), *A. lasiocarpa*, and *A. amabilis* but not in *A. baslamea* and *A. fraseri* (Table 2 & Figs. 1-17). This, except for *A. amabilis*, roughly agrees with the statement of Kennedy et al. (1968) that crystal frequency is in descending order of *A. concolor, A. grandis, A. magnifica, A. bracteata*, and *A. procera* but crystals are absent or extremely sparse in *A. amabilis, A. balsamea, A. fraseri*, and *A. lasiocarpa*. Wiesehuegel (1932) claimed that crystals were regularly present only in *A. concolor, A. magnifica*, and *A. bracteata*. Kukachka (1960) also noted that crystals appeared most commonly and abundantly in *A. concolor* and *A. magnifica*.

Differently from the other species, *A. lasiocarpa* shows the tendency of more styloids and elongate crystals than prismatic crystals (Fig. 5). Kennedy et al. (1968) noted more rhomboidal crystals than elongated ones except in *A. lasiocarpa*, as in our present results. They also noted that *A. amabilis, A. balsamea, A. fraseri*, and *A. lasiocarpa* were typified by the complete

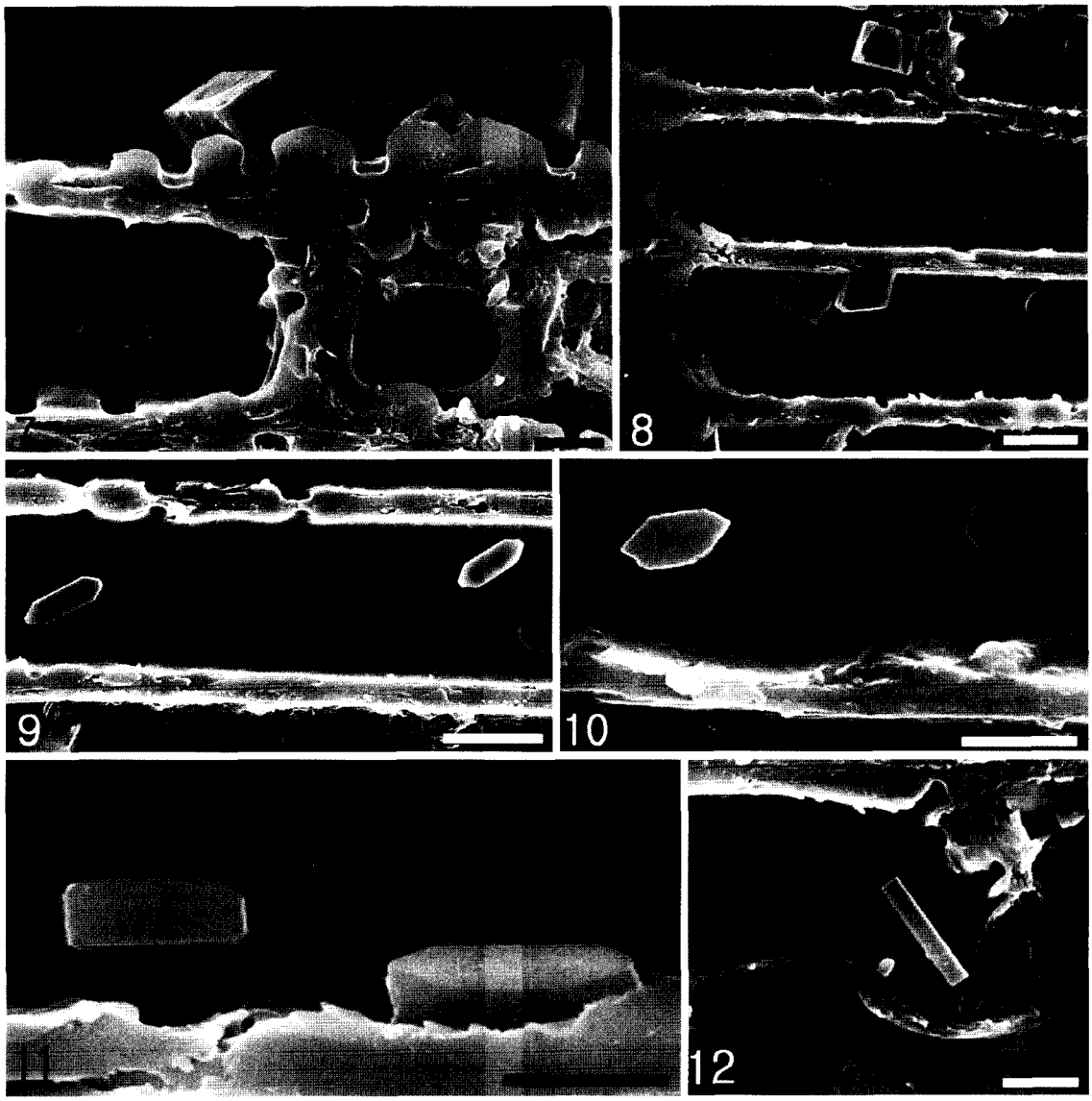
Table 2. Comparison of crystal frequency in woods of *Abies* species between some earlier and our present studies

Species	Kennedy et al. (1968)	Kukachka (1960)	Wiesehuegel (1932)	Ours
A. amabilis	Absent or extremely sparse	Sparse or infrequent	Absent	Absent or extremely sparse*
A. balsamea	Absent or extremely sparse	Absent	Absent	Absent
A. bracteata	Infrequent	–	Regularly present	–
A. concolor	Very frequent	Common to abundant	Regularly present	Very frequent*,+
A. fraseri	Absent or extremely sparse	Absent	Absent	Absent
A. grandis	Frequent	Sparse or infrequent	Absent	Frequent*
A. lasiocarpa	Absent or extremely sparse	Absent	Absent	Extremely sparse**
A. magnifica	Frequent	Common to abundant	Regularly present	Frequent*
Abies nobilis (=*A. procera*)	Infrequent	Sparse or infrequent	Absent	Somewhat frequent*

*=more prismatic crystals than elongate crystals and styloids in ray parenchyma cells
**=more elongate crystals and styloids than prismatic crystals in ray parenchyma cells
+=occurrence of crystal sand, prismatic crystals, elongate crystals, and styloids in axial and ray parenchyma cells



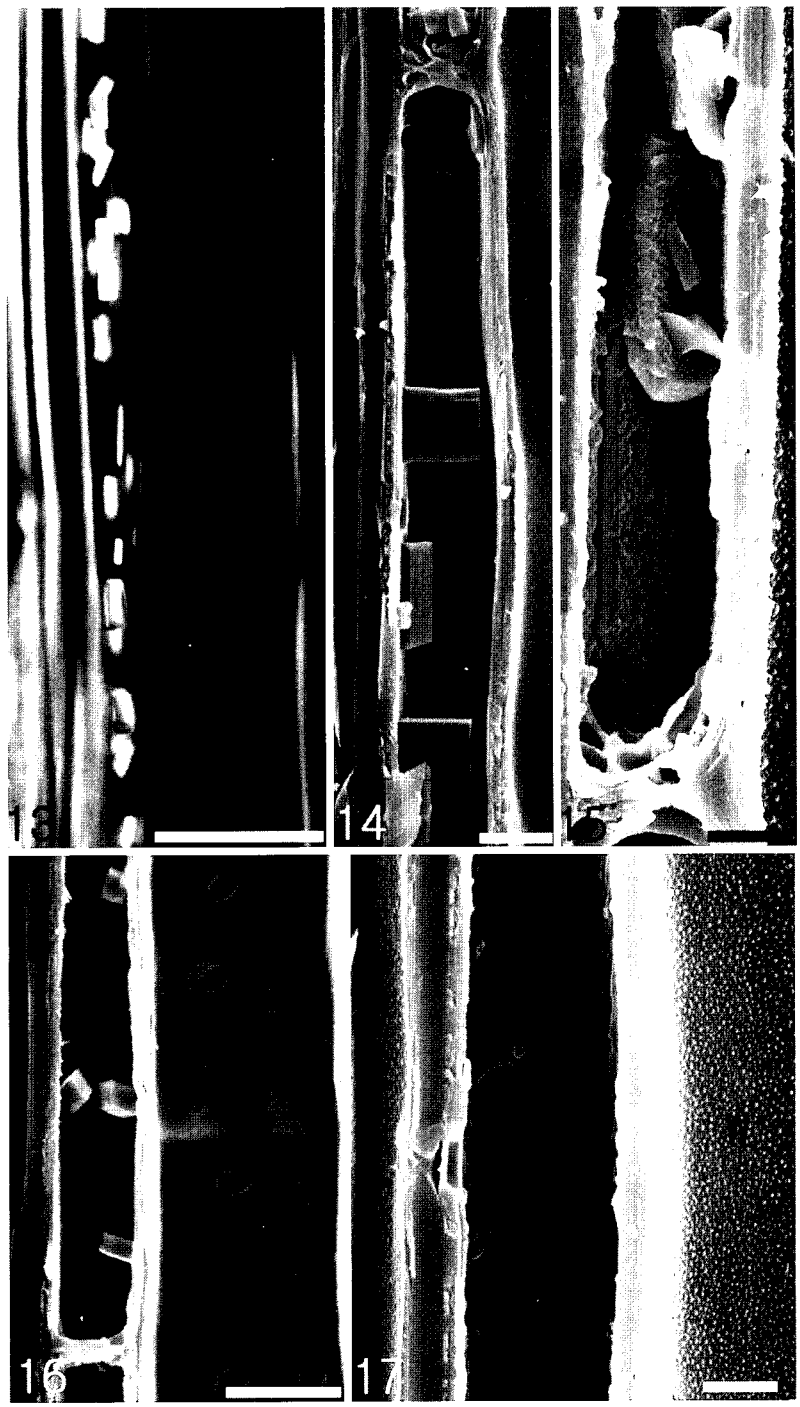
Figs. 1-6. Light micrographs showing prismatic crystals, elongate crystals, and styloids in ray parenchyma cells. - 1 & 2: *A. concolor*. - 3: *A. nobilis*. - 4: *A. amabilis*. - 5: *A. lasiocarpa*. - 6: *A. magnifica*. 1 & 3-6: radial surface; 2: tangential surface. - Scale bars=50 μm in 1-4 & 6; 30 μm in 5.



Figs. 7-12. Scanning electron micrographs showing crystals in ray parenchyma cells in radial surface. - 7 & 8: prismatic crystals and crystal sands in *A. concolor*. - 9 & 10: elongate crystals in *A. concolor* and *A. grandis*, respectively - 11 : an elongate crystal and a styloid in *A. nobilis*. - 12: a styloid in *A. magnifica*. - Scale bars=5 μm in 7 & 10-12; 10 μm in 8-9.

absence of rhomboidal crystals except in a very few instances, and elongated crystals were also only infrequently present and were especially easy to overlook due to their smaller size.

A. concolor contains crystal sand, prismatic crystals, elongate crystals, and styloids both in the axial and ray parenchyma cells (Figs. 1-2, 7-9, 11 & 13-17), whereas the other species show prismatic crystals, elongate crystals, and styloids only in the ray parenchyma cells (Figs. 3-6, 10 & 12). Ray parenchyma cells containing



Figs. 13-17. Crystals in axial parenchyma cells of *A. concolor* in radial surface. - 13: various types of crystals from prismatic crystal through elongate crystal to styloid. - 14 & 16: prismatic crystals. - 15: an elongate crystal and a styloid. - 17: crystal sands. W=warty layer of tracheid. 13: light micrograph with DIC (Nomarski); 14-17: scanning electron micrographs. - Scale bars=30 μm in 13; 10 μm in 14; 5 μm in 15 & 17; 20 μm in 16.

crystal sand and axial parenchyma cells having crystal sand, prismatic crystals, elongate crystals, and styloids are probably reported here for the first time in *A. concolor*. Also, this disagrees with the comment of IAWA Committee (2004) that crystals in softwoods appear to occur only in a single cell type in a given taxon.

Two or more crystals are very frequently identified in an unsubdivided cell, and these crystalliferous cells occur commonly in the upper and lower margins of rays even though crystals are observed in the entire rows of some rays (Figs. 1-9, 11 & 13-17). IAWA Committee (2004) described that prismatic crystals were more or less common in the marginal and submarginal ray cells and that these cells were not subdivided and that one or more crystals might be found in any single cell.

For wood identification purposes, when considering the earlier and our present studies, the presence or absence of crystals appears to be the most powerful diagnostic character for separating *A. concolor, A. grandis*, and *A. magnifica* from *A. nobilis* (=*A. procera*), *A. lasiocarpa, A. amabilis, A. balsamea,* and *A. fraseri.*

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<국문초록>

침엽수재에 있어서는 결정을 지니는 세포가 드물게 존

재하기 때문에 전나무속, 가문비나무속, 은행나무속 및 소나무속과 같은 경우 이들의 존재 여부는 수종 식별 인자로 귀중한 가치를 지니게 된다. 따라서 본 연구는 광학현미경과 주사전자현미경을 이용하여 북미산 전나무속 수종의 목재에 존재하는 결정의 분포와 형태를 조사하여 목재 해부 및 식별에 필요한 정보를 추가적으로 제공하기 위해 실시하였다. 출현 빈도 측면에서 볼 때 다각형 결정, 신장형 결정 및 주정이 *Abies concolor, A. grandis* 및 *A. magnifica, A. nobilis* (=*A. procera*), *A. lasiocarpa* 그리고 *A. amabilis*의 순으로 적게 관찰되었지만 *A. balsamea* 및 *A. fraseri*에서는 그 존재가 전연 확인되지 않았다. 다른 수종과는 달리 *A. lasiocarpa*는 다각형 결정보다는 신장형 결정 및 주정이 더 많이 지니고 있었다. *A. concolor*에서는 사정, 다각형 결정, 신장형 결정 및 주정이 축방향유세포 및 방사유세포 모두에서 관찰된 반면 나머지 수종 모두에서는 다각형 결정, 신장형 결정 및 주정이 방사유세포에만 존재하였다. 사정을 지니는 방사유세포 그리고 사정, 다각형 결정, 신장형 결정과 주정을 지니는 축방향유세포는 아마 본 연구에서 최초로 밝혀진 것으로 여겨진다. 결론적으로 결정의 존재 여부는 *A. nobilis* (=*A. procera*), *A. lasiocarpa, A. amabilis, A. balsamea* 및 *A. fraseri*로부터 *A. concolor, A. grandis* 및 *A. magnifica*를 식별해 내는데 있어 중요한 가치를 지니는 것으로 밝혀졌다.