CHAPTER 2

LITERATURE REVIEW

Clay minerals are the characteristic minerals of the Earths near surface environments. They form in soils and sediments, and by diagenetic and hydrothermal alteration of rocks. Water is essential for clay mineral formation and most clay minerals are described as hydrous alumino silicates. Structurally, the clay minerals are composed of planes of cations, arranged in sheets, which may be tetrahedral or octahedral coordinated (with oxygen), which in turn are arranged into layers often described as 2:1 if they involve units composed of two tetrahedral and one octahedral sheet or 1:1 if they involve units of alternating tetrahedral and octahedral sheets. Additionally some 2:1 clay minerals have interlayers sites between successive 2:1 units which may be occupied by interlayer cations, which are often hydrated. The planar structure of clay minerals given a rise to characteristic platy habit of many and to perfect cleavage [27, 28], as seen for example in Fig. 2.1.

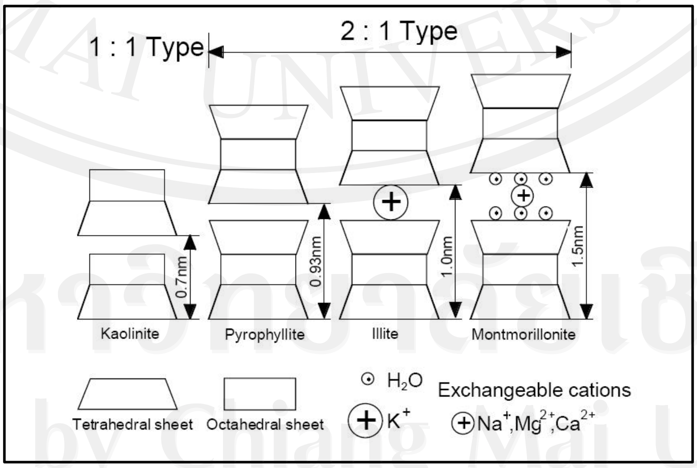


Figure 2.1 The structure of clay minerals [27]

2.1 Bentonite

Bentonite is the clay rocks altered from glassy igneous material such as a volcanic ash or tuff, the physical property of bentonite showed in Fig. 2.2. Bentonite had been used as industrial raw material in numerous applications such as palletizing iron ores, foundry bond clay, ceramic, drilling mud, sealant, animal feed bound, bleaching clay, agricultural carrier, cat box adsorbent, adhesive, catalyst and catalyst support desiccant, emulsion stabilizer cosmetic, paint, pharmaceutical, civil engineering pillared clay organoclay, and polymer-clay nonocomposits. [29, 30]

Figure 2.2 Physical property of bentonite

Bentonite is greatly affected from the acid activation, ion exchange, heating and hydrothermal treatments, and some other physicochemical process. For example, physicochemical properties such as strength, swelling, plasticity, cohesion, compressibility, particle size, cation-exchange capacity, pore structure, surface area, surface acidity and catalytic activity as well as the mineralogy can change considerably by these modifications [25, 27, 31].

Commercial importance of bentonite depends on the contents of their clay nonclay minerals. Dominant clay minerals in bentonite are smectites such as montmorillonite, beidellite, saponite, nontronite, and hectrorite [27].

Bentonite is seldom found as monomineralic clays which may contain other clay and nonclay minerals, also some organic impurities. Nonclay minerals produce sharper X-ray diffraction (XRD) peaks than the smectites and other clay minerals, and this distinction is an important diagnostic criterion for their identification. The most common nonclay minerals in bentonite are silica polymorphs, feldspars zeolite, carbonate, sulfites, sulfides, sulfates, oxides and hydroxides [32].

a. Bentonite structure

Bentonite, which consists essentially of clay minerals of the smectite group, has a wide range of industrial uses. A particular feature of this group of mineral is substitution of Si^{4+} and Al^{3+} in the crystal structure by lower valency cations. This leaves unsatisfied negative charges which are balanced by loosely-held ‘exchangeable’ cations such as Na^{+}, Ca^{2+}, Mg^{2+} and H^{+} located mainly on the interlayer crystal surfaces. The structure, chemical composition, exchangeable ion type and small crystal size of bentonite are responsible for several unique properties, including a large chemically active surface area, a high cation-exchange capacity, interlayer surfaces having unusual hydration characteristics, and sometimes the ability to modify strongly the flow behavior of liquids [33, 34]. The crystal structure of bentonite is summarized in Fig. 2.3.

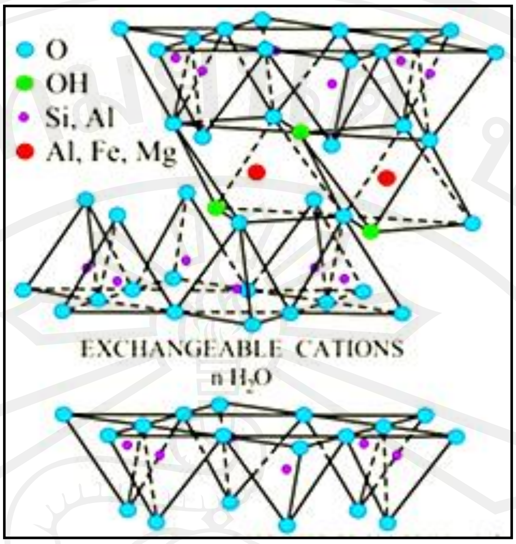


Figure 2.3 The crystal structure of bentonite [27]

It is desirable at this point to understand the nature of bentonite. Various definitions of bentonite have been given in the literature. Bentonite is a rock term used to designate a naturally occurring.

Chemically, bentonite is described as a hydrous aluminum silicate containing small amounts of alkali and alkaline-earth metals. Structurally, bentonite is made of two basic building blocks, the aluminum octahedral sheet and the silica tetrahedral sheet, that in Fig. 2.4 and Fig. 2.5. A single bentonite unit call consists of two silica tetrahedral sheets, between which is an aluminum octahedral sheet in Fig. 2.4. Lengths and widths of bentonite flakes are form 10 to 100 times the thickness. The bentonite lattice is negative in charge, owing primarily to isomorphous replacements of ions within the structure. This negative character is balanced by cations which are held on the surface of the flacks. Cations held in this fashion by the clay can be readily exchanged; the cations most commonly found in nature are sodium and calcium [28].

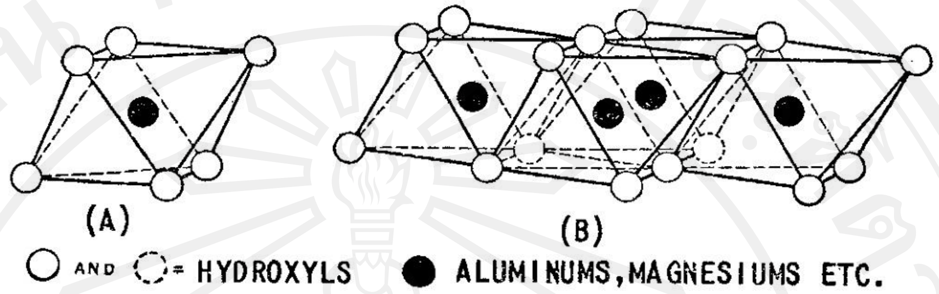


Figure 2.4 Diagrammatic sketch showing (A) single octahedral unit, and (B) portion of an octahedral sheet structure [32]

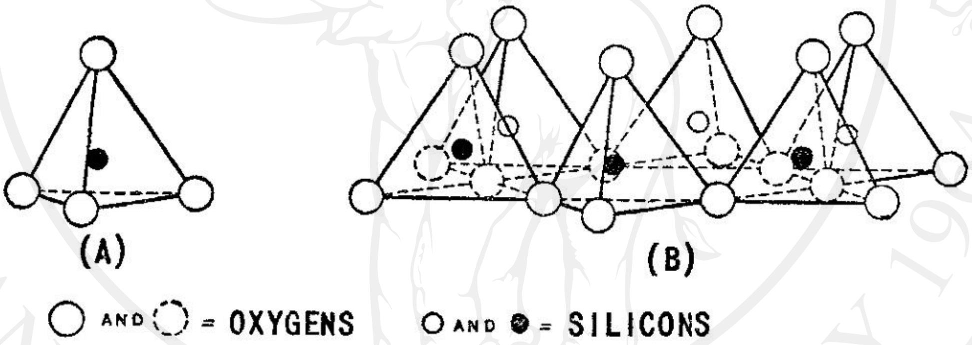


Figure 2.5 Diagrammatic sketch showing (A) single silica tetrahedron, and (B) portion of a silica tetrahedral sheet structure [32]

Bentonite has a cation-exchange capacity of about 70 to 110 meq/ 100 g of clay. Generally the laws of mass action dictate which will be present as exchangeable ions on the clay. The exchangeable cation, both by type and amount that are associated with the bentonite are of great importance since they largely control its physical prosperities [35, 36].

Bentonite adsorbs water whenever it is available. Water adsorption to the greatest extent on the basal surface of the clay and in this fashion pries adjacent flakes apart, resulting in an overall volume increase of the clay. Evidence of this swelling mechanism is seen as an increase in the *c*-axis dimension of the clay in Fig. 2.6. The water which is adsorbed primarily on the basal surfaces of the clay consists of a regular, rather than a random, arrangement of water molecules; the energy with the water orients and is bonded to the clay flake that measured as heat of wetting [37].

Many types of organic material are absorbed by bentonite, and this adsorption is somewhat similar in manner and orientation to that of water. Organic material adsorbed on basal surfaces also increases the *c*-axis dimension of the clay. Some of the parameters governing organic adsorption include type and composition of the organic material, the organic concentration, pH, and the presence of absence of water in the system [31].

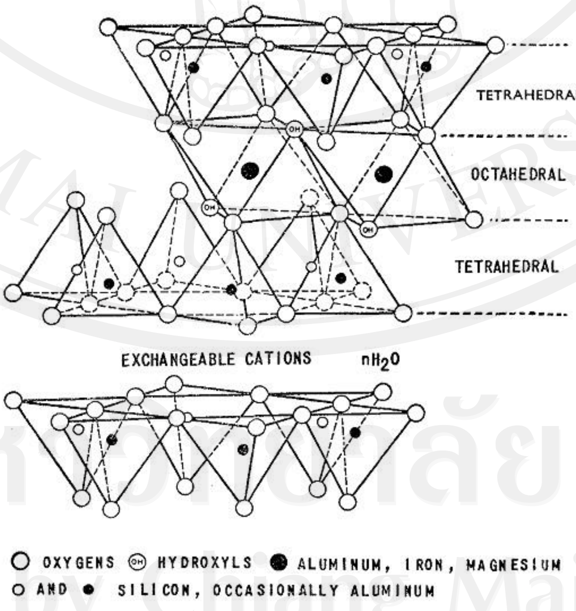


Figure 2.6 Diagrammatic sketch of the structure of bentonite [31]

b. Swelling

The physical state of smectite and corresponding bentonite may be changed with increasing water content, from an anhydrous solid to a hydrated material, semi-rigid plastic gel and suspension, respectively. Smectite-water systems are of great importance for the agricultural, industrial, environmental and civil engineering activities and drilling mud for oil recovery [38].

The change in the physical state of a bentonite from an anhydrous solid to gel is called swelling. The swelling of smectite occurs between the 2:1 (TOT) layers in agglomerated particles. Depending on the extent of the increase in the basal spacing, between two 2:1 layers, two types of SWE mechanisms can be purposed such as crystalline (initial or microscopic) SWE and osmotic (macroscopic) SWE .

Crystalline SWE results from the multimolecular adsorption of water on the basal crystal surface. Crystalline SWE occurs in a series of discrete steps, corresponding to the intercalation of 0, 1, 2, 3, and 4 layers of water molecules by adsorption from vapor phase. Crystalline SWE is controlled by a balance between strong electrostatic-attraction and hydration-repulsion forces. Thus, basal spacing is restricted in the range from 1.0 mn to 2.2 mm by the crystalline SWE. In this range, some of the physicochemical behaviors of swelling-shrinkage were investigated extensively [39, 40].

The basal spacing of a smectite may increase abruptly up to several decades' nanometers depending on water content by osmotic swelling in liquid water. Osmotic swelling was examined generally based on the diffuse double layer theory. The increase in the basal spacing by SWE depends on the bentonite mineralogy, extend of up taken water, and also size, valance, electronegativity, and hydration energy of exchangeable cations [30, 41].

c. Calcium bentonite and Sodium bentonite

Depending on the dominant exchangeable cations present the clay may be referred to as calcium bentonite or sodium bentonite, the two varieties exhibiting markedly different properties and thus uses. The terms non swelling bentonite and swelling bentonite are synonymous with calcium bentonite and sodium bentonite respectively. When mixed with water, swelling bentonite exhibits a greater degree of dispersion and better plastic and rheological properties than non swelling bentonite. Natural sodium bentonite, such as those in Wyoming, USA, are comparatively rare although the cation-exchange properties of bentonite enable the more widespread calcium form to be easily converted to high-swelling sodium bentonite by a simple sodium-exchange process. In some countries, notably Britain, calcium bentonite is referred to as fuller's earth, although elsewhere, and particular in the USA, this term is applied to any clay that has the capacity to decolorize oil and may consist of smectite or attapulgite [40].

d. Geological occurrence

Smectite is the essential and active component of bentonite on which their economic importance is based. The majority of commercial bentonite deposits contain Ca^{2+} and Mg^{2+} as the main exchangeable cations. However, smectite clay minerals become unstable with increasing age, depth of burial, and digenesis, and alter to mixed-layer, illite-smectite clays, sometimes referred to as K- or meta-bentonite, in which their valuable properties have been largely destroyed. Consequently, pure bentonite clay minerals are essentially absent in rocks of pre-mesozoic age. Whilst Jurassic bentonite is known, most economic deposits are Cretaceous or younger in age and this face is an important exploration criterion [41].

e. Field characteristics

Bentonite range in color form black though to white. Material from near outcrop often exhibits enhanced swelling properties. Despite their often characteristic appearance at outcrop, where they tend to exhibit a ‘frothy’ or ‘popcorn’ texture due to successive wetting and drying, deposits may be easily overlooked during field mapping, particularly in tropical areas where this feature may be obscured. In addition, because bentonite deposits sometimes exhibit a highly lenticular form, some may have no surface expression with any outcrops. Detection than can prove extremely difficult [33, 40].

2.2 Organoclay

Bentonite or their major clay mineral smectite had been known to be an efficient gellent for water systems, were not effective in gelling organic liquids. However, smectite and corresponding bentonite have limited use as coagulant to remove organic pollutants from both drinking water and wastewater. The increased threat of the environment pollution by different organic compounds and especially pesticides promoted investigations to modify of bentonite on the use as sorbents for organic compounds instead of activated carbon used before. The focus of the researches was on developing new hydrophilic and expanding lattice structure materials from natural bentonite.

It was seen that a bentonite having high swelling properties in water showed an aversion to water and a tendency to swell in various organic liquids after reaction with some organic ammonium slats. An organophilic compound obtained by exchange of organic cations for inorganic interlayer cations in called generally as organoclay. The organoclays were found to be effective gellents for organic fluids [42].

Several investigations have been conducted since the first preparation of orgnoclays by Jordan in 1949. The surface properties of bentonite were modified greatly by replacing natural inorganic exchangeable cations by larger alkylammonium cations . The metal cations are released into solution by the formation of organoclays. The intercalated organic cations act as pillars which hold the 2:1 layers permanently apart [43].

Organoclays may be prepared by using alkylammonium, α, w-alkyldi-ammonium and quaternary ammonium cations of the general forms $[CH_3(CH_2)_n NH_3]^+$, $[NH_3(CH_2)_nNH_3]_2^+$ and $[(CH_3)_3NR]^+$ or $[(CH_3)_2NRR']^+$ respectively. Here, R and R’ are large non-polar alkyl groups with the 12 or greater C atoms and they may contain aromatic rings [44].

It was shown that quaternary ammonium cations with relatively large R groups such as hexadecyltrimethylammonium cation improved adsorptive capabilities of organoclays for the organic compounds. On the contrary, organoclays prepared by smaller organic cations like tetramethylammonium showed very weak adsorptive capabilities for the organic compounds especially for the phenolic compounds tested.

Furthermore, organic cations are fixed on smectite surface form an organic phase derived from alkyl group. This organic phase functions as a partition medium for non-polar organic compounds and is highly effective in removing such compounds form water. Such small organic cations exist as discrete species on the smectite surface and do not form an organic partition phase. In this organoclays quaternary ammonium cations are spate from each other and function as pillars to permanently open the interlayers of smectite [9, 42, 44].

2.3 Concinium fenestratum

Coscinium fenestratum (Gaertn.) Colebr., belongs to Menespermaceae, called “Hamm” in Thai, and it is commonly known as tree turmeric, in Fig. 2.7 showed large climbing shrub with cylindrical stem, yellow wood and yellow sap. It has been used in traditional medicine in the northern part of Thailand with high popularity. It is a critically endangered medicinal liana [45]. In the traditional folk system of medicine, the plant has been mainly used for treating diabetes mellitus [46] and commonly prescribed as active ingredients with diverse therapeutic purposes [47]. The stem of the plant is used for treating poultice cuts and sores [48], ulcers, fever, jaundice, snakebitepiles etc, in ethanomedicine [49]. The plant is suggested to have thermogenic, anti-inflammatory, antiseptic, tonic effects and is used against opthalmopathy, inflammations and general debility [50]. Even though the root of *C. fenestratum* is considered to be a bitter tonic, dressing wound, ulcers. Stomachic and antiseptic, and is useful in treating dysentery and the wood of this plant is also considered as a bitter tonic and it is used as a substitute for calumba [51]. The decoction of the stem is useful in snake-bites and the decoction of stem bark is used to treat intermittent fevers [52]. This plant is used as a single herb and also in combination with other medicinal plants, in the traditional methods of treating herpes in India [53].

Figure 2.7 Physical properties of *C. fenestratum* [45]

The major constituent of the stem of *C. fenestratum* is reported as berberine and protoberberine alkaloids oxypalmatine, berberubine [54], (-)-8-oxotetrahydrothalifendine, (-)-8-oxoisocorypalmine and either (-)-8-oxothaicanine or (-)-8-oxo-3-hydroxy-2, 4, 9, 10-tetramethoxyberbine, and (-)-8-oxocanadine [55].

Similarly, characterization of quaternary alkaloids, 8-oxoprotoberberine alkaloids, and a steroid compound in *C. fenestratum* reported as benzylisoquinoline alkaloids, aporphine alkaloids, quaternary protoberberine alkaloids, tetrahydroprotoberberine alkaloids and a steroid compound [56]. One of the related species of *C. fenestratum*, *C. blumeanum* showed the presence of palmatine and jatrorrhizie as minor alkaloids. In addition, an ester triacontanyl effect was isolated from *C. blumeanum* [57] and minor alkaloids, 12, 13-dihydro-8-oxo-berberne as well as berberine, oxyberberine, tetrahydroberberine (canadine), sitosterol and stigmasterol [58]. Some of chemical constituents of *C. fenestratum* was showed in Fig. 2.8.

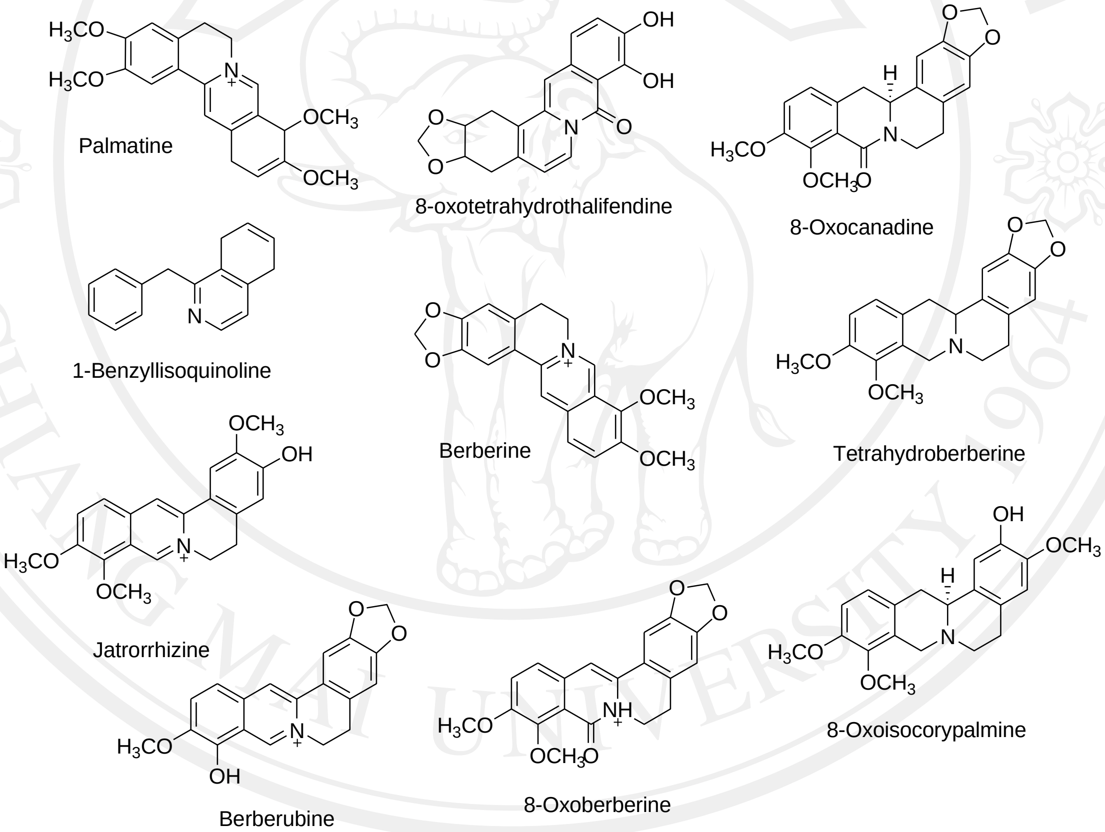


Figure 2.8 Phytoconstituents of *C. fenestratum*

Berberine

Berberine is a major constituent of *C. fenestratum* and it is a yellow crystalline alkaloid [49]. The berberine reported to be one of major compound in *C. fenestratum* [59] and it exhibits multiple pharmacological activities such as being active against hypertension, tumors, bacteria, inflammation, and HIV. It also has anti-protozoal, cholagogue, cardiotonic, anti-cholinergic, anti-arrhythmic effects, and anti-platelet aggregation. Berberine has antagonism effects of cholera and *E. coli* heat-stable enterotoxin. It inhibits the intestinal ion secretion, smooth muscle contraction, ventricular tachyarrhythmias, stimulation of bile secretion and bilirubin discharge and reduces inflammation. Some actions of berberine have been extensively studied and are addressed in the following sections [60] .

Physiological effects of berberine

Anti-diarrheal action

Berberine has been used for centuries in different part of world and is also used in the modern treatment to diarrhea. Its actions in this regard are manifested by its anti-cholinergic, Alpha-adrenoreceptor agonistic, antimicrobial effects. In *in vivo* study by Swapp *et al*. [61], berberine reduced the intestinal transit time of the secretion of water and electrolytes induced by cholera toxin. It has also been shown to directory inhibit some *V. cholera* and *E. coli* enterotoxin, reduce smooth muscle contraction and intestinal motility, and delay intestinal transit time in human [62, 63].

Anti-malarial action

Berberine has been used for the treatment of malaria. In Vietnam, it was collected from 14 medicinal plants and used in traditional treatment of disease. The methanol extract of *C. fenestratum* was found to have the strongest anti-plasmodial effect. Activity-guided fractionation led to the identification of berberine as the major activity component [64, 65].

Anti-tumor action

Berberine possesses anti-tumor properties as evidenced by the inhibition of Cyclooxygenease-2 (COX-2) transcription and N-acetyltransferase (NAT) activity in colon and bladder cancer cell line. It action is transient but markedly inhibits the growth of mouse sarcoma cells in culture [66, 67].

Cardiovascular action

Both clinical trials and animal research have indicated that the administration of berberine prevents ischemia-induced ventricular tachyarrhythmia. It stimulates cardiac contractility and lowers peripheral vascular resistance and blood pressure. An animal was studied and indicated that berberine may suppress the delayed after-depolarization on the ventricular muscle [68, 69].

Anti-inflammatory and antihepatoxic action

Berberine is an effective anti-inflammatory agent. *In vitro* studies utilizing human cell lines demonstrated that it inhibits Activator Protein 1 (AP-1), a key transcription factor in inflammation and carcinogenesis. By using human peripheral lymphocytes, berberine exerts a significant inhibitory effect on lymphocyte transformation. It was suggested that its anti-inflammatory action may be due to the inhibition of DNA synthesis in activated lymphocytes [70, 71].

Other activities

It was found that berberine upregulates Low-Density Lipoprotein Receptor (LDLR) expression in human hepatocytes thorough an Extracellular signal-Regulated Kinase (ERK)-dependent mechanism. These researchers found that berberine significantly lowered blood cholesterol, triglyceride and LDL cholesterol in patients with hyperlipidemia and elevated LDLR expression in the Hepatitis B virus (HBV) full genome-infected human hepatocytes. In addition, berberine in acreased adenosine monophosphate-activated protein kinase and acetyl-coenzyme A carboxylase phosphorylation. These findings indicated that berberine increases glucose uptake through a mechanism distinct from insulin, and stimulated adenosine monophosphate-activated protein kinase seems to be involved in the metabolism effect of berberine [72-74].

2.4 Carbamate pesticides

Carbamate were introduced as pesticides in the early 1950s and still used extensively in pest control due to their effectiveness and broad spectrum of biological activity (insecticides, fungicides, herbicides). High polarity and solubility in water and thermal instability are typical characteristics of carbamate pesticides, as well as high acute toxicity. The carbamates are transformed into various products in consequence of several processes such as hydrolysis, biodegradation, oxidation, photolysis, biotransformation and metabolic reaction in living organisms [75].

Carbamate pesticides are esters of carbamates and organic compounds derived from carbamic acid which in Fig. 2.9. This group of pesticides can be divided into benzimidazole-, *N*-methyl-, *N*-phenyl-, and thiocarbamates. The compounds derived from carbamic acid are probably the insecticides with the widest range of biocide activities [76].

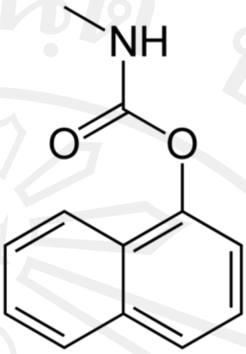
Figure 2.9 General structures of carbamate pesticides

Highly toxic acetylcholinesterase (AChE)-inhibiting pesticides, organophosphates and carbamates are intensively used throughout the world and continue to be responsible for poisoning epidemics in various countries. The carbamates are inhibitors of AChE and are responsible for the greatest number of poisonings in the rural environment. The use of pesticides in the Brazilian rural environment has brought a series of dire consequences to the environment as well as to the health of rural works. The clinical effects of carbamate pesticides depend on the dose, route of exposure, type of carbamate involved, use of protective gear, and the premorbid state of the victim [76, 77].

a) Carbaryl pesticide

Carbaryl, also known by trade name *Sevin* which showed the information in Table 2.1, is a chemical in carbamate family ised chiefly as an insecticide. It is white crystalline solid. It is an NMC insecticide which was first registered in 1959 for use on cotton. In 2001 identified the N-methyl carbamate (NMC insecticides) as a group which shares a common mechanism of toxicity. Therefore, Environmental Protection Agency (EPA) was required to consider the cumulative effects on human health resulting from exposure to this group of chemicals when considering whether to establish, modify, or revoke a tolerance for pesticide residues in food, in accordance with the Food Quality Protection Act (FQPA) [78, 79].

Table 2.1 Carbaryl structure and information

Structure	
Molecular	$C_{12}H_{11}NO_2$
IUPAC name	1-napthyl methylcarbamate
Other name	Sevin

Usage information

The pesticide carbaryl is used in agriculture to control pests on terrestrial food crops including fruits and nuts trees, many types of fruits and vegetables, and grain crops, cut flowers, nursery and ornamentals, turf, including production facilities; greenhouses, golf courses, and in oyster beds. Carbaryl is also registered for use on residential sites (e.g., annuals, perennials, shrubs) by professional pest control operators and homeowners on gardens, ornamentals and turf grass. EPA estimated over 1.4 million pounds of carbaryl are applied each year on agricultural crops over 200,000 lbs are applied annually for turf, landscape and horticultural uses in the U.S.

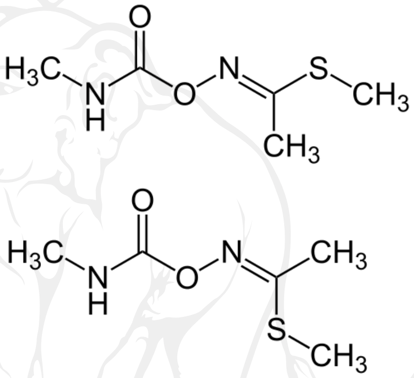
In agricultural uses, carbaryl is used on a myriad of crops. Example of crops currently proposed for continued carbaryl use and which are grown in areas with Pacific salmon and steelhead include cranberries, cucumbers, bean, eggplant, grapefruits, grapes, hay, lemons, lettuce, nectarines, olives, onions, orange, parsley, peaches, peanuts pears, pecans, peppers, pistachios, plums, potatoes, prunes, pumpkins, rice, sod, spinach, squash, strawberries, sugar beets, sunflowers, sweet corn, sweet potatoes, tangelos, tangerines, tomatoes, walnuts, watermelons, wheat. Carbaryl is also used to tin fruit in orchards to enhance fruit size and enhance repeat bloom. In non-agricultural uses, carbaryl is used extensively by homeowners, particularly for lawn care. Examples of non-agricultural use sites include home and commercial lawn, flower beds around building, recreation areas, golf course, sod farms, parks, right-of-way, hedgerows, Christmas tree plantation, oyster beds, rural shelter belts, and applications to control ticks, grasshoppers and adult mosquitoes. Carbaryl is also used for pet care (pet collars, powers and dip, in kennels and on pet sleeping quarters) [80, 81].

b) Methomyl

Methomyl was first registered for use in the U.S. in 1968. It is currently registered for use on a wide variety of sites including field which showed information in Table 2.2. As such its structure is similar to both aldicarb and thiocarboxime. When pure, methomyl is a white crystalline solid with a slight sulfurous odor. At room temperature, it is moderately to highly soluble in water and alcohols.

Methomyl is an oxime carbamate insecticide that controls a broad spectrum of arthropods such as spiders, ticks, moths, files, fettles, aphids, leafhoppers and spider mites often found on various field crops, ranging from fruits to tobacco. Methomyl is formulated as soluble concentrated, a wettable powder or a water-soluble powder and is the active ingredient of Du Pont 1179^{TM}, Flytek^{TM} and Kipsin^{TM} among other trade formulation [Kamrin and Montgomery 1999]. Furthermore, the main formulated water-soluble products contain approximatly 25-90% methomyl, whereas the water-miscible products only contain some 12.5-29% [81, 82].

Table 2.2 Methomyl structure and information

Structure	
Molecular	$C_5H_{10}N_2O_2S$
IUPAC name	(E,Z)-methyl N-{[(methylarnino)carbonyl]oxy}ethanimidothioate
Other name	Lannate, Mesomile, Methomex, Nudrin

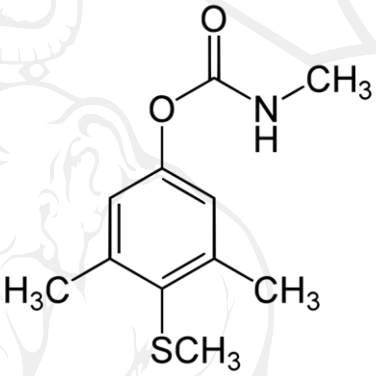
Usage information

In agricultural uses, methomyl is used for a variety of agricultural uses including alfalfa, anise, asparagus, Harley, beans (succulent and dry), heets, Bermuda grass (pasture), blueberries, broccoli, broccoli raab, Brussels sprouts, cabbage, carrot, cauliflower, celery, chicory, Chinese broccoli, Chinese cabbage, collared, (fresh market), corn (sweet), corn (field and popcorn), corn (seed), cotton, cucumber, eggplant endive, garlic, horseradish, leafy green vegetables, lentils, lettuce (head and leaf), lupine, melons, mint, nonbearing nursery stock (field grown), oats, onions (dry and green), peas, peppers, potato, tomatillo, tomato, turf (sod farms only), wheat and orchards including apple, avocado, grapes, grapefruit, lemon, nectarines, orange, peaches, pomegranates, tangelo and tangerine. In non-agricultural, methomyl has several non-crop uses that are outside uses involves scatter bait or bait station formulations including other following use sites; bakeries, beverage plants, broiler houses, canneries, commercial dumpsters which are enclosed, commercial use sites. Commissaries, dairies, dumpsters, fast food establishments, feedlots, food processing establishments, hog houses, kennel, livestock barns, meat processing establishments, poultry houses, poultry processing establishments, restaurants, supermarkets, stables, and warehouses [76, 83].

c) Methiocarb

Methiocarb was first registered as a pesticide in the U.S. in 1972. EPA issued a Registration Standard for methiocarb in March 1987, requiring additional product chemistry, residue chemistry, ecological effect, environmental fate, toxicology, and occupational and residential exposure data. The methiocarb producers deleted all food uses form their product labels in 1989 to 1992. So residue chemistry studies uses no longer required. The technical producer is no longer supporting the commercial turf use of methiocarb. If end-use registrants do not support this use, it will have to be removed from product label. Currently, 22 pesticide products are registered which contain the active ingredient methiocarb. All methiocarb products for outdoor use except products with homeowner uses are classified as Restricted Use Pesticide and may be applied only by under the direct supervision of certified applicators [78, 84].

Table 2.3 Methiocarb structure and information

Structure	
Molecular	$C_{11}H_{15}NO_2S$
IUPAC name	3,5-Dimethyl-4-(methylthio)phenylmethycarbamate
Other name	Mercaptodimethur, Mesurol

Usage information

Methiocarb is a carbamate that has been used as an insecticide and bird repellent. Three registered products contain methiocarb, with a single registrant (Bayer, CropScience Pty Ltd). Two products are palletized and the third a wettable powder that is sprayable after mixing. Baysol Snail & Slug Bait is used for the control of slugs and snails in home gardens. Mesurol Snail and Slug Bait is used in a range of cropping situations, including sunflowers, canola, berry crops, vegetables, vineyards, greenhouses, citrus and ornamentals (including nurseries and cut flower production). Mesurol is also used as a cover spray for snail, slug, insects and bird control [81, 85-87].