CHAPTER 2

LITERATURE REVIEW

Taxonomic Background of Discolichens

The taxonomic positions of discolichens were revised for several times into new various ranks of taxonomic units by many lichenologists (Hale, 1984). Recently, discolichens contain 7 orders, 30 families and their hierarchical ranks are shown in appendix B (Lumbsch & Huhndorf, 2010). Lichens from two orders, Lecanorales and Teloschistales were treated in this study.

Order Lecanorales

In this order various thalli are formed and apothecial ascomata with or without a thalline margin may occur (Kirk et al., 2001, p. 273). Asci are unitunicate with a typical spore dehiscence through a specialized ascus tip. Iodine staining reaction of the ascus apex is conspicuously blue. The dominant photobiont are 1-celled green algae (Tehler, 1996). This order comprises 16 families, namely Aphanopsidaceae, Biatorellaceae, Brigantiaeaceae, Catillariaceae, Ectolechiaceae, Haematommataceae, Lecanoraceae, Lecideaceae, Megalariaceae, Micareaceae, Miltideaceae, Mycoblastaceae, Ophioparmaceae, Pilocarpaceae, Psoraceae, and

Ramalinaceae (Lumbsch & Huhndorf, 2010). Lichens from 8 families were found in this study, namely Brigantiaeaceae, Haematommataceae, Lecanoraceae, Malmideaceae, Megalariaceae, Lecideaceae, Pilocarpaceae, and Ramalinaceae.

Brigantiaeaceae are characterized by a crustose or lobed thallus; apothecia with well-developed margins, thick-walled, often 1-spored asci; hyaline and muriform, thin-walled ascospores. This family consisted of 2 genera and 18 species (Kirk et al., 2001, p. 79).

Brigantiaea was first described by Trevisan in 1853. Later authors considered *Brigantiaea* as a synonym of *Lopadium* Körber, until (Santesson, 1952) suggested that it might be a good, independent genus (Hafellner, 1983). In 1982, Hafellner & Bellemere were convinced by this view and published a new circumscription of *Brigantiaea* based on ultra-structural characters (Hafellner, 1981; Hafellner, 1983). The genus was monographed by Hafellner in 1997, who recognized fifteen species and discussed its separation from other superficially similar genera such as *Letrouitia* and *Lopadium* (Kantvilas & Elix, 2009).

Brigantiaea is characterized by a generally crustose thallus that invariably contains atranorin, a green photobiont, relatively large apothecia, usually vividly colored orange or yellow due to the presence of anthraquinone pigments, single-spores, asci with an amyloid outer wall and a well-developed amyloid tholus, lacking any internal differentiation, simple to sparsely branched paraphyses with only slightly enlarged apices, and relatively large muriform, hyaline ascospores (Kantvilas & Elix, 2009).

Haematommataceae are characterized by a crustose thallus; immersed or sessile apothecia with a reddish disc a thalline margin, hyaline, elongate and multiseptate ascospores (Kirk et al., 2001, p. 222). This family was described by Hafellner in 1984 to accommodate the single genus *Haematomma* (Lumbsch, Nelsen, & Lücking, 2008). Before that, *Haematomma* had traditionally been placed in Lecanoraceae, but this was first questioned by Culberson & Culberson (1970) based on the presence of anthraquinone in ascomata of *Haematomma.* According to Hafellner (1984), Haematommataceae differ from Lecanoraceae also by its ascus type, slightly anastomosing paraphyses, and septate ascospores (Lumbsch et al., 2008).

Most species of *Haematomma* can readily be recognized by their intense red or reddish orange, lecanorine apothecia, but some sorediate species are typically sterile and may need further taxonomic investigation using molecular methods (Brodo, Culberson, & Culberson, 2008). Species can best be determined by using a combination of morphological and chemical characters (Staiger & Kalb, 1995; Brodo et al., 2008) and are ideal candidates for chemotaxonomic studies (Stocker-Wörgötter, Hager, & Elix, 2009).

Lecanoraceae are characterized by a crustose to squamulose thallus; sessile, rarely immersed, often brightly pigmented apothecia with a well-developed lecanorine margin, hyaline and nonseptate or septate ascospores (Guderley & Lumbsch, 1998; Kirk et al., 2001). Moreover, they lack an amyloid zone between the "masse axiale" and the internal wall layer (Rambold, 1989).

Lecanora, one of the largest genus in the family Lecanoraceae (Lumbsch, 2004, pp. 11-12), were originally included in the genus *Lichen* by Linnaeus in 1753 (Laundon, 2003, p. 83). *Lecanora* was first used by Acharius in 1810, and distinguished by its crustose thallus and apothecia having a thalline tissue containing algal cells. The genus was subsequently redefined by Massalongo in 1852 (Lücking, Wang, & Zhao, 2009). However, numerous species still belong to other, unrelated groups and the genus in its current circumscription has been shown to be polyphyletic (Arup & Grube, 1998).

Lecanora sensu stricto is characterized by the presence of atranorin in the thallus and oxalate crystals in the amphithecium. The asci are of the *Lecanora*-type, containing simple, colorless ascospores, the thalli are crustose and the apothecial margins usually contain algal cells (Lumbsch & Elix, 2004).

The types of amphithecia found in *Lecanora* include:

1) *allophana*-type with small crystals in the algal-containing and cortical part of the amphithecium;

2) *campestris*-type with small crystals only in the algal-containing part of the amphithecium;

3) *melacarpella*-type with small and large crystals;

4) *pulicaris*-type with large crystals.

Types of epihymenia include (Lumbsch & Elix, 2004; Jüriado, 1998):

1) *chlarotera*-type with coarse crystals in the epihymenium which are soluble in HNO_3, pigmented or not, if pigmented, pigmentation soluble in KOH;

2) *gangaleoides*-type lacking crystals, olive-green-pigmentation changing to green in KOH;

3) *glabrata*-type lacking crystals, red-brown pigmented, pigmentation insoluble in KOH; and

4) *pulicaris*-type with small crystals, brownish-pigmented with the pigmentation soluble or not in KOH.

Lecidella was established by Körber in 1855. However, most lichenologists have ignored this genus, because Fries (1874) reduced it to a synonym of *Lecidea* (Inoue, 1997, p. 127). Later Hertel (1967) and Hertel and Leuckert (1969) approached this assemblage on the basis of modern information, and the latter raised it again to autonomous genus. This kind of view is also accepted here (Inoue, 1997, p. 127). The vast majority usually inhabits exposed siliceous rocks and barks of various trees (Knoph & Sipman, 1999; Knoph, Garnitz, & Leuckert, 1999, p. 163). Consequently, taxa with lecideine apothecia as in the genus *Lecidella* had been transferred to the Lecanoraceae such as *Lecanora marginata* (Schaer.) Hertel & Rambold, 1985. (Guderley & Lumbsch, 1998, p. 103).

Maronina was introduced by Hafellner & Rogers (1990) to accommodate crustose lichens with lecanorine apothecia, a *Trebouxia*-like photobiont, *Lecanora*-type, polyspored asci and simple, hyaline, non-halonate

ascospores (Kantvilas & Elix, 2007, p. 137). This genus is superficially very similar to *Maronea* A. Massal., which likewise has lecanorine apothecia and polyspored asci, but which belongs to the family Fuscideaceae due to its distinctive ascus structure and photobiont (Hafellner, 1984; Kantvilas, 2001, 2004; Kantvilas & McCarthy, 2003).

Ramboldia was introduced by Kantvilas & Elix (1994) to accommodate crustose lichens with a green, trebouxioid photobiont, lecideine apothecia, an internally unpigmented excipulum composed of radiating, branched and anastomosing hyphae, asci of the *Lecanora*-type with an amyloid tholus and a broadly diverging "masse axiale", sparsely branched and anastomosing paraphyses, and simple, hyaline, non-halonate ascospores (Kantvilas & Elix, 2007, p. 135).

Vainionora described by Kalb in 1991 (Lumbsch & Guderley, 1996). Some of the species studied were found not to belong to the *L. coronulans* group and these taxa are listed among the excluded species. However, with the inclusion of taxa with a dark hypothecium in *Lecanora sensu stricto*, the distinction from *Vainionora* Kalb becomes a problem. When describing the genus *Vainionora* (Kalb, 1991), the larger apothecia, the well developed and pigmented hypothecium, the bacilliform conidia, and the presence of xanthones were considered important characters that distinguished this new genus from the *Lecanora subfusca* group. Five species were originally included in *Vainionora,* such as *Vainionora aemulans, V. flavovirens, V. pallidostraminea, V. stramineopallens*, and *V. warmingii*. This genus contain *O*-methylated chloronorlichexanthones (such as thuringione or 3-*O*-

methylthiophanic acid) and chlorinated lichexanthones while non-methylated norlichexanthones are common in *Lecanora sensu stricto.* There is also a difference in the length of the conidia. This difference is correlated with the tendency to produce large apothecia, and the presence of lichexanthones and *O*-methylated norlichexanthones.

A detailed discussion of the generic concept of *Vainionora* must await the forthcoming monograph by Kalb. All taxa with bacilliform conidia and a *Vainionora*-like chemistry are tentatively excluded from *Lecanora* and are listed among the excluded species.

Lecideaceae are characterized by a crustose to squamulose thallus; sessile apothecial ascomata with an absent or weakly developed thalline margin, hyaline, nonseptate, and thin-walled ascospores (Kirk et al., 2001). This family was proposed by Zahlbruckner in 1926 (Coppins, 1983, p. 19). The principal genera segregations were based mainly on spore features, like size, septation and the number of spores per ascus. It was divided in *Lecidea, Catillaria, Bacidia, Biatorella, Mycoblastus, Lopadium, Bombyliospora,* and *Toninia.*

Malmideaceae (Lecanorales, Lecanoromycetidae) a new family to accommodate the genus *Malmidea* was described by Kalb et al. (2011). Morphologically, this family is similar to Pilocarpaceae as far as the ascus structure concerns. The thallus of most species of *Malmidea* is composed of goniocysts which is a rare character in Pilocarpaceae, only present in *Calopadiopsis* and *Pseudocalopadia* (Lücking, 2008). *Malmidea* Kalb, Rivas Plata & Lumbsch is established for the *Lecidea piperis* and *Lecanora*

granifera-groups, including the bulk of species previously placed in the genus *Malcolmiella* Vězda. Consequently, lecideoid taxa having been transferred to the genus *Malcolmiella* are now placed in the new genus *Malmidea.*

Megalariaceae are characterized by a crustose thallus, ascomata with a well-developed margin of hyphal tissues and 1-septate ascospores. Two genera namely *Catillochroma* and *Megalaria* were proposed to belong in this family by Kalb in 2007 (Fryday & Lendemer, 2010).

Catillochroma was proposed by Kalb in 2007 (Fryday & Lendemer, 2010, p. 588). It was considered to be separated from *Megalaria* by the anatomy of the exciple. The author described the exciple of *Catillochroma* as bi-layered, with a distinct prosoplectenchymatous outer layer and the production of zeorin in the thallus (Fryday & Lendemer, 2010, pp. 588-594).

Pilocarpaceae are characterized by a crustose thallus; brightly colored apothecia and a poorly developed exciple, composed of loosely intertwined hyphae; the ascospores are often elongated with one or more septa and hyaline. In PLWS 1 genus with 1 species of this family was found (Kirk et al., 2001, p. 407).

Micarea was first validly described in 1825 by Elias Fries (Coppins, 1983, p. 20). The generic name was little used by most 19th century lichenologists (*M. prasina*). In 1976 Vězda & Wirth expanded Hedlund's concept of *Micarea* by including *Lecidea sylvicola.* The first species of *Micarea* to be described was *Lecidea* (*Micarea*) *lignaria* Ach. (1808) (Coppins, 1983, p. 20).

Ramalinaceae (Bacidiaceae) are characterized by a crustose, squamulose or fruticose thallus; pale to black apothecia without a well-developed thalline margin, asci with a well-developed apical cap; ellipsoidal to elongated, usually septate ascospores. The Ramalinaceae (Bacidiaceae) consist of 29 genera and 422 species (Kirk et al., 2001, p. 56).

At first, the genus *Bacidia* was placed in the family Lecideaceae by Zahlbruckner (1926). It was characterized by a crustose thallus, plane to convex, biatorine or lecideine apothecia, a hyaline to dark hypothecium, 8 (rarely 16) spored asci, acicular, fusiform or bacillar, transversely two- to multi-septate, hyaline spores and unbranched paraphyses, often thickened at apices. Recent researchers, e.g. Hafellner (1984) have laid emphasis to the nature of the ascus tip (tholus) after I (KI) application and the nature of paraphyses and their tips. The genus has been placed in an own family Ramalinaceae (Lumbsch & Huhndorf, 2010, p. 20).

Order Teloschistales

Species in this order are distinguished by asci with a unique tholus with a thick amyloid external wall layer. Ascospores are often hyaline and polardyblastic. In the thallus as well as in the apothecia, anthraquinoide pigments are produced. Many species are described and they can be found on various substrates (Hafellner, 1988, pp. 47-50). It is composed of 3 families.

Letrouitiaceae is a monotypic family including one genus, *Letrouitia*, characterized by a green or brownish crustose thallus which is lacking anthraquinone pigments. The ascomata are without a well-developed thalline

margin. The ascospores are hyaline and multiseptate, sometimes muriform (Kirk et al., 2001, p. 280). 18 species are currently known. Members of this family are widely distributed in subtropical and tropical regions.

Megalosporaceae are characterized by a crustose thallus, sessile apothecia with a brown to black disc; the ascospores are large, hyaline and thick-walled. The first species described in Megalosporaceae was *Megalospora tuberculosa* [=*Lecidea tuberculosa*], which was described by Fée in 1825 [1924]. In PLWS, 1 genus and 1 species from this family were found (Kirk, et al., 2001, p. 310).

The genus *Megalospora* was described in 1843 by Meyen & Flotow, with a single species, *M. sulphurata*. Their description was largely based on the apothecium structure and the data on the spores were inaccurate, as was pointed out by Müller Arg. (1883). Flotow (1850) later changed the name of the genus into *Heterothecium* (Sipman, 1983, p. 13).

Telochistaceae are characterized by diverse thalli, brightly colored apothecia with parietin or related substances, usually with a well-developed thalline margin, simple to 3-septate polarilocular ascospores with strongly thickened septa (Kirk et al., 2001, pp. 515-516). Only 4 species in 1 genus are currently known from Thailand (Wolseley, Hudson, & Mccarthy, 2002).

Caloplaca was described by Acharius in 1798 (Arup, 2009). *Caloplaca holocarpa* (Hoffm. Ex Ach) A. E. Wade, growing on wood is the oldest name in the group. *Caloplaca pyracea* (Ach.) Th. Fr. is also an old name and was described by Acharius in 1803, but it grows on bark. This genus is a large heterogeneous group of mostly crustose species. By far the most of the

species of *Caloplaca* have apothecia with orange, red or deep red disks and colorless 2- to 4-celled and polarilocular spores.

Studies Discolichens in Thailand

The first study on discolichens in Thailand was performed at Koh Chang Island, Trat Province by the Finnish lichenologist Vainio (1909, pp. 104-152), He published the collections made by a Danish Expedition during the years 1899-1900. He reported on four species of Lecanoraceae, namely *Lecanora subfusca* (L.) Ach., *L. subgranulata* Nyl., *L. cinereocarnea* (Eschw.) Vain. and *L. monodorae* Vain., two species of Lecideaceae, namely *Lecidea* (*Catillaria*) *testaceolivens* Vain. and *L. unicolor* Vain., and one species of Gyalectaceae, *Gyalecta lutea* (Dicks.) Tuck. (= *Coenogonium luteum*).

Twenty years later, Vainio (1921, pp. 33-48) published on lichens from to Doi Suthep-Pui National Park, Chiang Mai Province, collected mainly by Hosseus. From Lecanoraceae, 5 species, namely *Lecanora cinereocarnea* (Eschw.) Vain., *L. lividoglauca* Vain., *L. lividocarnea* Vain., *Lecanora* (*Aspicilia*) *fumigata* Vain. and *Lecidea russula* Ach. (= *Ramboldia russula*) and from Haematommataceae; 1 species, *Haematomma puniceum* (Ach.) Vain. were mentioned.

Paulson (1930) recorded discolichens from Kaw Tao Island, Surat thani Province and mentioned in Ramalinaceae; two species, *Bacidia umbrina* var. *turgida* Th. Fr. and *B. atrosanguinea* Th. Fr., in Teloschistaceae; 3 species

namely *Caloplaca aequata* Ach., *C. aurantiaca* (Lghtf.) Th. Fr. and *C. pyracea* (Ach.) Th., and in Lecanoraceae 1 species, *Lecanora subfusca* Ach.

Sato (1962) published on the collections of three members of the Osaka City University Biological Expedition to Southeast Asia 1957-58 who had found *Lecidea* (*Biatora*) *russula* Ach. (Vain.) (= *Ramboldia russula*) at Doi Inthanon and Doi Suthep Pui National Parks.

Feeya Amatawiwat (1994) from Princess of Songkla University studied chemotaxonomy and chemistry of lichens in Southern Thailand. She exposed 17 species, of crustose discolichens, namely *Lecanora allophana* (Ach.) Röhl., *L. atra* (Huds.) Ach. (= *Tephromela atra*), *L. blanda* Nyl., *L. rupicola* (L.) Zahlbr., *Haematomma fauriei* Zahlbr., *H. ochrophaeum* (Tuck.) Mass, *H. pachycarpum* (Müll. Arg.), *Pyrrhospora russula* (= *Ramboldia russula*), *Bacidia palmularis*, *Brigantiaea* sp., *Byssoloma* sp., *Lecidea granulans*, *Letrouitia* sp., *Lopadium* sp., *Porpidia* sp., *Caloplaca* sp., *Dimerella* sp. (= *Coenogonium*) and *Megalospora tuberculosa* (Fée) Sipman.

Mongkolsuk, Boonpragob, and Homchantara (1996) from Lichen Research Unit of Ramkhamhaeng University studied the biodiversity of lichens at Queen Sirikit Botanic Garden, Mae Rim District, Chiang Mai Province during the years 1994-1995. They recognized thirteen families, namely Ramalinaceae, Biatoraceae, Candelariaceae, Ectolechiaceae, Fuscideaceae, Haematommataceae, Lecanoraceae, Lecideaceae, Letrouitiaceae, Megalosporaceae, Miltideaceae, Psoraceae, and Trapeliaceae, eighteen genera and nineteen species. One year later 1995-1996, They (1997, pp. 49-83) investigated the biodiversity of lichens at Phuteen Sounsai Forest,

Nahaew National Park, Loei Province and distinguished eleven families, fifteen genera, and fifteen lineages of discolichens.

Boonpragob, Homchantara, Coppins, McCarthy, and Wolseley (1998, pp. 209-219) surveyed and published the discolichens of Khao Yai National Park with a total of ten families, thirteen genera and eighteen species of *Bacidia* s. lat., *Brigantiaea leucoxantha* (Spreng.) R. Sant & Hafellner, *Byssoloma chlorinum* (Vain.) Zahlbr., *B. leucoblepharum* (Nyl.) Vain., *B. tricholomum* (Mont.) Zahlbr., *Fellhanera* sp., *Calenia graphidea* Vain. and *C.* aff. *phyllogena* (Müll. Arg.) R. Sant., *Calopadia* aff. *fusca* (Müll. Arg.) Vězda., *Echinoplaca epiphylla* Fée, *E. pellicula* (Müll. Arg.) R. Sant., *Dimerella* sp. (= *Coenogonium*), *Lecidea* s. lat. spp., *Letrouitia domingensis* (Pers.) Hafellner & Bellem., *L. subvulpina* (Nyl.) Hafellner & Bellem., *Megalospora tuberculosa* (Fée) Sipman, *Micarea* sp., *Pyrrhospora russula* (Ach.) Hafellner (= *Rambolia russula*).

Wolseley, Hudson, and McCarthy (2002, pp. 13-59) provided a catalogue of the lichens of Thailand based on published reports. It includes publication details of 554 species and infra-specific taxa together with information on their distribution in Thailand. They compiled a sum of fourteen families, eighteen genera and forty-seven species of discolichens, found in Thailand (see Appendix C).

In 2004, The Lichen Research Unit, Department of Biology, Faculty of Science, Ramkhamhaeng University collected 42 species of discolichens from ten families and seventeen genera in Khao Yai National Park during the years 1999-2001.

In 2007, Aptroot, Saipunkaew, Sipman, Sparrius, and Wolseley published new lichens from Thailand, mainly microlichens from Chiang Mai and encountered discolichens in to 13 families, 20 genera and 46 species (see Appendix C). However in the same year, Papong, Boonpragob and Lücking reported on 13 new records of foliicolous discolichens from Thailand. These species included *Bacidia micrommata* (Kremp.), *Bacidina pallidocarnea* (Müll. Arg.) Vêzda, *Byssolecania hymenocarpa* (Vain.) Lücking & Kalb, *Byssoloma annuum* (Vain.) Thor, Lücking & Matsumoto, *B. fadenii* Vêzda, *B. gahavisukanum* Sérus., *B. guttiferae* (Bat. & Peres) Lücking & Sérus., *B. subdiscordans* (Nyl.) P. James, *Calopadia puiggarii* (Müll. Arg.) Vêzda, *Echinoplaca tetrapla* (Zahlbr.) Lücking, *Fellhanera bouteillei* (Desm.) Vêzda, *F. mastothallina* (Vain.) Lücking & Sérus., and *F. rhaphidophylli* (Rehm) Vêzda.

Kalb, Buaruang, Papong, and Boonpragob (2009, pp. 109-123) presented 4 species of discolichens in 2 families and 2 genera, found in Thailand. They described three new species, one in Lecanoraceae, *Ramboldia siamensis* Buaruang, Elix & Kalb, which was collected at Phu Luang Wildlife Sanctuary, Loei Province and two Pilocarpaceae, namely *Malcolmiella duplomarginata* Papong & Kalb (= *Malmidea*) and *M. piae* Kalb, from Sai Yok National Park, Kanchanaburi Province and Queen Sirikit Botanic Garden, Chiang Mai respectively.

Kantvilas, Papong, and Lumbsch (2010, pp. 557-561) published further observations on the genus *Maronina*, with descriptions of two new taxa from Thailand. They described two new taxa, namely *Maronina orientalis*

Kantvilas & Papong var. *orientalis* and *M. orientalis* var. *corallifera* Kantvilas & Papong.

Table 1

Sixty-Four Species were Reported on Discolichens in Thailand

Genera-Species	Genera-Species	Genera-Species
Bacidia atrosanguinea	*Byssoloma guttiferae*	*Caloplaca pyracea*
Bacidia micrommata	*Byssoloma leucoblepharum*	*Dimerella* sp. *(= Coenogonium)*
Bacidia palmularis	*Byssoloma* sp.	*Echinoplaca epiphylla*
Bacidia umbrina	*Byssoloma subdiscordans*	*Echinoplaca pellicula*
Bacidina pallidocarnea	*Byssoloma tricholomum*	*Echinoplaca tetrapla*
Brigantiaea leucoxantha	*Calenia aff. phyllogena*	*Fellhanera mastothallina*
Brigantiaea sp.	*Calenia graphidea*	*Fellhanera bouteillei*
Byssolecania hymenocarpa	*Calopadia aff. fusca*	*Fellhanera rhaphidophylli*
Byssoloma annuum	*Calopadia puiggarii*	*Fellhanera* sp.
Byssoloma chlorinum	*Caloplaca aequata*	*Gyalecta lutea (= Coenogonium luteum)*
Byssoloma fadenii	*Caloplaca aurantiaca*	*Haematomma fauriei*
Byssoloma gahavisukanum	*Caloplaca* sp.	*Haematomma ochrophaeum*

Table 1 (Continued)

Genera-Species	Genera-Species	Genera-Species
Haematomma pachycarpum	*Lecanoraallophana*	*Malcolmiella duplomarginata (= Malmidea)*
Haematomma puniceum	*Lecidea (Biatora) russula (= Ramboldia russula)*	*Malcolmiella piae*
Lecanora (Aspicilia) fumigata	*Lecidea (Catillaria) testaceolivens*	*Maronina orientalis*
Lecanora atra (= Tephromela atra)	*Lecidea granulans*	*Maronina orientalis var. corallifera*
Lecanora blanda	*Lecidea russula (= Ramboldia russula)*	*Megalospora tuberculosa*
Lecanora cinereocarnea	*Lecidea unicolor*	*Porpidia* sp.
Lecanora lividocarnea	*Letrouitia subvulpina*	*Pyrrhospora russula(= Ramboldia russula)*
Lecanora lividoglauca	*Letrouitia domingensis*	*Ramboldia siamensis*
Lecanora monodorae	*Letrouitia* sp.	
Lecanora subfusca	*Lopadium* sp.	

Chemistry

Lichen substances play an important role in identification and classification. There are two main groups of the lichen products, which are primary metabolites (intracellular) and secondary metabolites (extracellular) (Elix, 1996, pp. 154-180). Proteins, amino acids, polyols, carotenoids, polysaccharides and vitamins are examples of the primary metabolites (intracellular). Most of the intracellular products isolated from lichens are non-specific, and occur in free-living fungi, algae and in higher green plants as well (Hale, 1983).

The majority of organic compounds found in lichens are secondary metabolites of the fungal component, which are deposited on the surface of the hyphae rather than within the cells. More than 630 secondary metabolites are known from lichens, one of them parietin, a widespread anthraquinone, the orange pigment, present in most Teloschistales. Most of the secondary metabolites present in lichens are derived from the acetyl-polymalonyl pathway, but some come from the shikimic acid and mevalonic acid pathway.

The large majority of depsides, depsidones, dibenzofurans, usnic acids and depsones all appear to be produced by such mechanisms and all are restricted to lichens. In addition to the compounds of known chemical structure, many of unknown structure are given working names and assigned to compound classes, because they are frequently encountered and recognized by TLC.

In the 1860s, Nylander carried out preliminary studies showing that chemical test had considerable potency in lichen taxonomy. The first chemical tests used iodine solution (I), potassium hydroxide (K; KOH), and calcium hypochlorite (C). A further test reagent was KC (K solution followed by C). The first extensive chemical investigations on lichens were conducted by Hesse and Zopf. In 1907 Zopf's publication of *Die Flechtenstoffe*, in which the descriptions of over 150 lichen compounds were summarized, appeared.

Thallus spot tests and the distribution of pigments provided the first evidence that the lichen substances were not evenly distributed throughout the thallus. In some species the striking red or orange anthraquinone derivatives and the yellow pigment usnic acid were obviously restricted to the upper cortex. Similarly, spot tests demonstrated that many of the colorless depsides and depsidones were restricted to the medullary layer.

For example, lichexanthone and russulone, a tetracyclic anthraquinone, were located in different parts of *Lecidea russula* Ach. (= *Ramboldia russula*), i.e. the former in the thallus, the latter in the apothecia (Culberson & Elix, 1989). At the family level; anthraquinones and particularly parietin, is found in the Teloschistaceae.