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# MATERIAL FLOWS AND MATERIAL HISTORIES

JENS SOENTGEN

In environmental science we often hear of "material flows," "resource flows," or "material cycles" as well as of demands that "the material cycle should be closed" or "material flow management" should be practised. When actors intervene in "natural material cycles," they are often referred to in the masculine singular, for instance, when it is said that "man" intervenes in this or that "material cycle".

Such formulations have their origins in scientific disciplines such as ecological chemistry or in ecologically oriented economic sciences. These disciplines attempt to identify certain ecological effects of particular materials that are traded as (legal) goods; their aim is to identify opportunities for ecological improvements like, for instance, a minimisation of the carbon footprint of this or that product. Today, there is a variety of methods for carrying out such analyses, and some of these methods have already been standardised. They bear names such as "material flow analysis," "life cycle assessment," "carbon accounting," etc. There is no doubt that these quantifying methods are important in the attempt to make the production, transport, use, ~~or~~ disposal of certain goods more sustainable.

On the other hand, metaphors of material flow and the concepts and images of the cycle may obscure the important fact that things and materials must first be brought to and kept on those "pathways" that are then idealised as flows or circular pathways (for a similar argument, cf. Caviola & Sedlaczek 2020). Materials are very often mobilised (and immobilised) in contexts of human action; they are isolated, named, explained, manufactured, traded, perhaps smuggled, used, and then dumped, discarded, contained, washed away, burned or buried, or transported onward by certain collectives in certain political and legal situations – legally or illegally, secretly or openly, based on certain cultural attributions of meaning.

Moreover, there is a second shortcoming in the scientific talk about flows or circles. The materials, the substances themselves are viewed in a much too passive and mechanic manner. No substance moves in geometric ways; no movement of any substance ever returns completely to its starting point. In addition, substances never move in isolation; more or less numerous other substances are always co-mobilised as well, yet their movements are usually undesirable, often unforeseen, and only rarely find their way into representation. Once they have been released into the open, substances more or less quickly spread over the world according to their own plan: for instance, they

migrate through the air or seep into the ground, are transported onward by groundwater to appear elsewhere. Or they enter organisms and are transported from there along the food chain, sometimes being transformed or accumulated during the process. On their way, they may meet other dissolved or evaporated materials and, as a consequence of this meeting, start to change; very often they transform when exposed to sunlight.

The mobilisation of materials and its unforeseen and sometimes even toxic effects must therefore be made clear in a different and more precise way – and to do so, it makes sense to study the movements of materials in *material histories*, which may complement the quantitative approach of "material flow analysis".

## Materials

In the following, materials are not primarily understood as purified laboratory objects but as everyday phenomena that all people deal with, at least, but not exclusively, in the context of cooking, eating, drinking, and body-care.[1] Examples are water, soap, skin cream, salt, flour, sugar, sand, glass, steel, rust etc. It is possible to develop a clear phenomenological notion of materials in the sense of that particular stuff or another, i.e., a notion that is developed independently from chemistry but can be linked at the same time to chemical research. Nearly three decades ago, I tried to do this, departing from older, yet still very important phenomenological research into the concepts of 'thing' and 'material'.

To start such an endeavor, it is important to distinguish materials from things. Materials differ from things; in particular, in that they can be portioned, i.e. they are divisible in any direction without losing their identity. For example, if you divide a piece of chocolate into two portions, the resulting pieces are still pieces of chocolate. If you tear a thing, say a book, in half, you do not get two books, but a torn book, or simply "paper". Any given material can be portioned within certain, very broad limits without losing its identity. Things, on the other hand, cannot be treated in such aggressive ways. They have distinct sides, at least a front and a back, which hide each other. The typical thing is a material thing: it is made of one material or an assembly of several materials. Thus, any characterisation of materials is also a contribution to the characteristics of things.

Because substances are portionable, it is possible and even normal to find any kind of substance in many places at the same time, or at least in more than one place. Substances *occur*, i.e. they do not only exist at one place in the world as is usually the case with certain types of things (art works for example).

Portionability, however, is but one half of the concept of substance: its mechanistic half. Not only chemical studies but also a phenomenological analysis can reveal that

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1 Materials may also be referred to as "substances" or even "stuff" (from German, *Stoff*). Cf., for instance, Soentgen (1997; 2008; 2019: 18–23).

**Figure 9.1:** Jens Soentgen, *Ramified Dissipation of a Textile Dye on Paste,* 2014.

materials always develop their own activity: they feature auto-mobility, distribute themselves into the world, mingle with the world, and mix with other substances (cf. Soentgen 2014). Moreover, they diffuse, and ~~also~~ change very easily, ~~hence~~ transforming themselves: for instance, milk becomes sour and flocculates; water becomes stale and eventually evaporates; rubber left in the sun becomes brittle and sticky. They are always on the move, sometimes even on the run, being entangled in never ending processes. Certain materials also have an inherent tendency to produce ~~certain~~ forms (Figure 9.1): water produces drops when it falls, or waves of a certain angle when a ship travels through it; salt produces cubic crystals, sugar produces more elongated, coffin-like boxes; sand forms heaps that have a certain steepness, depending on the type of sand, and it also forms ripples and dunes when moved by wind or water (cf. Soentgen 1997: 126–144).

The neglect of this auto-activity in material culture studies seems to result from the custom of deriving the notion of material from the notion of things.[2] Surely, all (material) things are made of one or more materials, from the very simple to the extremely complex, as is the case with, for instance, modern technological devices (smartphones etc.). However, things are only one type of material object and should

2 For a critical discussion of the relations between objects, things, and materials, see Marcel Finke's essay in this volume.

not be overestimated. Things are usually produced to serve a certain purpose; the substances they are ~~comprised~~ of are stabilised in order to guarantee that the thing will fulfill that purpose for a long time. For instance, stainless steel, shatterproof glass, or flame retardant textiles are used, i.e. materials that have a kind of paralysed materiality, so to speak. Even salt is treated to prevent clumping, and milk is pasteurised to guarantee longer durability.

However, there are also other types of material objects in our world, objects that are not made to fulfill a specific purpose, that are not stabilised, and that clearly exhibit the autonomous mobility and auto-activity innate to all materials. The most important of these material objects is dust. Even in the cleanest apartments or laboratories, dust will inevitably form. It occurs in our rooms and out of doors by itself, moves in unpredictable ways, disappears, and does not stand still, waiting until we move towards it, as a thing waits for our activity. Dust is active in itself; it seems to be pure activity, being always on the move. Accordingly, metaphorical language often stresses this auto-activity, liveliness, and irregularity: bigger agglomerations of dust are called "ghost turds," "Wollmäuse" ("wool-mice"), or "moutons" ("sheep"). Dust touches us, it is sticky; once we have it on our skin or shirt, it is hard to get rid of. It can even enter our bodies; this invasive character is why researchers in the field of environmental health science focus on that material in particular. Dust is material, but gravity is not very important to it: it can resist gravity for hours or even days; as it is floating dispersed in the air, light or minimal air-movements are sufficient to move it. Moreover, dust is of uncertain composition, and always ready to transform: in the kitchen it forms greasy and resinifying layers on top of the furniture, i.e. sticky deposits that are hard to eliminate due to the mixture of fibers and oil droplets. The auto-activity of dust is a feature common to all materials and substances; once we have noticed it, we will find it everywhere. Materials therefore not only have *aptitudes* (German, *Eignungen*) through which they can be incorporated into things, and thereby into human actions; they also have *tendencies* (German, *Neigungen*). There is an autonomous activity in them that might be slowed or shut down for a while but can never be switched off or controlled entirely; nor can it be completely predicted. As stated before, this aspect can be proven purely phenomenologically, yet it can also be linked to certain scientific notions: what is called the "chemical potential" in chemical thermodynamics can be seen as a quantitative conceptualisation of the tendencies inherent in this or that chemical substance.

The auto-activity of materials, their typical profile of activities and behaviour is the basis of their identity as this or that particular material. There is a diversity of distinct materials that cannot be reduced to one general type of 'matter', which has different appearances. The material world is truly pluralistic. The immanent tendencies of materials, their being on the move, and their typical interactions are the basis of their identity as this or that material. If we want to know whether this white stuff is sugar, a single perception like sweetness is not sufficient; a mere glance at its appearance is not enough, either. We have to interact much more closely with the substance, and have to bring it into interactions with other substances in order to check its tendencies, reactions, behaviour: Does it melt at a given temperature? Does it form caramel if we put it into a

**Figure 9.2:** Fine dust in Bejing, China, 2017.

hot pan? Does it form coffin-like crystals? Then we discover the typical tendencies that lead to the natural behaviour of this or that stuff, and that creates its identity as this or that substance, this or that material.

The tendencies of materials lead to their stubborn behaviour, which manifests itself in space and time: on the one hand, it shows itself in the autonomous dispersal and migration movements of materials. On the other hand, it comes to the fore in transformation tendencies: in certain environments, if it is brought together with other substances, humidity, or sunlight, a substance may transform, it may crystallise, condense, evaporate, or combine with other substances to form new substances or materials, etc. Smog is a good example here, as it forms out of the remains and results of combustion processes in vehicles, of evaporated gasoline, of stirred dust (Figure 9.2); when the sun shines on that soup, it transforms in a way that is very hard for chemists to analyse, and even harder to model. Moreover, it is difficult to predict the health effects of this soup on human organisms, although certain very general assumptions are possible.

Since the behaviour of substances can only be studied highly selectively in the laboratory, their transformations, and thus also their ecological or physiological effects, can only be predicted to a very limited extent. The reason for this is not only the enormous material complexity of ecosystems and organisms, but also the fact that the behaviour of materials is predictable only to a limited extent, anyway. Even very small amounts of certain materials (catalysts) may cause an unexpected transformation to take place or,

in turn, an expected one fail to occur.[3] That is why the spectrum of effects of a certain material can usually only be determined ex post. As soon as materials are released into the real world from the vessels in which they have been enclosed, they cross borders: of bodies, of ecosystems, but also political borders. Crossing borders is always problematic, it often leads to issues or even conflicts. And that is where the history of materials begins, a history that can be studied by means of the humanities, but that cannot be modelled.

The frequently unforeseen auto-activity of substances, their ability and tendency to react with other substances, may have serious health effects or may cause serious ecological damage. A supposedly harmless chemical such as thalidomide, which was supposed to serve as a light, harmless sleeping pill in a drug called Contergan, has fatal effects in specific periods of pregnancy. Other supposedly stable and non-toxic substances, namely chlorofluorocarbons (CFC), which were used, among other things, in refrigerators, where they replaced the toxic substances previously used, diffuse undecomposed through the atmosphere until they are broken down at high altitudes by the hard radiation in the stratosphere, eventually setting in motion undesirable and problematic chain reactions that ~~significantly contribute~~ to the depletion of the ozone layer.

To sum up: If we think of materials, we should not only have in mind a ~~neat~~ line of separated and neatly labelled laboratory glasses. The ~~neatly~~ prepared material in the glass is only an artificial product; it does not "exist naturally" (Wald 1896: 616–617). Wherever pure materials are shown or sold to us, be they iron, PVC, gold, silver, platinum, copper or salt, "pure cotton," "pure silk," or medical preparations, we can be sure that alongside every grain, every fiber or every drop of such a pure material, we could place a bucketful of waste air, waste water, rubbish, and waste material that arose during their production. Everyday experience also teaches us that completely pure, isolated materials hardly ever occur: even clear water contains limestone and air, as you can see immediately when it is heated. Wherever there are substances, there is a tendency for them to mix and mingle with one another, to transform. The material world is an indissoluble hustle and bustle, a 'soup', a fermenting 'heap', being in a constant state of transformation; not a single material can be extracted without inevitably moving many other materials along with it at the same time. Materials have an anarchic wanderlust – as soon as they can, they disperse, literally crumble, seep away, and evaporate into the air, into the ground, penetrate the body, start complicated reaction-cascades with other materials, enter food chains. Materials are sociable beings, always ready to mix, to transform, to react and spread themselves about.

Consequently, people not only do something with substances; substances do something with people, too. What do they do? The auto-activity of substances is fundamentally ambivalent. On the one hand, it is the basis of any creative interaction or entanglement with materials. Cooking, brewing, baking, winemaking, or cheesemaking use and cultivate the auto-activity of certain substances; even activities such as writing

3 For an account of the industrial use of catalysts as means of material mobilisation, see Benjamin Steininger's essay in this volume.

with chalk on a board or painting on canvas require it, as it would be impossible to write or paint on a surface if there was not a certain stickiness of the chalk or graphite particles, or of the paint. This auto-activity is also the basis of any effort to learn something new about one substance or another: indeed, it is the basis of chemistry. We can mix certain substances, we can provide appropriate temperatures or pressures, but the *chemical reaction* is something that the substances start and end by themselves. Of course, we can create favourable environments, but then the chemical reaction happens autonomously. Chemistry is a partially successful effort to study and systematise the auto-activity and innate processuality of substances. On the other hand, the auto-activity of substances may also have negative aspects, if it leads, for instance, to contamination, pollution, unexpected health effects, holes in the ozone layer, or even climate change.

I have already stated that once there are borders that are transgressed, there will also be conflicts; and conflict is something that people like to talk about. Now, what do we mean when we speak of the history, or better: the histories of materials, in the plural? A history is the narrative representation of contexts of action (cf. Köller 2006). Histories are probably the oldest medium for representing and conveying knowledge. They are not only recounted in order to entertain, but also have a cognitive function. If one compares them to conceptual, theory-based forms of representation, it can be shown that histories are less precise, but have a greater power of integration, be it cognitive or social. Histories are by no means just a matter of bringing an event into a linear form; instead, the events must be put into perspective and linked in such a way that the individual phases of the event can be understood anew in the light of the preceding and following ones (Köller 2019: 373). In this respect, histories always integrate analysis and synthesis. They are therefore the medium of choice when it comes to ~~depicting~~ complex phenomena. At the same time, they also involve the listener emotionally; they speak to the whole person, not just to the mind (cf. Soentgen 2019: 209–224).

In addition to the concept of auto-activity, which refers to substances, the concept of action is central to research into the history of materials. I define this term quite broadly here. It refers to actions such as interpreting and communicating, but also, of course, to prospecting, manufacturing, exchanging or selling, using and consuming, regulating by law, burning, burying and dumping. This may relate to actions of an individual, but also to collective actions, i.e. actions in which the individual participates or which he or she carries out together with others (Janich 2001: 44–45). Whether collective or individual: actions are always social. Actions occur in social situations based on culturally mediated or at least culturally influenced interpretations of the situation. Actions do not occur in isolation, which is what the term "action context" refers to. A detailed analysis of the actions (and ~~omissions~~) of individual or collective players involved in the manufacture, trade, use, and disposal of materials shows that the "material flows," which in many depictions are represented as almost naturalised, and usually as running from south to north (Espahangizi 2014: 204), are by no means merely natural phenomena but are always socially mediated.

Actions are central to material histories: actions in quite specific social and cultural contexts, in certain historical situations, actions of individual or collective players

**Figure 9.3:** Kris Krüg, *Spilled Oil in the Gulf of Mexico after the BP Deepwater Horizon Oilspill Disaster,* 2010.

who act on the basis of identifiable motives and interpretations of the situation (cf. Kondylis 1999: 437–480). Usually, these actions can only be reappraised with sufficient precision from an historical distance. These contexts of action and interpretation are objectified in histories. And it is obvious that frequently, such histories are not told for the very first time, but were circulating already in the field of research. The material historian often has to deal with a plurality of histories from the outset; she or he is not the first to tell them, but encounters narratives everywhere in his or her field of investigation (cf. Soentgen 2019: 217–222). She or he comes across narratives as, for instance, histories of justification (cf. Müller 2019), as histories of extenuation, as histories of guilt, as scandals or utopias, because almost always, when action is taken, this action is embedded, justified, or criticised in the context of histories. Wherever scientific standards are applied, such histories need to be critically analysed and related to each other.

The phenomena with which material histories are concerned are not simple "flows," but rather huge, historically developed cooperation contexts, ever-changing networks of actors, bystanders, ecosystems, and materials, which are for their part in no way limited to waiting to see what people do but are active themselves – even if they are not actors in the proper sense (as they do not have intentions). This network of cooperation is further complicated by the fact that every purposeful action has side effects, some of which are foreseen, desired, or tolerated. Many of them, however, occur unexpectedly and are undesirable, and often they cannot be separated from the actually intended result of the action (cf. Soentgen 2019: 45–51).

What is important in all of this is the decisive observation that materials for their part do something, too, even if not intentionally: they develop a constantly perceptible activity of their own that can be described, and which thwarts, overtakes, and sabotages human plans of action. Crude oil leaking from a damaged tanker or drilling rig spreads itself over the surface of the sea (Figure 9.3). This is already an autonomous activity, which is supplemented by a self-transformation, as the oil becomes stickier over time. Numerous other examples could be cited. This interaction of the materials' autonomous activity and human actions and interpretations is a crucial part of the dramaturgy of many material histories.

## Histories of Materials

Histories of materials have a hidden and complex tradition; only two strains of this tradition will be mentioned here in order to characterise, by contrast, the current research. The oldest tradition of research into the history of materials seems to exist in the context of the history of pharmacy and chemistry, where the term "material history" (in German, *Stoffgeschichte*) has long been established. For instance, the work *Histoire générale des drogues* by Pierre Pomet (1694), who was the pharmacist of Louis XIV, can be described already, at least partly, as a collection of material histories, despite the fact that the underlying interest was primarily pragmatic. Later, however, more ambitious histories appeared. The historian of chemistry Ferdinand Hoefer (1869: 101–223) included over 60 sketches on the history of certain substances or materials in the first volume of his *Histoire de la chimie*, which first appeared in 1842. Subsequently, Hermann Kopp (1845; 1847) dedicated the entire third and fourth volumes of his important *History of Chemistry,* which is still indispensable today because of its intimate knowledge of the historical sources, to studies in the history of materials. James Riddick Partington, probably the most cited twentieth century historian of chemistry, worked on the history of certain materials, too, and on gunpowder in particular (Partington 1960); although in his magnum opus, the monumental, four-volume *History of Chemistry*, he chose a biographical approach (cf. Weyer 1974: 192–200).

In the twentieth century, the most extensive research project in the history of chemical substances was part of the eighth edition of the *Gmelin Handbook of Inorganic Chemistry*, which was begun in 1922 and discontinued in 1997. The individual volumes of Gmelin's handbook contain historical accounts for all chemical elements and some important compounds such as limestone. But even for these extensive studies, it holds true that the laboratory aspect was always the guiding focus. These "laboratory histories" provide information about the interpretations that certain substances have experienced in the course of history; interpretations that are often reflected in their chemical designations. Aspects that go beyond the laboratory, the lecture hall, and the textbook are only considered insofar as they concern occurrence, economic, or technical aspects. Other social or ecological aspects, other places and scenes that these materials

may pass through or in which they may appear, such as, for instance, streams, rivers, drinking water wells, battlefields, hospitals, courtrooms, or parliaments, are left out.

In addition to these early histories of materials that have arisen in the context of academic research, there is also a significant and important tradition of storytelling about materials outside of science. Histories in which the heroes are not people or animals, but materials or things, are older than one might expect. At first, such histories appeared as *encomia paradoxa*, as paradoxical eulogies in the context of ancient rhetoric. In humanism, this type of eulogy was further cultivated (cf. Soentgen 2013). One striking example is the so-called *it-narratives* (also known in English literary studies as *novels of circulation*), i.e. narratives whose hero is a thing such as a gold coin or a coat that moves from hand to hand (cf. Blackwell 2007). They were particularly popular in the British Empire of the eighteenth century, reflecting the increasing quantity of goods traded in the British Empire.

As an explicit methodological concept, however, "material histories" in the sense implied in this paper appeared for the first time in the context of a literary programme formulated by the Russian writer Sergei Tretyakov in 1929, in his polemical renouncement of the "classic novel" (Tretyakov 1985: 102). Instead of revolving around individual heroes of the novel, that is, around bourgeois personalities, Tretyakov (1985: 104) recommends that the writers "build up the narrative as a kind of 'biography of the thing'." By "thing," against the background of a materialist understanding of the world, he primarily (but not exclusively) means materials: "Books about wood, crops, coal, iron, flax, cotton, paper, locomotives, factories have not yet been written. We need them, and they can only be produced in a satisfactory way by using the method of the 'biography of the thing'" (ibid.: 106; my translation). The compositional structure of the new narratives he outlines "can be compared to an assembly line, along which the raw product passes. Human effort turns it into a useful product" (ibid.; my translation).

With this literary concept, Tretyakov found a lot of disciples – or at least he described a literary genre and a pattern of observation that were in vogue, and many novels based on this model have been published and researched since then (cf. Soentgen 2013). Tretyakov himself referred to the novels of Pierre Hamp, who, in his socially critical series of novels *La peine des hommes,* dealt, for example, with flax or seafood in this way. The method was intended to enlighten (in the Marxist sense of enlightenment) and motivate people to take action, or so Tretyakov (1985: 105) hoped.

At present, at any rate, a strongly increasing interest in material histories can be noticed in journalism and literary production, as well as in cultural studies and social sciences, especially in historical scholarship; this is accompanied by significant methodological innovations and advances. A recent publication even notes a "booming field of research" (Waltenberger 2020: 5). Indeed, we find an ever-growing corpus of material histories. They mainly (but not always) deal with conflictual matters, i.e. contested substances such as petroleum, heroin, sugar, saccharin, phosphorus, DDT, CFC, agent orange, napalm, chlorine, rubber, carbon, plastic, aluminium, and synthetic sex hormones (cf., for instance, Bensaude-Vincent & Loeve 2018; Böschen 2000: 41–104; Chang & Jackson 2007; De Ridder 2000; Klose & Steininger 2020; Marks 2001; Marschall 2008; Martini

2012; Meikle 1995; Merki 1993; Mintz 1985; Neer 2013; Schlögl-Flierl & Emeis 2021; Simon 1999; Soentgen 2019: 131–149). Those studies are different to the older contributions to the field of history of chemistry, insofar as they leave the laboratory and focus on the interdependencies between work in the laboratory and political, cultural, ecological, and economic contexts. They not only trace what happens in the laboratory, but also explore the wider social life of a substance, asking questions like: How did this or that particular material, this or that chemical transformation process move politics, economy, and ecology? What types of conflicts (conflicts of interest or conflicts of value; cf. Aubert 1965; Bogner 2014) did it trigger? How do these diverse worldly engagements and entanglements re-enter into laboratories? What histories are told about it, what is the function of these histories, and how can these histories be critically examined and organised?

There are links between the approach of material histories and newer developments in speculative materialism. As early as the 1930s, materialist philosopher Ernst Bloch (1985: 544–546), following Giordano Bruno and Henri Bergson, conceived matter as something not merely passive but conceptualised it as an active, even creative entity. Without taking notice of the preceding endeavours of Bloch, Jane Bennett (2010) and other protagonists of the so-called "new" materialism have likewise tried to develop a more active notion of matter.[4] Even if this resonates with the notion of auto-activity advocated in this paper, there are important differences between material histories and new materialism. The former do not refer to an abstract entity called *matter*; rather, they always pay attention to this or that particular stuff, this or that material in a certain time and at certain places, in specific social and cultural contexts. Matter is not the same as materials, as can be seen if we look at the opposites: matter is distinguished from 'nothing' or a 'vacuum,' whereas materials are distinguished from things and from each other. Matter is something monistic; in contrast, materials form a pluriverse, and thus can only be studied and understood properly in their plurality. The term 'matter' is part of certain physical or metaphysical theories; the term 'materials' is part of everyday discourse.

The result of any study into the history of a specific material, ideally at least, is not a colourful juxtaposition of disparate concepts and information, but an integrated history.[5] The knowledge that this story offers is evidence-based and reflective, not naïve, as it incorporates not only empirical material, but also reflections on already circulating histories about this or that material. It is scientific because the terms are scientifically clarified and the statements about the contexts of action into which this or that substance or material is integrated are empirically secured by, for example, archive studies, participant observation, etc. Histories of materials analyse and at the same time also aim to synthesise, trying to develop an ~~(sometimes more)~~ integrating history. Their synoptic view ~~means that they~~ fulfil two central scientific functions,

4 For a critical review of New Materialism, cf. Keller (2019).

5 An excellent example is the book by Swiss science historian Christian Simon (1999) about DDT. It deserves special mention, as it brings different narrative strands together in an almost ideal way, and convincingly accompanies the narrative with pictures that not only illustrate but also expand on what is being said by telling new sub-histories.

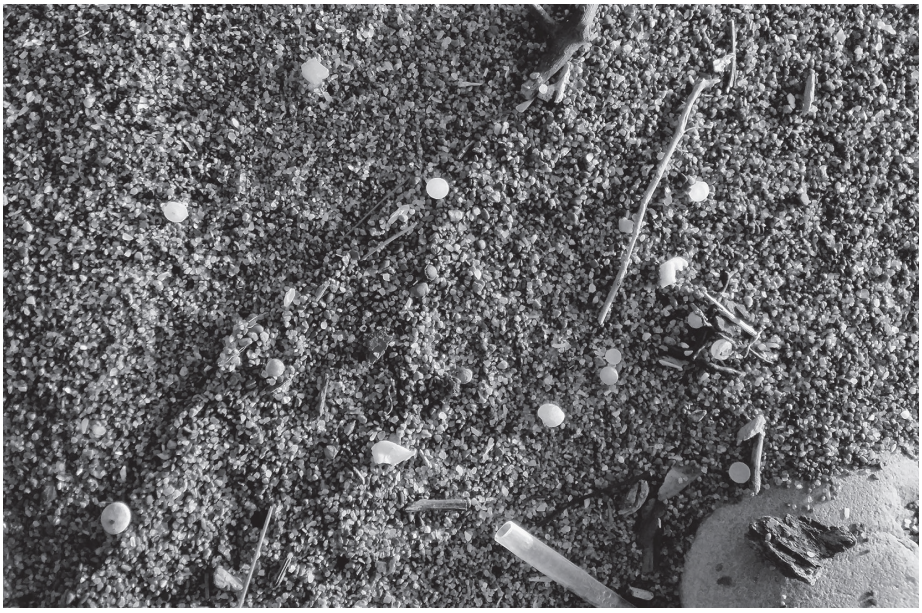

**Figure 9.4:** Micro and macro fragments of plastic on a beach, 2017.

namely explaining and predicting. Histories of materials can explain why materials appear in this or that place at this or that time like, for instance, the microplastics on the beach (Figure 9.4), or the DDT in the liver of the white whale (beluga). They explain this by depicting certain actions and inactions in connection with the autonomous activity of the material; in short, by telling the history of the material. And if one knows the history of a material, one is in a position to predict, if only in a quite general way and for a certain time, what will happen next, and how the story may continue (Soentgen 2020). Such stories offer important orientation, even if they do not consist of mainly quantitative information.

Research into the history of materials may be called subdisciplinary or superdisciplinary. I would prefer to call it interdisciplinary, as it relies on a methodology that brings together aspects from the sciences as well as from the humanities. The materials history approach avoids a radical constructivism supposing that anything in the world is merely a result of human action; at the same time, it seeks to overcome naturalism, which reduces everything to scientific entities. Instead, the approach takes materials as seriously as actions. Therefore, material histories may play a role in both typical fields of the humanities (such as art history, global history, or history of science) and in the sciences, especially in the area of global ecology, and may also serve as a bridge between the two sides of the 'great divide'.

The non-specialised material history approach might seem less impressive than a highly specialised scientific method using sophisticated instruments and concepts. However, non-specialised means can be very useful, as is exemplified by the human hand, which is non-specialised, too, but precisely because of this is extremely useful.

Similarly, the non-disciplinary nature of material histories is particularly suitable for productive interdisciplinary projects (cf., for instance, Ertl & Soentgen 2015; Schlögl-Flierl & Emeis 2021), which can then consolidate into new disciplinary lines of research, as the example of the resource strategy between geography and economics shows (cf. Reller *et al.* 2013).

To sum up: Histories of materials analyse and interpret (1) the historically evolved contexts of actions and inactions through which materials are set and kept in motion, whether purposefully or otherwise; (2) they take into account, collect, analyse, and critically reflect the already existing representations of these actions in the form of popular narratives or other (pictorial, metaphorical etc.) representations; they are alert to (3) the autonomous activity of materials, which is part of these contexts of action, supporting them, but often also thwarting them; they are (4) an interdisciplinary (and sometimes even transdisciplinary) approach that (5) presents its results as an integrated, critically reflected, and evidence-based history (or, more popularly, as a story). The aim of research into the history of materials is to better understand seemingly familiar materials in their contexts. In doing so, not only certain areas of culture and politics, certain times, and certain cultural and political developments may be more thoroughly comprehended, but also specific landscapes (cf. Haumann 2020; Waltenberger 2020) and other ecological phenomena.

## Material Histories' Contribution to an Ecology of Materials

It is evident that the approach of material histories has made and will continue to make valuable contributions to research in the humanities and the social sciences. It offers new perspectives on old questions and develops completely new programmes of research. But how does it relate to research in the natural sciences? Is it more than an ornament in textbooks on general and inorganic chemistry? The knowledge acquired by research into the history of this or that material is not quantifiable, or at best only partially, and does not immediately offer starting points for an "optimisation of material flows." On the other hand, however, the knowledge acquired through research into the history of materials, which is presented as a ~~history~~ story, always contributes to a more accurate picture of things than a quantitative construction of "material flows" can offer. A better understanding and orientation are made possible by telling a new history, with critical inclusion of the histories already circulating in the field of investigation. This does not start from specific events or decisions, but rather from an initially inconspicuous player, this or that material, which is set in motion but soon becomes active itself as well. Research into the history of materials has its own precision, which in many cases opens up areas that are, in general, inaccessible to purely quantitative research methods of the natural sciences or economics, simply because they cannot be grasped by using their methodology.

That is to say that material histories offer precise answers where the statements of scientific research remain vague. Therefore, they are not only a possible addition but actually a necessary complement to research in global and chemical ecology. If we are interested in a realistic picture of what there is, material histories are inevitable, insofar as they take over where scientific research comes to a halt. Hence, they are able to answer questions that global ecology poses yet cannot answer. While chemical ecology talks of "material flows," material histories may reveal what or who causes these materials "to flow" in the first place.

The link between material histories and global ecology can be shown best if we take a look at the beginnings of the latter. Vladimir Vernadsky, who coined the modern term of the "biosphere" and developed the first research programme of a global ecology (cf. Levit 2001), was also the first scientist to clearly formulate the observation of an epochal break in the history of the biosphere. In the important revised German translation of his *Geochemistry* (1924) he noted that while the movements of the elements in the biosphere were carried out by organisms, mainly plants and micro-organisms, in former epochs, such movements are at present, at least since the start of industrialisation, being carried out more and more by humankind (Vernadsky 1930: 231). He states that "humans" have mobilised nearly every chemical element of the Periodic System of Elements, while most of these elements remained immobile in former times of the biosphere. Vernadsky saw the dawn of a new epoch that he labeled "Psychozoikum" – and which today is called the Anthropocene.

He especially mentioned the increasing content of carbon dioxide in the atmosphere as one example of where and how "humans" are intervening. Moreover, he also pointed towards the metals, which are mainly moved by human action. Newer research in global ecology offers countless examples to back this early diagnosis (cf. Rockström *et al.* 2009). However, it is not enough, it is not precise enough to simply state that "humans" are altering the carbon cycle, as Vernadsky did and as natural scientists continue to do today. Instead, we need to know which humans, where, guided by what cultural representations and ideas emitted that portion of the global emission of carbon dioxide. At least, such is the information that will be needed if we are interested in more precise representations of what is happening, instead of vague generalisations. Such information is relevant if we want to change ~~anything~~. We cannot foster change if we appeal to "humankind" in general. It is only if we can gain a more precise knowledge about the actors, their world-view, their interpretation of the past and their outlook on the future, that we may be able to distinguish possible and preferable changes from mere utopias.

Any ecology of materials, but also any global ecology, must incorporate material histories if it is interested in practical applications that are more than just technical interventions. The price for this is not vagueness – the humanities are no less exact than the natural sciences – but the need to tolerate different methods and different cultures and norms of exact research.

As the materials history approach focuses on actions and inactions, and their representations, it can answer the question of what part of "humankind," what specific

human collective actually set and has kept this or that material in motion, developed this or that "material flow," to what ends and in what cultural and political context, under what circumstances, and with what ecological and environmental health consequences. The knowledge offered by studies into the history of materials is neither less exact nor less important than the quantitative results of scientific research. It complements them and thus enables us to get a closer look at the material world: A view that offers better orientation and enables us to understand the material world in a broader way, and that will help, in some cases, to develop realistic political options that go beyond mere technological utopias.

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