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Review

SAPROPEL – MINING CHARACTERISTICS AND POTENTIAL USE IN MEDICINE

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Found in lakes, freshwater sapropel is a sediment with a fine structure containing more than 10% of organic matter as well as residues of aquatic organisms with a small content of inorganic components of biogenic origin and mixture of mineral ingredients. The mud was first used in medicine by ancient Greeks, and it gained more popularity together with development of balneology in Europe in the 19th century as a remedy for several diseases. The last century also brought wider popularity in its cosmetic use. Despite its wide usage, mechanisms behind its effects are not so clear yet. Broad but fragmented studies on the effects of sapropel are available, but few have used modern research methods. There is evidence suggesting that its positive health effects are linked to its thermal capacity, ability of penetration in tissues and biological activity of its components, e.g., humic substances. Evidence also suggests antimicrobial activity and positive effects on skin regeneration. This review aims at summarising available knowledge on the structure and composition of sapropel and its effects on the human body, as well as its potential for further evidence-based use in medicine and cosmetics.

Keywords: *peloids, general characteristics, mud therapy, health benefits.*

INTRODUCTION

Human beings have always been plagued by the need to protect their health and beauty and defend against various illnesses. This can be seen as far back as the 5th century BC when the ancient Greek scientist Herodotus (484–425 BC) conceived the method on the use of mineral waters. In the works of the founding father of medicine, Hippocrates (460–370 BC) references to the curative effects of salted sea water can also be found (Jackson, 1990). In the 19th century, a new scientific discipline — balneology started to develop thanks to the English doctor J. Currie and the founder of modern hydrotherapy — Austrian doctor V. Priessnitz. Balneology uses mineral and thermal waters as well as different types of mud for the improvement of health and treatment of various maladies (Michler, 2005; Miclaus *et al.*, 2011). During the 17th–19th centuries, mud therapy gained popularity in Europe, where there was a rapid development of balneology, with clinics founded in Germany, France, Italy, Austria, and Romania. Experiments testing the application of mineral waters and mud were carried out, testing for the effects of different variables such as temperature, application periods, and chemical composition such as the level of sulphur and nitrous oxides needed for the treatment of patients suffering from arthritis. Mud remedies also gained popularity in cosmetology and cosmetic surgery of the time, with mud being used to speed up the regeneration and renewal of skin (Routh *et al.*, 1996; Groven, 2013; Correia *et al.*, 2016). Later, during the early 20th century, the use of hydrotherapy was combined with other types of therapies, e.g., peloid therapy (also called mud therapy), massage, iontophoresis, phonophoresis physiotherapy, and physical exercise. These methods were aimed at fortifying the patients' health and were rather effective in many cases (Becker, 1994; Guillemin *et al.*, 1994). These therapeutic methods produced effective outcomes for a variety of health problems, such as rheumatological disorders, osteoarthritis, fibromyalgia, spondylosis, and a number of different musculoskeletal disorders (Falagas *et al.*, 2009). Despite the rather long use of peloids including sapropel, scientifically proven results that can be called evidence, started to appear only during the last hundred years. With the recent revival and development of non-pharmaceutical methods in medicine, the importance of positive scientific evidence of the health effects of sapropel has increased. Detailed and systematic search of peloids and sapropel is essential to encourage scientifically sound medical and cosmetic use of sapropel based on firm evidence (such as balneology) at the same time facilitating a wider usage of local natural resources in healthcare and medical cosmetics.

Peloids formed during complex biological transformations of Holocene sediment. It consists of mud substance, crystal frames and a colloid fraction. F. Guimaraes and L. Guimaraes were the first researchers who started to use the term "peloids", in 1931 (Gomes *et al.,* 2013). The first chemical analysis of peloids was already performed in 1807 by French chemist Desser (Tserenkhand and Badnainyambuu, 2016). The mud substance is composed of various minerals, while the crystal frame is formed by poorly dissolved plaster, clay, and carbonate particles. The colloid fraction, however, is more complex, consisting from different organic substances such as silicic acid and iron and aluminium hydroxides. The organic substances constitute from 50 to 98% of dry mass in peat mud and from 15 to 95% in sapropel. Organic substances in mud are mainly composed of humic substances, waxes, vitamins, ferments, and amino acids. Peat mud also contains lignin and celluloses. Other various complex substances based on oxygen, carbon, iron, phosphorus, silica, sulphur etc. also possess biologically active characteristics. Hydrogen sulphides found in mud as soluble sulphides, hydrogen sulphide and ferrous-sulphide are believed to have significant medical effects. There are several types of sapropel and the most common classification used is linked to their origin, e.g., seawater sapropel and freshwater sapropel (Segliņš and Brangulis, 1996; Tserenpil *et al*., 2010; Stankeviča and Kļaviņš, 2013).

The structure and content of sapropel depends on the place of extraction and can vary significantly. There have been several attempts to establish a common classification involving the freshwater, seawater, and thermal muds based on their mineralisation level. The most popular classification method used today was elaborated by V. Aleksandrov in 1958 (Dēliņa *et al*., 2016). This classification system defines:

1) inorganic sediment mud — mud from various lagoons, mud from the seabed, rivers and lakes (partially);

2) organic sediment mud, including sapropel — mud from the seabed of various lagoons as well as freshwater and saltwater lakes;

3) peat mud — dominated by a humic organic substance with some inorganic impurities;

4) mixed mud — consisting of inorganic substances and a small amount of plant residues;

5) volcanic mud, including hydrothermal mud;

6) artificial mud with a similar structure to some groups of natural mud (Dēliņa *et al*., 2016; Rautureau *et al*., 2017; Gomes *et al*., 2013).

SAPROPEL

Sapropel is a fine-graded organic sediment found in freshwater lakes that is produced by sedimentation and transformation of residues from aquatic plants and various living organisms together with mineral particles (e.g., sand, clay, calcium carbonate, etc.) (Stankevica *et al*., 2016). Freshwater lakes in Latvia can possibly contain both sapropel and peat mud. The difference between them mostly lays in their finer structure, acidity, content of organic and humic substances, and the types of sedement-forming living organisms. Peat mud was formed in an anaerobic environment while the sapropel mud commonly developed in an environment that contains oxygen. The pH level of peat mud mainly is acidic while sapropel is neutral. The organic part in peat mud is usually around 50% while in sapropel mud it can typically fluctuate between 15 to 85%. Peat mud is mostly formed by various plants that grow in swamps, deciduous and coniferous trees, scrubs, grasses and mosses (Stankeviča and Kļaviņš, 2013), while sapropel is typically formed by aquatic organisms, such as phytoplankton, zooplankton, and water and coastal plants (Korde, 1960; Stankeviča and Kļaviņš, 2013; Leonova *et al*., 2015). The name "sapropel" originated from Greek words: *sapros* — rotten and *pelos* — clay. First the terms "gyttja" un "dy" were used by the Swedish researcher H. von Post in 1862, but German researcher R. Lauterborn proposed the term "sapropel" in 1901, which was widely introduced in the scientific terminology by D. Potonie (Nijenhuis, 1999; Stankeviča and Kļaviņš, 2013).

Sapropel is a renewable natural resource; the average intensity of formation of sediment varies from 0.1 to 6.64 mm per year depending on the type of lake and climate. Sapropel mud develops in lakes and similar water basins where the formation of biomass exceeds mineralisation; such processes are widespread in lakes found in mild climate zones, particularly in forested areas, shallow and overgrown lakes as well as swampy river beds and valleys (Stankeviča and Kļaviņš, 2013).

MINING OF SAPROPEL IN THE WORLD AND LATVIA

The most intensive formation and accumulation of sapropel occurred in the mild climate zones of Europe and Asia, but the deposits of sapropel have not been thoroughly surveyed. They have been found in Belarus, Ukraine, Russia, Mongolia, Germany, Poland, Czech Republic, Romania, Estonia, France, the Scandinavian countries as well as North America (Anderson, 1996; Tserenpil *et al*., 2010; Strakhovenko *et al*., 2014; Leonova *et al*., 2015; Pleiksnis *et al*., 2015). In some countries the study of sapropel deposits has been mostly focused on saltwater sapropel and freshwater sapropel extraction opportunities have not been properly and systematically addressed (Leonova *et al*., 2015).

There are more than 2250 lakes in the territory of Latvia, but only 16 of them cover more than 10 km^2. The total lake surface in Latvia is approximately 1000 km^2 or 1.5% of the territory of Latvia. It has been proven that most of the Latvian lakes and some of the swamps can contain sapropel deposits. It has been estimated that the total stock of sapropel in Latvian lakes could be around 700 million m^3 (Nikodemus *et al*., 2018). Silicate sapropel with ash content of over 65% (as well as limonite sapropel with iron oxide content over 10%) has the potential for further usage (Segliņš and Brangulis, 1996). The largest sapropel deposits with over 300 million m^3 are found in several regions in Latgale: Rēzekne — 94.2 million m^3, Preiļi — 66.1 million m^3 and Daugavpils — 65.3 million m^3. Significant deposits are also found in the regions of Krāslava and Ludza (Lācis, 2003; Noviks *et al*., 2019, pp. 113–116).

CHARACTERISTICS OF SAPROPEL

As mentioned before, sapropel is a fine-graded organic sediment of freshwater lakes that contains more than 10% of residues made of organic substances and various living organisms with a small content of inorganic biogenic compounds and mineral ingredients (e.g., sand, clay, calcium carbonate etc.). Sapropel is a pasty substance with different colours (light grey, rose, brown, olive or black) with a pH level from 5 to 8 and humidity in the range of 65 to 95% (Korde, 1960; Kurzo *et al*., 2012; Leonova *et al*., 2015).

Sapropel sediments in lakes and swamps started to develop after the last ice-age, which took place 12–15 thousand years ago (Stankeviča and Kļaviņš, 2013). However, massive formations of sapropel started to develop during the Holocene period (10 000 years BC) and the oldest know deposits are roughly 11–12 thousand years old (Stankeviča and Kļaviņš, 2013). Sapropel could have an autochthonous origin if the formation had been caused by the sedimentation of the lake biomass, as well as allochthonous origin in cases where the lake biomass deposits were supported by additional biomass and organic compounds (humic substances) from inbound rivers. Higher levels of organic substances are found in sediments of autochthonous origin (Strakhovenko *et al*., 2014; Yermolaeva *et al*., 2016).

There are several theories that describe the formation process of sapropel. The most popular theory is that the main mass of sapropel is composed by three main components: mineral substances of allochthonous origin, inorganic compounds with biogenic origin and organic substances (both autochthonous and allochthonous origin) — residues of plants and small aquatic organisms (Schepetkin *et al*., 2002; Lācis, 2003; Stankeviča and Kļaviņš, 2013; Strakhovenko *et al*., 2014). A literature review by Stankeviča and Klaviņš (2013), which also covers various classification systems of sapropel, found that there was no agreement on a single theory and that there are various opinions and systems used. The most popular classification system used for freshwater sapropel that can be used for the determination of potential sapropel use is a three-group approach (biogenic, clastic, and mixed sapropel) that is further divided into several classes (organogenic, organogenic-silicates, diatoms, silicates, carbonates, and iron containing) (Stankeviča and Kļaviņš, 2013).

STRUCTURE AND CHARACTERISTICS OF SAPROPEL

Sapropel has a complicated chemical structure that is determined by the biological and biochemical variety of organisms and the compounds forming it from the three main components — organic substances, minerals, and residues of plants and aquatic organisms (Strakhovenko *et at*., 2014; Leonova *et al*., 2015). One of the most important characteristics of sapropel is its colloidal structures, as these structures can tie up a significant amount of water that is very slowly released afterwards. After drying, the mud loses its ability to attract more water and thus the specific mass and density are higher.

The potential for the use of sapropel is determined mostly by its composition, physical, and mechanical characteristics. In general, the most important properties of sapropel are the following: high dispersity, good plasticity (colloid characteristics), thermal capacity, low heat transfer, absorption capacity, homogeneity, consistence, biostimulation, antioxidation, and antimicrobial characteristics (Schepetkin *et al*., 2002; Suárez Muñoz *et al*., 2015; Dēliņa *et al*., 2016).

CHARACTERISTICS OF ORGANIC COMPOUNDS

Various authors have slightly different definitions of organic substances that form sapropel. They can be defined as insoluble leftovers of hydrobionts (e.g., fishes) and colloid organic substances that have been brought from inbound waters, including biological and organic components that are mostly biopolymer and adsorption complexes with a low molecular mass (Kurzo *et al*. 2012; Stankeviča and Klaviņš, 2013; Strakhovenko *et al*., 2014). However, sapropel has a very low content of carbohydrates. Organic and humic substances that can be found in sapropel are shown in the Figure 1 (Stevenson, 1982).

The main substances that are formed in the process of plant humification are fulvic and humic acids; they comprise a general category of naturally occurring, biogenic, heterogeneous, and refractory organic substances of high molecular weight (Stevenson, 1982).

Other important components of sapropel are various waxes (lipids). Their composition is characterised by fatty acids, carotenoids, paraffins, and waxes. The wax components of sapropel have high potential use in medicine as they have

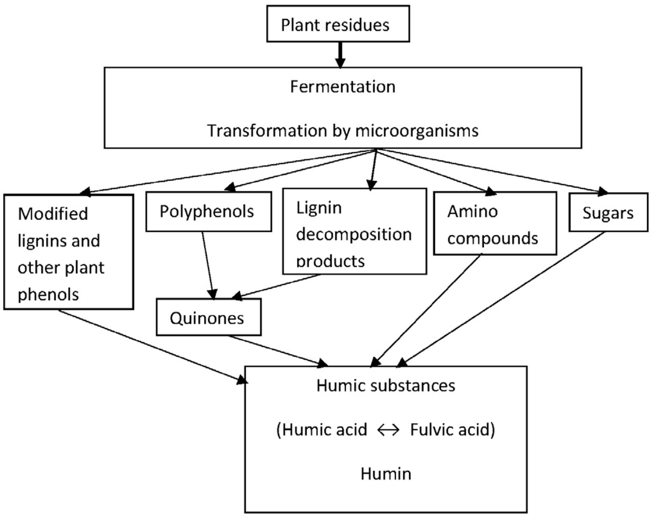

Fig. 1. Formation of organic and humic substances in sapropel (by Stevenson, 1982).

high bactericidal, bacteriostatic and antioxidant activity. There is also a high level of carotenoids in freshwater sapropel (Stankeviča and Kļaviņš, 2013; Kurzo *et al.*, 2017).

CHARACTERISTICS OF HUMIC ACIDS AND FULVIC ACIDS

Humic substances form a significant part of sapropel. Their age can vary from several hundred years up to 10 000 years, depending on their deposition site. Molecular size can vary from 400 up to 1 000 000 daltons. Humic substances in sapropel can form metal complexes, dissolve hydrophobic organic substances and reduce surface tension (Meng *et al.*, 2017).

Depending on their water solubility there are three different fractions:

- humine: fraction that is insoluble in water;
- humic acids: fraction that is soluble in water if the pH is higher than 2;
- fulvic acids: fraction of humic substances that is soluble in water regardless of pH.

Humic substances can form in various environmental settings, usually they have autochthonous origin, or they can be brought from various other environments, e.g., washed out from soil to the surface or from deep-water sediments. Humic substances form as a result from secondary synthesis (humification) during decomposition, when biomolecules are transformed after being produced by various microorganisms that consume residues of plants or aquatic organisms. Humification is an extremely complicated biochemical process — decomposition of residues of plants and aquatic organisms, mineralisation of organic substances, effects of microorganisms to organic resides etc., which leads to further decomposition of organic substances, further transformation and accumulation of different substances (Kireicheva and Khokhlova, 2000). There has been some research on the toxicological properties of humic substances that showed that toxicity of humic substances formed in natural processes is very low (Krūmiņš *et al.*, 2013).

CHARACTERISTICS OF MINERAL SUBSTANCES

The content of mineral substances in sapropel is very different among deposits. Formation of mineral complexes in sediments of freshwater lakes is often linked to inbound river waters in lakes where sedimentation of minerals as well as soluble minerals occurs. The most common sediment materials leached into waters are quartz, dolomite, silicates, and aluminosilicates (feldspar, hydrous mica, chlorite, kaolinite etc.) (Leonova *et al.*, 2015; Glavaš *et al.*, 2017). Biochemical processes lead to deposition of Mg, Ca, Sr, Ba, Fe, Mn, carbonates, plaster, hematite, pyrite, marcasite, and vivianite in sapropel (Tserenkhand and Badnainyambuu, 2016). Iron phosphates as well as iron oxides are also rather common in all types of sapropel and their contents are linked negatively to carbonate content. The content of iron phosphates in carbonated sapropel is 0.4% on average, mixed sapropel — 0.8% and 1.4% in silica sapropel, respectively (Stankeviča and Kļaviņš, 2013).

Depending on the concentration of microelements sapropel can be divided into:

- silica sapropel;
- mixed type sapropel;
- organic sapropel;
- carbonated sapropel.

Sapropel also contains microelements Mn, Co, Mo, Cu, Ni etc. Silica sapropel is particularly rich in microelements, but relatively low concentrations of these microelements can are found in carbonated sapropel. The total content of B, Ni, Cu, Co, V, Mo, Cr can vary from 20 to 150 mg/kg dry mass, and for Ti, Mn, Zn from 200–2000 µg/kg dry mass. Some other elements are also found, e.g., iodine can be deposited in sapropel from plants (Stankeviča and Kļaviņš, 2013). Another research direction is analysis of processes that occur during the maturation of sapropel and other peloids; these are believed to be associated with changes in the redox environment as well as the processes that cause release of ions and other compounds and their incorporation in the sediment. Some of the potentially toxic elements (e.g., Cd, Pb, Hg, Cr, As, Fe, Zn, Mn, Cu) are also of concern to researchers as they can penetrate the skin, especially after contact with sweat (Suárez Muñoz *et al.*, 2015).

Another unresolved issue is the effect of various heavy metals that are found in sapropel as there are risks that, if the sapropel is used for medical or cosmetic purposes, further reactions are possible between these metals and other components of sapropel, especially when they interact with human biomembranes and can easily resorb through the skin (Mihelčič *et al*., 2012).

CHARACTERISTICS OF MICROORGANISMS

Freshwater sapropel can contain waste amounts of various microorganisms — 1 gram of sapropel (upper level) can contain up to 1–2 billions of microorganisms (Stankeviča and Kļaviņš, 2013). There are significantly larger bacterial populations in sapropel sediments that are rich with organic substances, compared with mineral sapropels. For example, the bacterial population size can be as high as 7.76 (10^8) cells per cm^3 near surface levels (seawater sapropel) and as low as 1.0 (10^6) per cm^3 below the sea floor (Cragg *et al*., 1998). Apparently, the available oxygen levels in sediment at different depths influence the diversity of microorganisms and their chemical and biochemical reactions, and also influence the general sedimentation rate of sapropel as the presence of oxygen can both stimulate or inhibit the growth of microorganisms in sapropel (Wurzbacher *et al*., 2010; Stankevica *et.al*., 2014).

Fungi and actinomycete are known to participate in synthesis of antibiotics and sulphanilamide, and bacteria and algae produce vitamins that also participate in organic substance decomposition, thus participating in humification (Nikolajev, 2003). Not only the living organisms are responsible for destruction of various organic substances and creation of sediment, but they also can regenerate and preserve some of the organisms. New therapeutically active compounds can be formed during maturation by the action of the growth of living organisms including diatoms, cyanophycean, bacteria, protozoa, and the organic compounds originated by their metabolic activity and degradation (Gomes *et al*., 2013). Microorganisms are also responsible partly for the release of various gasses (hydrogen sulphide, ammonia, methane etc.). All these processes of biologically active and antibacterial substance sedimentation can lead to potential health effects when sapropel is used in balneology.

However, in the deepest levels of sapropel the microbiological activity is practically nil, thus making the humification processes slow. Studies in Latvia (lakes Kaņieris and Babītes) found that the spread and biochemical activity of microorganisms are directly linked to depth of sediment as well climatic conditions (time of the year) (Sturis, 1965). Similar results were also found in Russia (Lake Ochki) (Leonova *et al*., 2015). The highest activity of microorganisms was found in the sediment levels ranging from 0.1 to 0.5 meter depth, but activity decreased rapidly from a depth of more than 1 meter (Sturis, 1965). Table 1 lists the groups of microorganisms found in sapropel samples using oat agar. The following groups of bacteria were identified in samples: ammonifying bacteria 1.5 × 105 colony forming units (CFU); *Genus bacillus* 4.7 × 02 CFU; *Oligotrophyc bacteria* 3.8 × 102 CFU. However, the full spectre of bacteria determined using DNS sequencing has not been performed yet.

Table 1. Percentage of microorganisms found in sapropel

Microorganisms	Quantity (%)
Bacteria	92.3
Actinomycetes	5.1
Micromycette	2.6

USE OF SAPROPEL IN MEDICINE

The multidimensional effects of sapropel on the human body can be explained by its complicated chemical composition and biological structure. Its effects are also linked to significant thermal capacity as well as the content of various metals and other chemical elements, hormones, amino acids etc., which have the potential to penetrate the dermal barrier. Biological activity of sapropel is determined by a variety of components that are known to be biologically active, e.g., humic substances, fulvic acid, hemotamalanic acid, water soluble vitamins (ascorbic acid (C), thiamine (B1), riboflavin (B2), pantothenic acid (B5), pyridoxine (B6), folic acid (B9), and cyanocobalamin). A significant number of fat-soluble vitamins like tocopherol (E), vitamins D and P have also been found as well as some microorganisms known to be capable of producing antibiotics that are antagonistic towards several saprophytic pathogens (Kireicheva and Khokhlova, 2000; Szajdak and Maryganova, 2007).

The presence of quartz and calcite in sapropel can also contribute to the beneficial effects of sapropel and its potential application in balneology (including spa and beauty therapy). The small quartz and calcite particles are known to have stimulatory effect on certain mechanisms in the body, for example, circulation (Glavaš *et al*., 2017).

The acid base balance (pH) of sapropel is rather close to that of a healthy human skin that ensures better penetration into the deeper layers of skin. These characteristics to some extent provide a dual process. During application of sapropel there is penetration from sapropel towards human body and the reverse, as sapropel can absorb some toxins that are being transferred through skin. There is no evidence that sapropel would be responsible for side effects so its use in medicine should be expanded and more research is required to scientifically back the health effects of sapropel. Several sources (Veniale *et al.,* 2007; Gomes *et al.,* 2013; Rautureau *et al.*, 2017) state that peloids can be used for:

- improvement of blood and lymph flow, strengthening of blood vessels, improvement of oxygen exchange;
- improvement of antibacterial therapy due to antibacterial properties;
- enrichment of the body with calcium, magnesium, bromine, iodine, potassium and amino acids;
- reduction of skin aging processes due to its antioxidation properties;

- regeneration of hydro-lipid membranes;
- improvement of skin structure, reduction of subdermatic fat tissue; reduces wrinkles;
- reduction of swellings;
- improvement of nail and hair growth and prevention of hair loss;
- improvement of skin fat gland function;
- improvement of immune system function;
- reduction of symptoms of some skin diseases (psoriasis, seborrhoea, acne etc.).

Currently, sapropel products are mostly used in balneotherapy and cosmetology, especially for chronic conditions. The medical use of peat and sapropel in Europe dates back to the first half on 19th century. Traditional indications in European practice have been various diseases of the musculo-skeletal system, gynaecological, rheumatological, as well as dermatological disorders (Karelina, 1999; Badalov and Krikorova, 2012). A review by Stankeviča and Kļaviņš provided wide information regarding the use of humic substances (especially fulvic acids) for treatment of various diseases: asthma, respiratory diseases, autoimmune arthritis, oncological diseases, virus haemorrhagic fever, ulcerative colitis, diabetes, stomach bleeding, gastritis, duodenal ulcer etc. Several studies have shown that humic substances have anti-inflammatory effects. Some studies also showed that humic substances can protect liver cells from destructive changes caused by external factors and functional overload (Stankeviča and Kļaviņš, 2013). There is also relatively wide information about the effects of humic substances from natural sources on their ability to absorb heavy metals. Humic substances tend to create chelation complexes with toxic heavy metals, which provides an opportunity to use these substances for chelation therapy both for excretion of them and for reduction of toxic side effects. F. N. J. Ridwan observed that even 0.1% application of humic substances was sufficient to demonstrate assimilation of lead and cadmium in test animals (Krūmiņš *et al.*, 2013).

EFFECTS OF SAPROPEL ON MICROCIRCULATION IN SKIN AND MUSCLES (THERMAL CAPACITY)

Several studies have shown that the therapeutic mechanism of peloids in general and sapropel is based on relatively high thermal capacity, poor heat transfer and low convection capacity, which ensure that the accumulated heat is slowly radiated and thus provides slow and deep heat transfer to tissue (Schepetkin *et al.*, 2002; Suárez Muñoz *et al.*, 2015). Already in 1920, a theory was formulated that friction between the skin and peloids creates an electric potential that has a positive effect on microcirculation in skin and muscles. Application of sapropel influences various receptors in skin and mucous membranes, thus initiating reflective stimulation towards the neuro-endocrine system and circulation system, which influences functional changes of microcirculation and metabolism in tissues, organs and organ systems. Warmed sapropel application has been used as a treatment for phlegmons, mastitis, furuncles, chronic gastritis etc. Use of peloids can be viewed as an effective method to induce the whole-body reactivity. Clinical and experimental studies have shown that biological substances of sapropel have a high potential for penetration of skin and tissues and are capable of induction of cell response, thus improving circulation. Sapropel applications are known to improve peripheral blood circulation, oxygen transportation and metabolism. It also improves coronary circulation, changes contractility of myocardial tissue and peripheral resistance. During sapropel application, there is an increase in pulse and breathing rate, elevation of blood pressure, increased sweating, kidney function as well as reduced activity of the gastrointestinal system (Uzbekov, 1958; Kostjakova, 1985; Carabelli *et al.*, 1998; Odabasi, 2008; Espejo-Antúnez, 2012). Several studies showed that changes in microcirculation and small blood vessels cannot be explained solely by vasodilatation (Poensin *et al.*, 2003). Changes in markers responsible for inflammatory mechanisms and articular pain — TNF-alfa, IL-1ß, PGE2 and LTB4 levels were observed after sapropel application. A lower level of reaction is believed to be linked with metabolism stimulation in cartilage. Levels of pituitary hormones were observed to increase due to activation of the hypothalamic-pituitary gland axis as an answer to heat stress induced by the specific thermal capacity of sapropel (Bellometti *et al.*, 2000; 2002). Significant reduction in superoxide dismutase and catalase activity was found after the application of sapropel at 42 °C (Jokić *et al.*, 2010).

EFFECTS OF SAPROPEL ON TISSUE REGENERATION AND IMMUNE SYSTEM

Sapropel has biostimulating effects — it stimulates metabolism and the immune system, encapsulation around foreign bodies in tissue, better healing of wounds and regeneration of tissue and it has desensitisation properties. Sapropel stimulates functioning of phagocytes, resulting in intense tissue regeneration. A 12-day trial showed that after application of hot sapropel (47 °C) there were no significant changes in SP-selectine, IL-1 and TNF-alfa but there was a statistically significant reduction in the IL-6 level, showing that sapropel application could be considered as a safe procedure for patients with atherothrombosis (Basili *et al.*, 2001). Several cytokines and growth factors are responsible for inflammatory processes and degeneration of cartilage, including IL-1 and TNF-alfa that promote reduction of cartilage inflammation, while IGF I is responsible for protection of cartilage structure (Bellometti *et al.*, 1997). A study that involved 37 arthritis patients found that sapropel baths had positive effects both on homeostasis of cartilage and reduction of inflammation, reducing values of NO and myeloperoxidase, while there was no correlation in increase of GSH peroxidase (Bellometti *et al.*, 2000). Another study focused on analysing the fermentative and molecular mechanisms during sapropel application. It was found that TNF-alfa, IL-1ß, PGE2 and LTB4 levels were reduced

(Bellometti *et al.*, 2002), but synthesis of noradrenaline, cortisol, beta endorphins and insulin increased (Bellometti *et al.*, 1996).

ANTIOXIDANT EFFECTS OF SAPROPEL

It is possible to prepare various products from sapropel that have antioxidant characteristics. Research into antioxidant activity of humic substances showed that it had capacity for a direct effect towards neutralisation of various forms of active oxygen as well as several other chemical radicals that are produced as side products in metabolism (Fedko *et al.*, 2005).

Fulvic and humic acids in sapropel are another known antioxidant that reduces the amounts of superoxides and free radicals and thus can play a significant role in inflammatory processes. Fulvic acid is also known for natural chelation with capacity to reduce toxicity of various organic xenobiotics by reducing their transport within the cell. Humic acid in doses from 10 to 100 μg/ml has effect on lipid peroxidation, depending on the dose. Such changes are followed by destruction of glutathione and reduction in activity of catalase, dismutase superoxide, glucose-6-phosphatase and dehydrogenase. Humic acid and fulvic acids increased the amount of informative RNS in cells that is responsible for various biochemical processes. The amount of several enzymes increases, which in turn positively affects the rate of several catalytic reactions (de Melo *et al.*, 2016).

ANTIMICROBIAL AND BACTERIOSTATIC CHARACTERISTICS

Sapropel has antimicrobial and bacteriostatic characteristics — ability to hinder growth of pathogenic microorganisms or to destroy them, thus influencing faster end of inflammatory processes (Strus *et al.*, 2014; Suraganova *et al.*, 2014; Tretjakova *et al.*, 2015). Several microorganisms have been found in sapropel, which are capable of producing antibiotics that are antagonistic to several saprophytic pathogens. This ability has been successfully used in balneology. Antimicrobial activity has been evaluated against *Staphylococcus aureus, Escherichia coli ĄŅŃŃ 25922, Pseudomonas aeruginosa ĄŅŃŃ 27853, Bacillus subtilis ĄŅŃŃ 6633, Proteus vulgaris ATCC 4636, Candida albicans ĄŅŃŃ 885/653* and it was found out that antimicrobial activity is more evident with application (exposure) time (30, 60, 120, 240 minutes) (Suraganova *et al.*, 2014).

A study of Lake Pribic (Volinska region, Russia) and antimicrobial properties of its sapropel sediment confirmed antimicrobial activity against the following test cultures — *Escherichia coli ATCC 25922, Pseudomonas aeruginosa ATCC 27853, Basillus subtilis ATCC 6633, Proteus vulgaris ATCC 4636,* and *Candida albicans ATCC 885/653*, while it was not active against *Staphylococcus aureus* (Strus *et al.*, 2014).

Another study analysed the antimicrobial activity of dried sapropel mud (from Lakes Ruson and Ubagova, Latvia). Its antimicrobial activity was tested on the following cultures — *Staphylococcus aureus ATCC 25923, Salmonella enteritidis ATCC 13076, Enterococcus faecalis ATCC 29212, Bacillus cereus ATCC 10876, Escherichia coli ATCC 25922,* and *Candida albicans ATCC 10231* (Tretjakova *et al.*, 2015). It was found that the samples showed activity against a reference culture of *Staphylococcus aureus* (before exposure to direct sunlight) while samples from Ubagova lake did not showed any activity (Tretjakova *et al.*, 2015). It is possible that fresh or correctly stored sapropel has different antimicrobial activity than for dried samples (Tretjakova *et al.*, 2015). A study at Lebazje Lake (Tatarstan) analysed biological activity of sapropel, and found that the biological activity is linked to microorganisms — antagonists: spore forming mould, fungi and actynomicetes. Microorganisms in sapropel (nitrifying, denitrifying, ammonium groups, mycobacteria, funghi etc.) engage in production of nitrogen compounds that have effects on ferment activity of catalase, peroxidase, dehydrogenase. Sapropel is rich with water soluble vitamins and has strong antimicrobial activity against *Staphylococcus aureus*. Antimicrobial activity was also identified against *E. coli, C. perfringens* and *Ps. aeruginosa* (Platonov *et al.*, 2014). It has also been found that sapropel contains large numbers of bacteria and actinomyceta that have antimicrobial activity against pathogens. Antagonism has been identified against typhoid and parathytic pathognes as well some pathogenic fungi (*Achovion Schorleini, Achovion gypseum etc.*) (Marchenko and Gurinovich, 1976).

Several publications also note antibacterial anti fungi activity of humic substances (Fedko *et al.*, 2005). Several patents have been registered for sapropel-based products using these characteristics of humic substances (Fedko *et al.*, 2005). Recent studies show mediatory capacity of H_2S (hydrogen sulphide) (gaseous form) and the effects of H_2S on regulation of inflammatory processes in tissues, which can be another mechanism for potential beneficial effects of sapropel towards reduction of inflammatory processes (Brancaleone *et al.*, 2014).

USE OF SAPROPEL IN MEDICINE AND COSMETICS

There is wide potential for use of sapropel in both medicine and cosmetology. Sapropel demonstrates powerful healing and restorative effects on the human body due to its composition and content of variety of chemically active substances — carotenoids, tocopherols, polyphenols, chlorophylls, flavonoids, phospholipids, enzymes as well as humic acids and some other biologically active substances. Traditional indications for balneology in European medical practice are musculo-skeletal disorders, gynaecological, dermatological diseases as well as some diseases in stomatology (Dunaev *et al.*, 1996). Sapropel has also been successfully used for treatment of chronic disorders (Strelis and Zhivotiagina, 1991; Karelina, 1999). Characteristics of fulvic acids and humic acids have been successfully used for treatment of diabetes, cold stress, rheumatic disorders, immune disorders etc. Fulvic and humic acids chemically link and excrete toxins and heavy metals (Krūmiņš *et al.*, 2013). Sapropel and its extracts are successfully used in cosmetic products due to their ability to prevent and reduce aging effects, improve regeneration of skin and regulate skin moisture levels as well as improve the natural ability of skin to protect the body against ultraviolet light. Sapropel also has antibacterial properties and many cosmetic products using sapropel have been invented and patented as soaps, tonics, cleansing masks, massage oils, shampoos etc.

However, the medical characteristics of Latvian sapropel have been insufficiently studied and further studies are necessary to elaborate evidence-based suggestions for its use in balneology, ensuring development of new medical procedures and services and promoting development of new export products.

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SAPROPELIS — IEGUVES VIETAS, RAKSTUROJUMS UN PIELIETOJUMS MEDICĪNĀ

Saldūdens sapropelis ir nogulumi ar smalku struktūru ezeros, kuri satur vairāk nekā 10% organisko vielu — ūdens organismu atliekas ar nelielu biogēnas izcelsmes neorganisku komponentu saturu, kā arī minerālo ingredientu piejaukumu. Sapropeli lietojuši jau senie grieķi, bet plašāku popularitāti tas ieguva 19. gadsimtā, attīstoties balneoloģijai, kur sapropelis tika izmantots vairāku slimību ārstēšanā. Pēdējā gadsimta laikā tas plaši lietots arī kā kosmētisko līdzekļu sastāvdaļa. Neraugoties uz sapropeļa plašo izmantojumu, zinātniskā izpēte par tā iedarbības mehānismiem nav pietiekami detalizēta. Veikti plaši, taču fragmentēti pētījumi, tomēr tādu, kuros lietotas modernas izpētes metodes, nav daudz. Pētījumi liecina, ka sapropeļa pozitīva ietekme uz organismu saistīta ar tā īpatnējo siltumspēju, kā arī spēju iekļūt audos un tā sastāvā esošo vielu, piemēram, humīnskābju, bioloģisko aktivitāti. Pētījumi liecina arī par sapropeļa antimikrobiālo ietekmi un pozitīvo iespaidu uz ādas reģenerāciju. Šī apskata mērķis ir apkopot pieejamo zinātnisko informāciju par sapropeļa struktūru un sastāvu, tā ietekmi uz cilvēka ķermeni un tā zinātniski pamatotas lietošanas potenciālu medicīnā un kosmetoloģijā.