Module 1

System Earth – The Basics

Teacher's Text

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This text is available together with the texts of 10 other modules of the project „Forschungsdialogue System Erde“ on the CD-ROM „System Earth“ as hypertext respectively the materials as pdf-files, videos, interactions, animations etc. The text has a navigation system with search functions that are easy to use.

You can also produce your own materials with the CD-ROM. Moreover, a student version can also be produced from the CD-ROM, which is designated for self-organised learning and contains no didactic information.

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The project "Research dialogue: System Earth" promotes understanding for planet Earth. By using solid knowledge, it is intended to stimulate the preoccupation and discussion concerning sustainable development of the Earth. Materials on the subject "System Earth" were developed by the IPN in close cooperation with geoscientists as well as teachers and then tested and evaluated in schools. An extensive CD-ROM is available for class work in the upper secondary level, which, among other things, contains animations, simulations, information texts and work sheets for all eleven modules on the subject System Earth. This text is a part of this CD-ROM, which is available from the IPN.
For primary school teaching, a book was developed on the subject, which includes a CD-ROM with computer games. Instruction materials for teachers are available on the internet (http://systemerde.ipn.uni-kiel.de).

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Bundesministerium für Bildung und Forschung

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1 General Aim and Reasons

The module "System Earth" – The Basics" gives a brief, phenomenological introduction to the complex system of the Earth: The subsystems: atmosphere biosphere, hydrosphere, and lithosphere, which interactions determine the development of the system Earth, are introduced as a superior system of categories. The four subsystems (spheres) are activated by the energy from the Earth's interior and by Sun energy.

The students repeat and extend their basic knowledge independently on the structure and the material aspects of the components of the four spheres of the Earth. They learn especially to identify interactions between the spheres and within the spheres. This takes place in the form of an introduction to the system concept for which two elements and an accompanying text is available. The instruction has a cyclical set-up, so that phases of repetition, explanation and intensification as well as application concerning fundamental concepts are linked to each other.

The basis of geoscientific research of the planet Earth is interdisciplinary interactive work. For this reason, the module "System Earth – the Basis" deals with previously acquired students' knowledge in subject instruction and places it in an interdisciplinary context using system Earth as an example. Moreover, the students become acquainted with the method of system analysis. This is an aid for structuring complex and strongly linked contents which they can also apply to other knowledge domains.

2 Subject information

The module "System Earth – The Basics" is an introduction to the complex system Earth with the subsystems, atmosphere, biosphere, hydrosphere and lithosphere. The interactions between the subsystems determine the development of the system Earth. The four subsystems (spheres) are activated by the energy from the Earth's interior and by Sun energy.

2.1 Milestones of the Earth's development

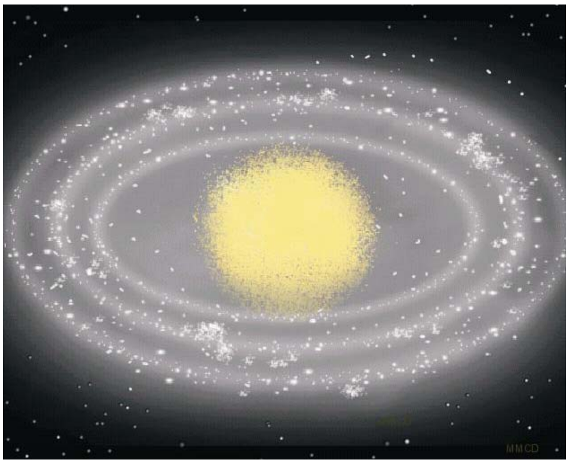
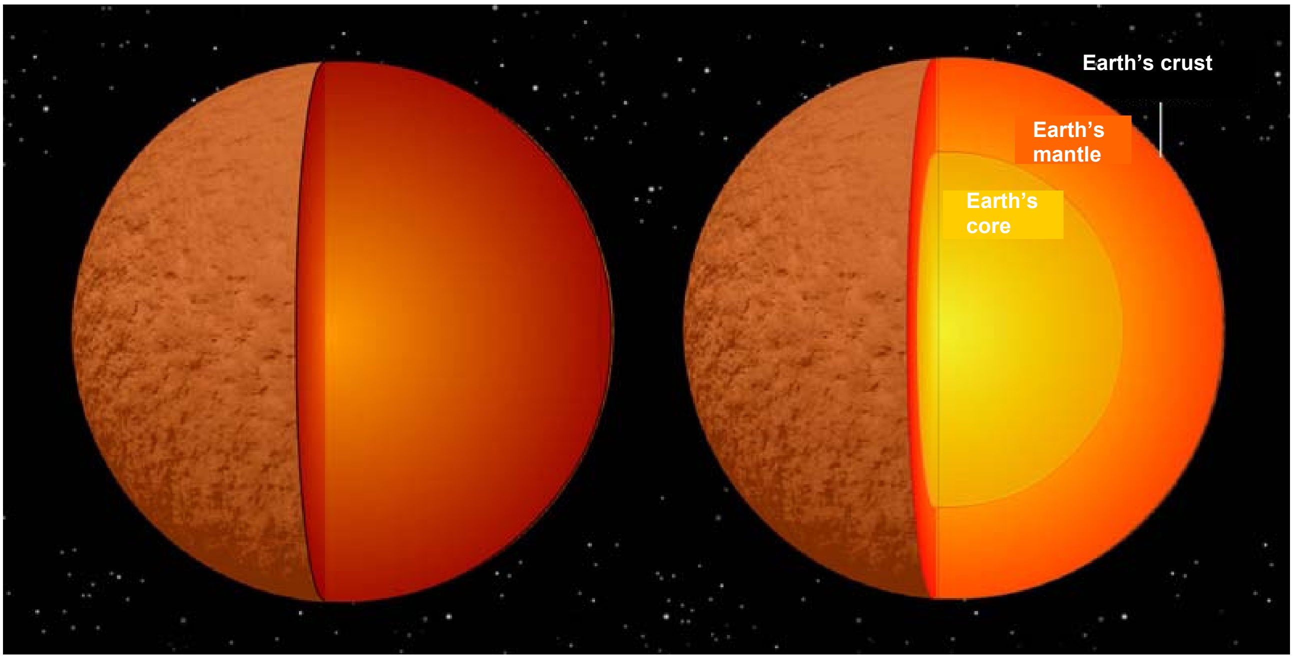


Illustration 1: The early Sun System.

A slowly rotating cloud of dust and gas – that was probably the origin of our planet system. The dust concentrated to material clouds, which extended much further out into space. About 5 billion years ago, material developed by forming a ball — first of all, the Sun evolved and somewhat later, the planets of the solar system (see ill. 1).

Because of gravity the Earth attracted, after its coming to being, a large number of meteorites, which moved freely in the solar system. These fell to Earth as hailstorm in the unimaginably long period of 800m years. Each meteorite released heat energy when it made an impact. Additionally, the radioactive disintegration of elements in the Earth's interior, comparable to a huge nuclear power station, resulted in temperatures rising. For this reason, the Earth became hotter and hotter.

The Earth, in an early stage, was probably homogenic and had no continents or oceans (see module "Plate Tectonics and Volcanism"). With increasing temperatures of the Earth's interior, the Earth partially melted and this resulted in a separation of different compositions (see. Ill. 2) Iron sunk down in the central area, and specific lighter material rose to the surface. As a result, an ocean of magna was probably created which covered the entire Earth.



Ill. 2: The Earth formed its composition in the course of its history. The left illustration depicts the homogenic Earth, whereas the illustration on the right shows the later Earth with its core, coat and crust.

Right from the beginning, the Earth was almost surrounded by a gas cover, the atmosphere,. As far as we know today, the primordial atmosphere was comprised of nitrogen, carbon dioxide and vapour. When the meteorite shower dried up about 3,8 m years ago, the Earth cooled down. The first stones gradually formed and the surface solidified to a solid crust called lithosphere. The oldest stone, which has been found to date, originates from the south coast of Greenland. It is 3,75 billion years old (LAMB and SINGTON 1998).

After the Earth had cooled down further, the vapour condensed in the atmosphere. The water drops fell to the ground and collected in the depression of the Earth's crust. In those days, very large amounts of water fell in downpours. The water masses, which form the hydrosphere nowadays, for example, the oceans, rivers, lakes and the ground water and the clouds were originally and mainly dispersed as vapour in the atmosphere. Moreover, water was also released from stones.

Thus, three of the four superior subsystems of the system Earth (see. Ill. 3), the **atmosphere**, the hydrosphere and the lithosphere developed one after another. As a **lithosphere**, we describe the Earth's crust and a part of the upper shell of the Earth, which is comprised of rocks (see Module "Rock circulation: Rocks as Documents of the Earth's History" and "Plate Tectonics and Volcanism"). The term **hydrosphere** describes all the regions covered by water such as oceans, rivers, lakes and also ground water in the ground (see Module "Water Circulation and Protected Drinking Water").

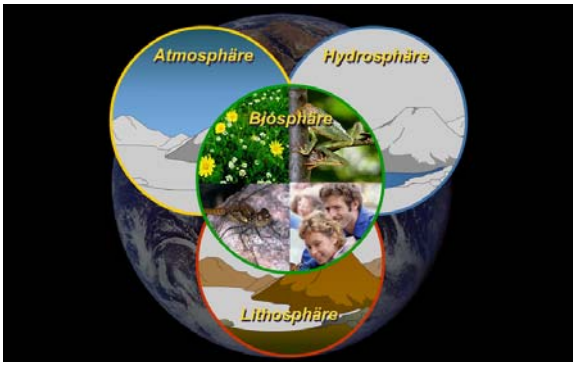


Illustration 3: The atmosphere, biosphere, hydroshere and lithosphere are the four higher-ranking systems of System Earth

Atmospheric gases dissolved in water. For this reason, right from the beginning, the oceans extracted carbon dioxide. In shallow water, organic compounds formed, such as amino acids, short protein chains and the first molecular elements, which are similar to today's idioplasm (see ill. 4). From this, primordial cells were formed which differentiated themselves from the environment with membranes. As a result of the interaction of the atmosphere, the hydrosphere and the lithosphere, the biosphere developed which consists of bacterial-like archaea, bacteria, unicellular organisms, fungi, plants and animals (see Module "Origin and Development of Life").

The oldest petrification of organisms is probably 3.5 billion years old (Stanley 1984). These fossils were formed from creatures, which are similar to today's cyan bacteria in their exterior form. They lived in the sea and formed structures, which are called stromatolithes. Nowadays, fossils and other rocks serve as keys to understanding this earlier period (see Module "Origin and Development of Life"). A further 1.5 billion years later, that is 2 billion years ago, different kinds of procaryoten existed on Earth, which all lived in the sea. These were archaea, bacteria-lime creatures.

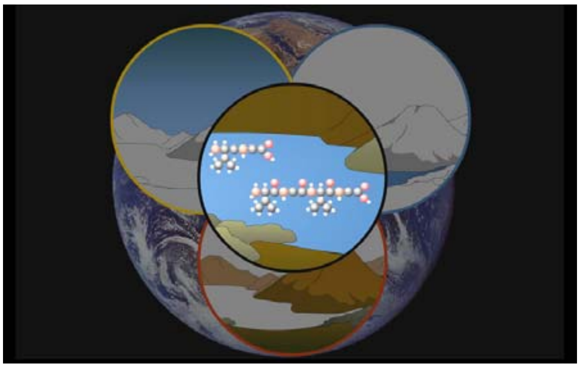


Illustration 4: The biosphere results from the interaction of atmosphere, hydrosphere and lithosphere.

Photosynthesis was finally developed from bacteria, from which oxygen is released and which is widely distributed in the plant world. Nowadays, oxygen from photosynthesis reacts immediately in seawater with iron salts to red iron oxide. First, it only penetrated the atmosphere in nominal amounts. Since the majority of iron compounds were oxidised after some time in salt water, oxygen was able to accumulate there. Therefore, the prerequisites for the development of cellular respiration for creatures also existed. In the case of **cellular respiration**, energy is extracted by the oxidation of organic materials with oxygen. However, for some million years, more oxygen was always released as was absorbed by breathing or other processes which sapped oxygen. Therefore, oxygen content of the atmosphere increased from about 0,2 % to 21 %. The value of 21 % adjusted itself gradually following the appearance of land plants more than 400 million years ago.

After the Earth had formed its shell-like structure, it was comprised of the Earth's core, the shell of the Earth and the Earth crust (see Module "Rock Circulation: Rocks as Documentation of the Earth's history"). Probably after about 2 billion years, the lithospheric plates were put into motion. They drifted apart so that huge oceanic pools were formed. As things developed, plates collided with each other and at the edge of the plates high mountain ranges were upfolded. The energy for this process, which is called plate tectonics, is also responsible today for the disintegration of radioactive elements in the core and in the deep shell of the Earth. (see module "Plate Tectonics and Volcanism"). Due to the difference in temperature between the Earth's interior and surface, convection currents are put into motion in both the shell and in the core of the Earth (see module "Convection in the Shell of the Earth, Ocean and Atmosphere"). The atmosphere is also in constant motion and both winds and temperature differences in the ocean result in huge ocean currents. The energy of the movements in the atmosphere and hydrosphere comes form the Sun.

2.2 System thinking as a new approach to the sciences

Scientific research has been providing insights into the world for centuries. It divided its research object into small and easily recognisable areas. This limitation to the exploration of details is called a reductionalistic procedure. It was so successful that both great technological challenges, such as the journey to the Moon as well as the exploration of the most inner part of material, were overcome. For a long time, it had been assumed that all natural processes could be analysed in this way. Only at the start of the 20th century did it become clear that this method was seriously limited by a number of phenomena. The following examples elucidate this.

- **Quantum mechanics:** For the behaviour of elementary particles, only probability forecasts can be made. Especially, the acceleration and the respective position of an electron cannot be measured exactly. Information, however, about both sizes would be necessary for an exact forecast of the future movement of this electron.
- **Chaos theory**: In 1961, Edward Lorenz discovered - when examining flow formulas, which are important for weather forecasting - a simple system that behaves deterministically and which can have a strong effect on the smallest change of contributory effects. For this reason, it is practically impossible to predict the behaviour of such systems. In this context, the hypothesis of the **butterfly effect** became known, according to which the beat of a butterfly's wing set a chain of events in motion and, as a result, can, in principle, cause a hurricane.
- **Earth system research**: Besides the behaviour of elementary particles and disturbances in the atmosphere there is a number of further phenomena, which cannot be explored using a reductionalistic approach. The following belong to this, the origin of life, climatic changes, structure formations on the surface of the Sun or population deviations.

  The system concept has proven itself to be valuable for the exploration of these aspects.

2.3 The system concept

A system consists of elements, which stand in relation to each other (see ill. 5). Systems are changeable. If we look out of the window, we see a cross-section of the system Earth at a special point of time, e.g. trees, clouds and water. These are elements of the system, which stand in relation to each other: trees exchange oxygen with the air by means of breathing and photosynthesis as well as carbon dioxide. They absorb water through their roots and emit condensation through their leaves. The view provides a momentary picture of a process of constant changes in the system: trees grow, air movements and water availability constantly change.

With systems, it is frequently meaningful to differentiate the macro- and micro-levels. Under the macro-level, the system in its entirety is to be understood (e.g. the entire Earth), whereas individual system elements (e.g. the spheres) are known as the micro-level. The classification of a system to such a level is dependent on the question. The roots of a tree e.g. can constitute a meaningful micro-level when observing the combination of cells when absorbing their water and nutrition intake. Roots, however, belong to the micro-level, when you examine the water household of the entire tree.

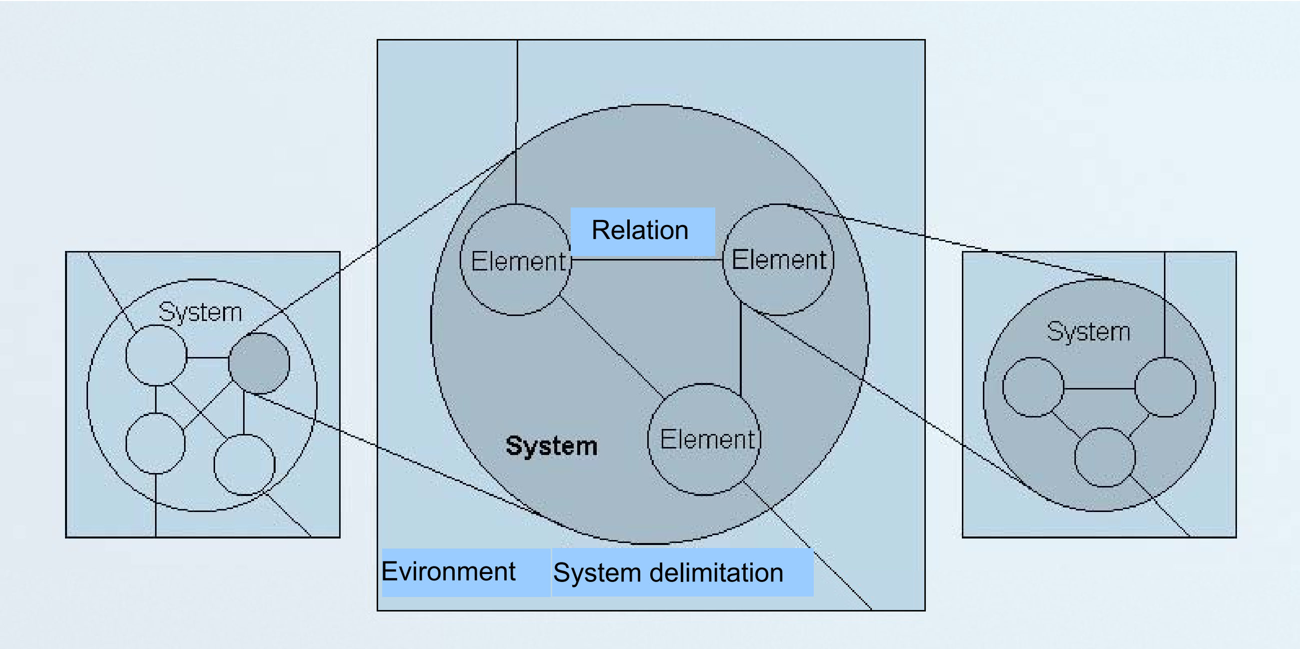


Illustration. 5: schematic illustration of a system. A system exists in a system environment. It consists of elements that stand in a certain relation to each other. System delimitation separates the system from the system environment (input respectively output). The system, which is illustrated in the middle, is on the micro-level in regards to the left illustration, whereas in relation to the system on the right it is on the macro-level.

Phenomena of self-organisation belong to the potentially unexpected observations on the macro-level. Hexagonal convection cells originate spontaneously in this way, e.g. by warming liquid on the stove under certain conditions (see module "Convection in the Shell of the Earth, Ocean and Atmosphere"). This phenomenon cannot be explained by means of the behaviour of individual molecules of a liquid. It is assumed that the creation of life of such a phenomenon is also self-organisation. Another example here of the same is the behaviour of balls (see ill. 6).

Types of systems

- Systems can be either **simple** or **complex**. A simple system has a relatively small number and few differentiating elements. Moreover, the amount and the density of the relations are relatively small. The opposite is true for complex systems. The complexity increases with the grade of interlinking of the elements. In this sense, the system Earth and its subsystems have a high grade of complexity. However, from the properties (simple, respectively, complex), you cannot form conclusions from the behaviour of systems or their predictability. There are quite simple systems, which demonstrate non-predictable behaviour (see Ill. 6) and complex systems with predictable behaviour (e.g. the function of chloroplasters by photosynthesis)

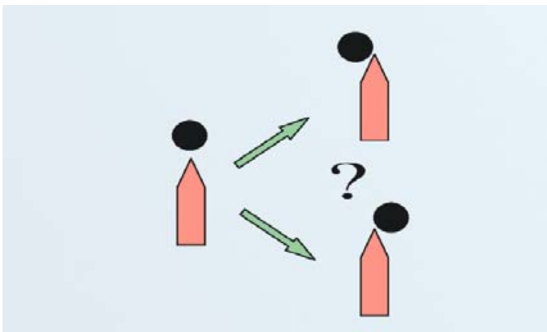


Illustration 6: A simple none forecastable system – it cannot be foreseen, in which direction the bullet falls down from the spire.

- Systems can be **static** or **dynamic.** Dynamic systems are differentiated in relation to their temporal relationship. Dynamic systems are subject to constant change, whereby a certain state can be maintained for certain periods of time. In this manner, the intake of nutrition, breathing and photosynthesis leads to a process, whereby materials are constantly absorbed into the organism and other materials are constantly released into the environment. In spite of this steady supply flow through the body, the form, the structure and the chemical compound of the tree remains mostly the same. The state of the constant supply flow or outflow is called the flow equilibrium. This remains intact due to the mechanism of rules Creatures are dynamic systems, moreover, the entire system Earth and its subsystems are usually dynamic. To a large extent, a church tower can be regarded as an example of a static system.

- Systems can be **closed** or **open**. Closed systems do not exchange energy or materials with their environment and, therefore, can only be postulated. In comparison, open systems are characterized by energy and materials, resulting from an exchange of energy or state. Real systems, for example, a tree or the Earth and its sub-systems are open.
- Systems can be **deterministic** or **stochastic**. According to the grade of determination of their behaviour, a differentiation is made between both these systems. Deterministic systems behave in a predetermined manner, the state of a deterministic system is, with the help of equations, derivable. In this manner, the heart of a healthy person, who is at rest, beats predictably. The ECG shows this. However, the behaviour of a deterministic system does not always have to be clear. For example, there are chaotic states, whose dynamics are deterministic, however their development is not predictable (see Section 2.2 "System thinking as a new approach to the sciences", butterfly effect). Stochastic systems, in comparison, are not determinable, that means, the state of a stochastic system is not deducible using equations from a previous state. Their development can only be predicted with a certain probability. Roulette can be seen as an example for a stochastic system.
- A system can be **stabile** or **unstable**. Stability or instability are differentiation criteria which characterize the possibilities of change inherent in a system. A system is stabile when it can buffer resp. compensate environment events to a certain extent. In stabile systems, the influence of disturbances is minimized by regulation mechanisms. Stabile systems return again to their state of exposition after the disturbance. In this manner, a tree reduces its steam release in the case of loss of water via the leaves; it regulates the width of the split opening. In comparison to this, unstable systems lose their original state in the case of disturbances. They can change completely. A glacier is an example for an unstable system. When atmospheric temperature rises over the melting point of ice, the glacier melts and becomes smaller and smaller.

2.3.1 Systemanalysis

In the case of system analysis, the system observer constructs a model. This depicts a selection of elements and relations of the system, which are of relevance for certain questions. For example, a plastic model of the wood of a tree only allows statements about the structure of different tissues of the tree and their situational relations, not about the cells from which the tissue is composed. Therefore, a system model just depicts a limited picture of the original. It is an idealised and abstractive illustration, which makes the structural elements or functioning of the system understandable. With the help of a system model, hypothetic statements can be made about elements and relations of a real existing system, which is not or not yet accessible to direct research. This was true for e.g. the model concept of plate tectonics, when it was developed by Alfred Wegener (see module "Plate Tectonics and Volcanism"). The statements of this model concept could be examined later using geological findings. If positive agreements result from empirical findings, then a model can be used for prognoses about the future development of systems.

A system analysis comprises the following steps:

- Delimitation of the system from the system environment;
- Identification of the (relevant) system elements;
- Identification of the (relevant) relations (effects and flows) between the element
- Identification of the system features;
- Identification of the relations of the systems to other systems.

The results of the analysis can be displayed in graphic form, e.g. in the form of concept maps and/or material flows – resp. diagrams of effectiveness (see Section 2.3.3 “How can you depict systems?”).

These results are the basis for the modelling of a system and for developing scenarios of future development. Certain models, e.g. of climate development serve as the basis for political decisions.

Example: The family as a system

Using the family as a system, the steps of a system analysis are to be explained. A first step to analysing the system “family” is the identification of the system limitation and the relevant system elements. The point of view under which this system is observed determines the course of the system delimitation. It also determines which elements are regarded as relevant. If, for instance, communication is the key point of observation within the family, then all the people in the family who talk to each other come into consideration. Hereby, the closeness of the relationship is not the sole decisive factor. Therefore, for example, a maid who has been employed for years by the family, who spends everyday with the family is a relevant element in the system family regarding communication. And even the domestic pets can also be important from this perspective for the function of the system family as a communication system. Concerning the issue “inheritance”, the maid is normally not a relevant element in the system family. However, there are perhaps family members who do not play an important role in the system under the aspect of communication, but become relevant system elements when it comes to inheritance. In a further step of system analysis, the identification of relevant relationships is of concern. Between the elements in the complex and strongly linked family system, there are a number of effect relationships and even material flow or supply relationships.

- An example of effect relationships within the family system is stress behaviour. Parental professional stress can have a negative effect on the well-being of other family members. On the other hand, the composure of the children can reduce the mother or father’s level of stress, which should then, in turn, increase the feeling of well-being of other family members.
- Money flows between the members of the family are an example for material (supply) flows, which characterize the system family. Money can pass from the parents to the children in the form of pocket money; the grandparents also give the children pocket money now and again. Children lend each other or their parents money. Moreover, using money flows within the family can make the aspect of connection between different systems clear. Therefore, the money, which flows within the family, can be supplied to the system, for example, by the employer. The firms, in which the parents are employed, are connected to the system “family” in this way. Finally, linked systems can be classified in hierarchies. Therefore, both

systems “family and firm” as in our example are classified in an economic system, which are hierarchically superior to both systems.

2.3.2 Example: System Earth

The Earth is a complex system with closely linked elements. The first step of the system analysis is also, in this case, the determination of the system delimitation and the identification of the relevant elements for a certain issue.

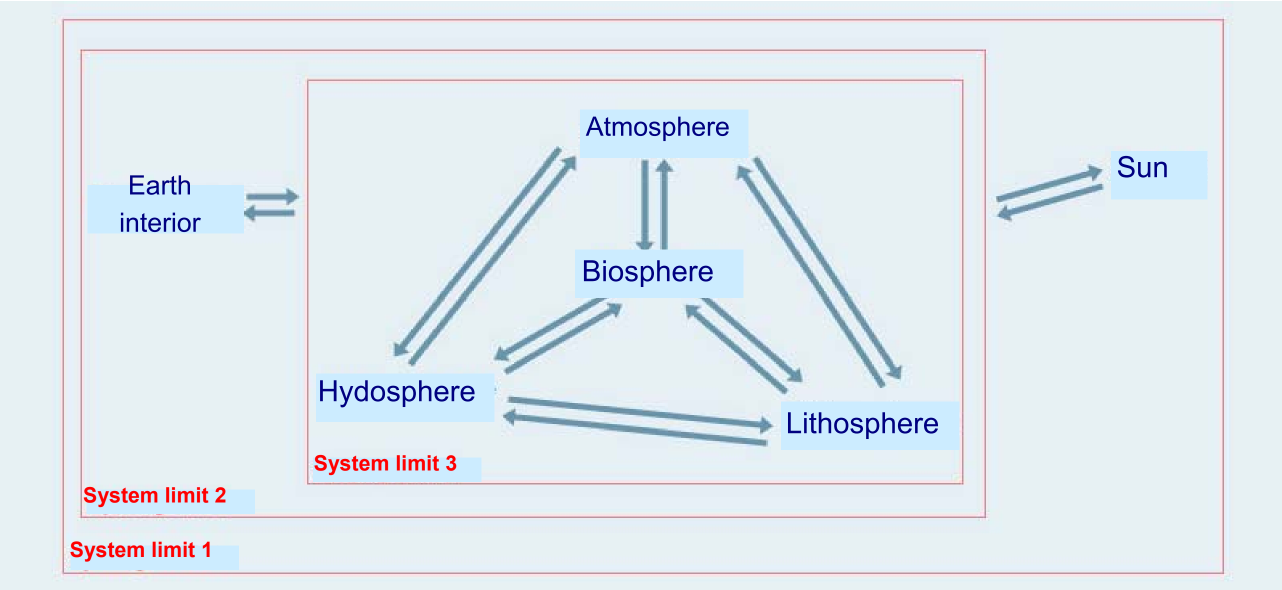


Illustration 7: Different system delimitations when viewing the Earth. The arrows represent the relations between the elements atmosphere, biosphere, hydrosphere and lithosphere as well as the Sun and interior of the Earth.

For example, you can consider the system Earth itself as an element of the Solar system. Then the limitation of the solar system is set as system limitation (see ill. 7.System limit 1). If you consider the system Earth without a relation to the Sun, then the system delimitation biosphere, hydrosphere, atmosphere, lithosphere and Earth interior are enclosed (see ill. 7, system limit 2). If you limit the observation of the system Earth solely to the interaction of the four mentioned spheres, then the illustration 7 in system limit 3 is the result.

The relationship between the four spheres in the course of about 4.6 billion years of continuous Earth history have permanently influenced the appearance of the Earth’s surface and the conditions for life:

- In bio-geochemical circulations, the relations are characterized, among other things, by material flows. For instance, in the carbon circulation, the paths of carbonaceous molecules resp. carbon atoms are described by the different elements of the system Earth (see module “Carbon Circulation” and HLAWATSCH and VENKE 2002).
  - Dissolved carbon compounds in salt water are absorbed by animals and processed to lime bowls.
  - After dying, the bowls sink to the floor and become fossilized.
  - By means of plate tectonics, these fossilizations resurface,
  - In the course of chemical weathering conditions dissolve.

- And the dissolved carbon compounds return again to the sea over the rivers.

- Interactions can be differentiated by river relations. An example for an effect is the intensification of the (natural) greenhouse effect by carbon dioxide.
- Plate tectonics and climate conditions are activated by flows of energy, which have no connection to the four spheres. For this reason, system Earth is described as an open system. It is influenced by two large energy flows:
  - In the centre of the Earth, large amounts of heat (endogenic energy) in the form of liquid materials originate due to radioactive decomposition and condensation in the interior of the Earth's core. The energy is transported to the surface. At the same time, the same amount of energy flows in the direction of the Earth's surface, as is reformed in the Earth's interior (flow equilibrium). As a result of the energy flow, heat neutralisation or convection currents originate in the shell of the Earth. These convection currents are regarded as the motor of plate tectonics (endogenic processes).
  - The other large energy current comes from the Sun (exogenic energy). The Earth not only receives a large amount of energy from solar radiation, but also emits radiation energy. As a result of the solar radiation, which radiates in different places with different intensities, strong temperature differentiations are maintained between the warm tropics and the cold polar regions. The temperature differences activate, on the other hand, neutralisation currents in the atmosphere and on the ocean, which are known as immense wind systems and ocean currents. Wind and water form the surface of the Earth through erosion, transport and radiation energy (exogenic processes).

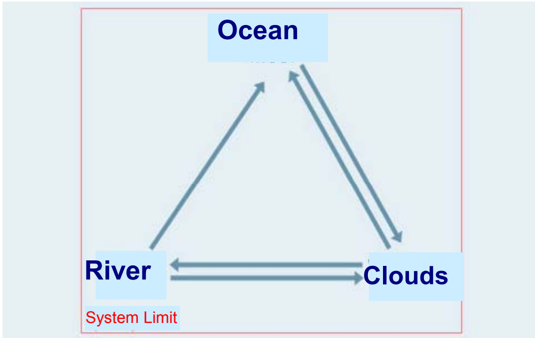


Illustration 8: This section from the water circulation is an example of a qualitative material flow diagram: Due to vapour and condensation, water molecules from the seas or rivers become a component of the clouds and re-enter the sea and rivers in the form of downpour.

This tiny selection from the network of relations in the Earth's system should elucidate that just a minute change in a sub-area of a sphere can have effects on all the other spheres.

2.3.3 How can you depict systems?

Illustrations of systems reflect the structure i.e., the elements and the relationships between the elements. Visual objects, graphics or mathematical formulas can for example, depict systems. Each of these forms of illustration emphasizes a specific aspect of the system. The selection of suitable forms of illustration depends on the aim, which is being pursued with the analysis of a system.

Visual illustrations (flow and effect diagrams) play a significant role. These depiction forms are especially suitable to convey the specific structure of complex systems.

Flow diagrams state how materials or energy in a system flow or are transformed. Arrows illustrate the flows between system elements. The arrows state in which direction the flows or transitions occur. These can be either qualitatively or quantitatively illustrated. Of especial interest for the geosciences are biogeochemical material circulations (see module "Carbon Circulations" and "Water Circulation and Protection of Drinking Water").

- **From a qualitative view** the arrows mean "flows in the direction of " is transformed to " (see ill. 2).

- **In the case of a quantitative illustration**, special system sizes, so-called state units are classified to system elements (see section 2.3.4 “State of a system”). They serve the purpose of making statements about the state of the system.

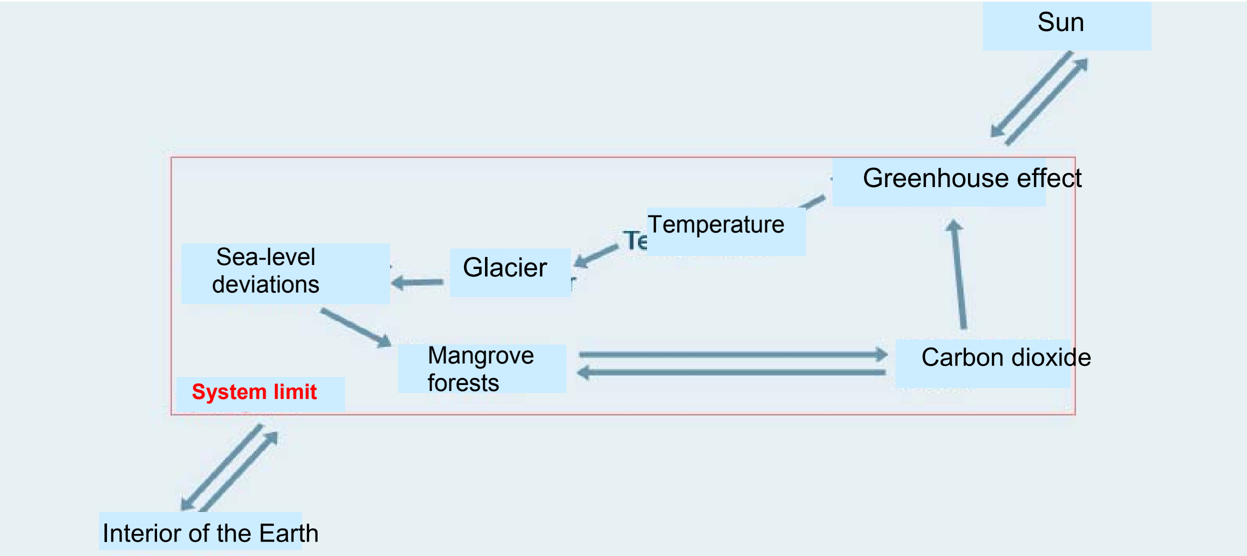
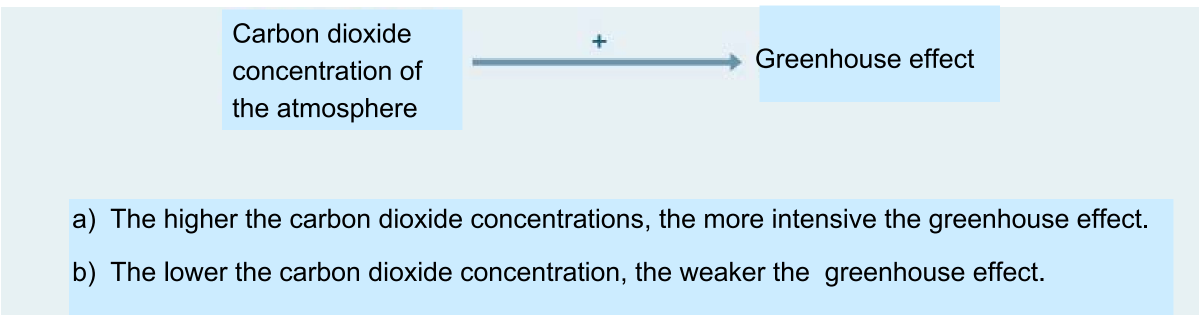


Illustration 9: This section of the climate system is an example for a qualitative effect diagram: Mangroves have an effect on the carbon dioxide concentration in the atmosphere which has an influence on the greenhouse effect and then influences the temperature in the atmosphere close to the Earth. The temperature has an effect on the melting, rasp. growth of glaciers, which, in turn, influences the sea level.

Effect diagrams form the effect relationships (causal relations) between system elements using arrows. They run in the direction of the effect and can, therefore, be depicted either qualitatively or quantitatively:

- **From a qualitative point of view**, the arrows mean “effects”. What is of especial interest for the geosciences are the effects of the individual components in the biogeochemical circulations. The effect diagram in illustration 9 shows qualitative exemplary effects of individual elements on the climate system.
- **In the case of the quantitative illustration**, system elements are classified to state units (see 2.3.4). The correlations between two system sizes can be either positive or negative:
  - Positive correlations are depicted by arrows which are provided with a “+”. The stand for “the more , the more ” and “the less , the less”.



  - Negative correlations are depicted by arrows equipped with a –“. They stand for “the more , the less ” and “the less , the more ”. They are also described as counter meaningful correlations (for the illustration in an arrow diagram, see Bayrhuber and Schaefer, 1978)

Temperature $\xrightarrow{-}$ Glacier

a) The higher the temperature, the smaller the glacier.

b) The lower the temperature, the higher the glacier.

Mathematical forms of illustration of systems occur in the form of equations. They are based on notation rules of mathematical technical language. Equation systems reflect the process characteristics of a system. For this, an exact knowledge of state units is necessary, which frequently can only result from research in the context of geoscientific large projects. These forms of illustration portray the basis of computer-supported models.

2.3.4 State of a system

The state of a system is described by state units (e.g. volumes, mass, energy). An individual state unit describes the state of system elements. Example: the system contains 25 litres of water. In this case the element water is described by the state unit volumes. Because water is a stored material, the state unit volume is also called stored size. State units have units of amounts, e.g. the unit litre (L), kilogramme (kg) or kilojoule (Kj). State units refer to a certain point of time. For example, the bath contains (storage) different volumes of water at different points of time.

3 Didactical Information

3.1 Learning aims

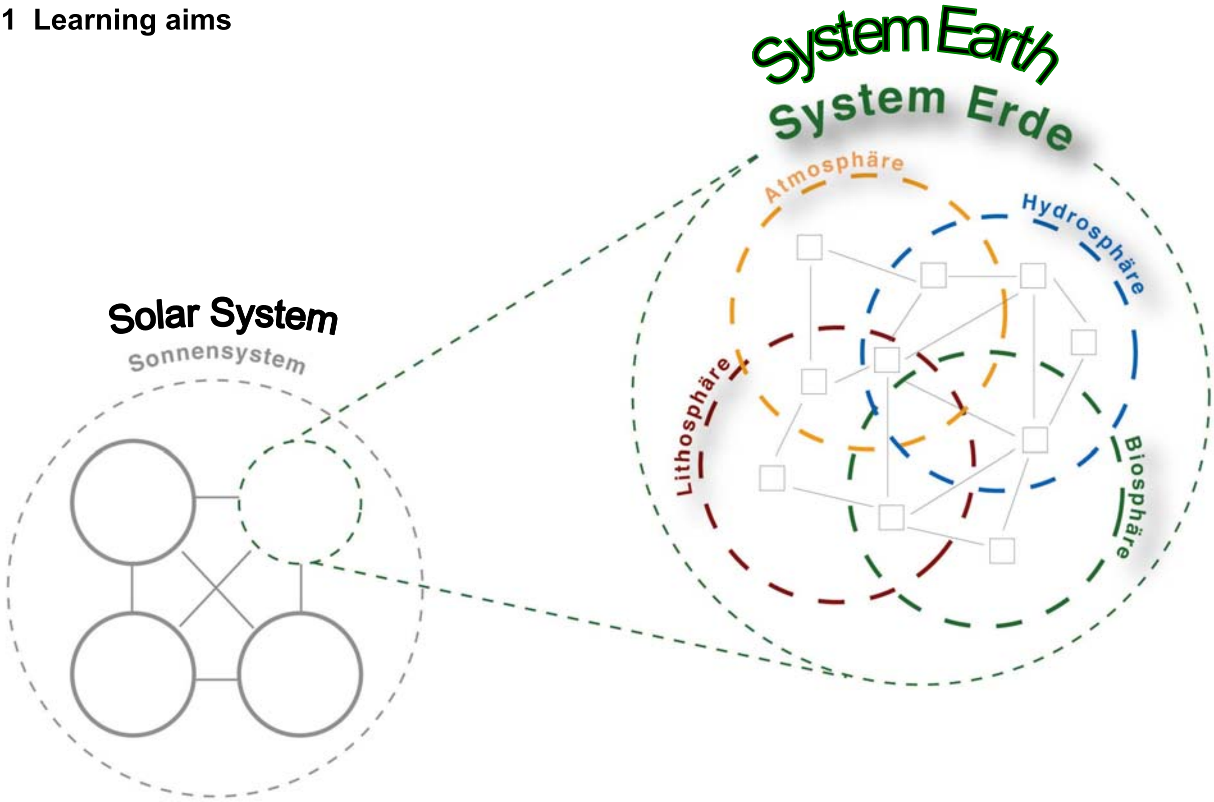


Illustration 10: The module "System Earth – the Basics" provides information about the complex overall system Earth with the four spheres as superior sub-systems as well as information on the system theoretical basics of the concept "Research dialogue: System Earth.

The system Earth is to be processed in its essential features together with the sub-systems: atmosphere, biosphere, hydrosphere and lithosphere (see ill. 10). It is intended that the students acquire a fundamental knowledge of the terms system and model so that they can apply these concepts in the course of further instruction in different combinations of contents. In view of the system Earth, the students should recognize in detail, that

- The four sub-systems: atmosphere, biosphere, hydrosphere and lithosphere illustrate elements of this system, which are differentiated from each other as material, are subject to dynamic changes and influence each other mutually;
- The person influences the element of the system Earth and its further development.

Moreover, he or she

- should recognize phenomena which are inherent to the larger system Earth;;
- that meaningful partial systems of the overall system can be isolated, without ignoring the overall context;
- know that based on the knowledge the changes of individual system elements, the development is possible of scenarios of further development of the system Earth;
- know that these systems are described by models;

- system models can be portrayed by flow and effect diagrams;
- know that system delimitations and the development of system models are dependent on the observer.

3.2 Learning prerequisites

None

3.3 References to horizontal and vertical links of contents

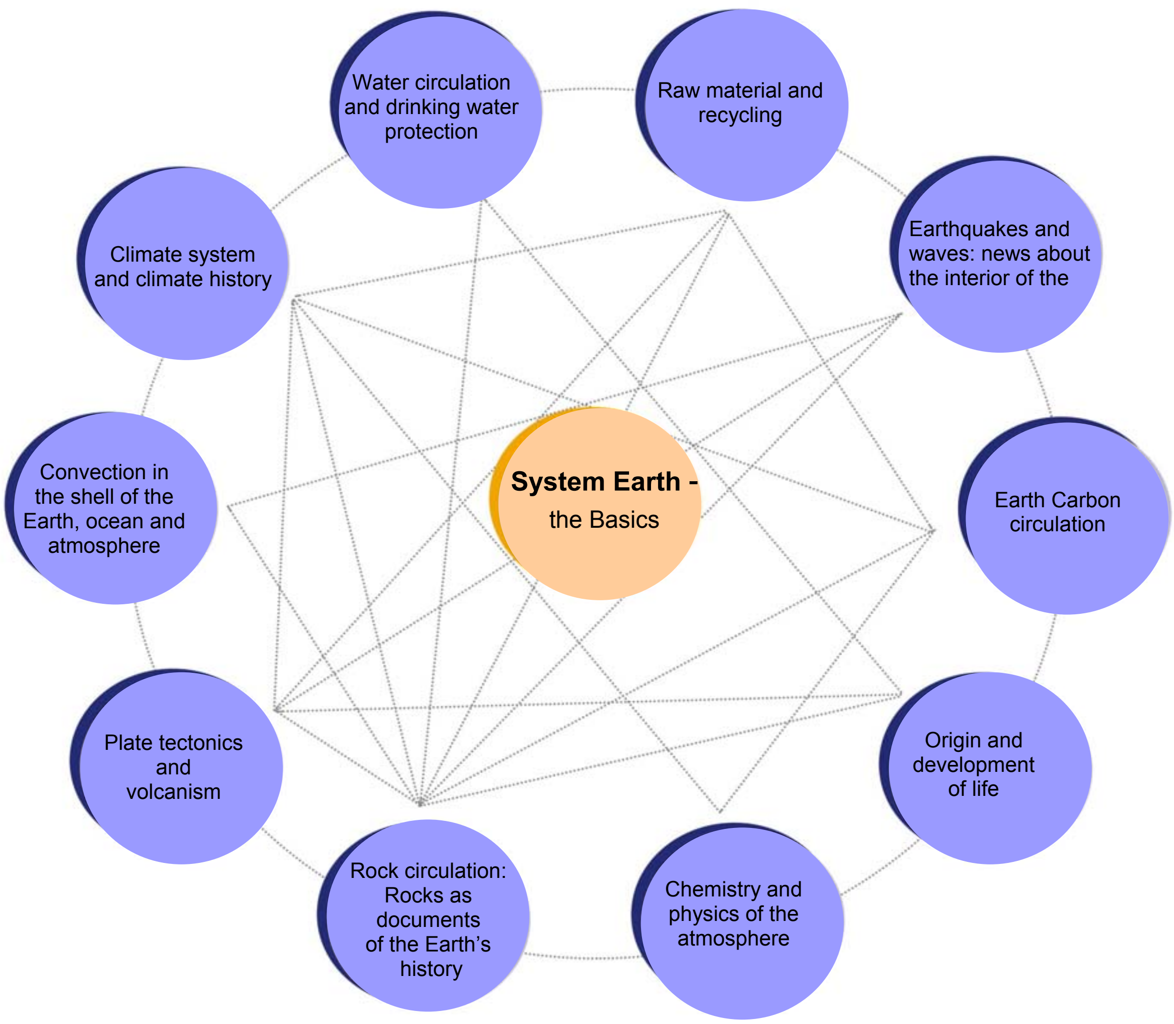


Illustration 11: Module overview of the project "Research dialogue System Earth". The subject analyses of the module are linked on a CD-ROM "System Earth" in the form of hypertexts with each other in order to make the relationships of technical contents for biology, chemistry, geography and physics instruction clear in a geo-scientific context.

The **system theoretical** and geoscientific basis for understanding System Earth and its exploration will be illustrated in the present module. The contents are interdisciplinary and basal. They offer the basics for a network of contents from different subjects, among others, biology, chemistry, geography and physics in the following instruction (see ill. 11).

3.4 Explanations and References to the materials

The materials are classified to two elements. These elements contain reading texts, which are compiled from the subject analysis.

The complete accompanying text is on the CD-Rom “System Earth” and only for teachers. An extra CD-Rom can be burnt for students, so that they can work on the computer with it. This student version comprises the same contents and the same extent of the function. However, it does not contain any didactical information or problem solutions. It can be made by clicking on the homepage of the CD-Rom “System Earth” on “Student version “. There you just follow instructions. Alternatively, the subject analyses can be processed in a program for text processing using the functions “copy” and “insert”.

For the structural elements, the materials in chapter 6 are available. Material 1 only has information for teachers.

Based on Element 1 **“Introduction to the System Concept”** (about 1 teaching hour) (Material 1) is to be introduced with the help of folios (Module 1, Element 1, Material 2) and by using working sheets (Module 1, Element 1, Materials 3 and 4) in the system concept.

With Element 2 “The Earth as a System” (about seven teaching hours) (Material 1) students should make concept maps which serve the purpose of illustrating the acquired concepts of system Earth gained in every-day life and in class. The students collect concepts which occur to them about “System Earth” and make a concept map in groups with other students. A student information sheet is available for this (Module 1, Element 2, Material 2). A member of each group presents their results. Building on this, the entire system Earth with the most important sub-systems come into perspective for the students. A computer animation (Module 1, Element 2, Material 6) presents the Earth as a system and following this, a computer-supported quiz illustrates the milestone of the history of the Earth (Module 1, Element 2, Material 4). This serves as an addition, control and manifestation of the newly acquired knowledge. Following this, based on concept mapping, the students will be introduced to the method of system analysis. The students receive an information sheet (Module 1, Element 2, Material 3) about this, they order their associations to their own concept maps of the subsystems (atmosphere, biosphere, hydrosphere and lithosphere) and identify effects and flows. For safe-guarding the results, the questions are available in Material 5 (Module 1, Element 2). The use of the accompanying texts in this context was already referred to above.

For the introduction described here in the instruction concept “Research dialogue: System Earth”, four -six class hours are necessary depending on the learning group. Since geography, biology, chemistry and physics classes as well as other subjects such as economics or politics benefit from this instruction, it is recommended combining these subjects for a week or to use a project day. The students should receive the opportunity after this to make their own system model when working independently.

Every student should put a file together on “System Earth”, in which all materials are collected which have a context to the subject according to the concept” Research dialogue: System Earth” in the participating subjects, biology, chemistry, geography and physics.

“Drawing Tool” (Module 1, Element 2, Material 8) was developed for individual projects with the CD-ROM “System Earth”, with which material flow and effect diagrams can be made. This interaction can be found down on the right under the preview pictures and was also integrated into all other interactions. Especially students who already have basic knowledge on the topic “System Earth” profit from using this tool.

4 Suggestions for instruction layout

The class instruction according to the concept "Research dialogue: System Earth" can take place in three phases, which is stretched over three years and is described as follows.

The module "System Earth – the Basics" (especially Element 2) comprises the **first phase**. The students are introduced to system analysis and to the milestones of the Earth's development. The newly learnt knowledge can be applied and substantiated through the materials of the other modules after that. In this first phase, knowledge and under comprehension deficits are discovered which can be closed using the materials in the other modules.

In the **second phase**, intensified knowledge can be acquired, e.g. about the composition of the Earth's interior or the Earth's atmosphere, processes of material and energy transports, plate tectonics and the creation as well as the development of life.

Some of the elements contain special materials with which the acquired ability in the introductory phase of making models of system Earth, respectively the subsystems are developed further. The students will be specially instructed to make material flow and effect diagrams. The topics "Water Circulation" and Rock Circulation" are especially suitable as an introduction. Material flow diagrams are to be made for this. The students can intensify their knowledge, for example, on the subject of carbon dioxide circulation, in which they first of all make a material flow diagram and then an effect diagram. In this way, the students intensify their knowledge about system analysis using increasingly more complex knowledge domains.

In order to stimulate student activity, materials are available for group work which can be divided up (group puzzle method), (Module 3, Element 6; Module 6, Element 3; Module 8, Element 4; Module 9, Element 1). With the help of the puzzle group method, the introduction in the project method, which is at the heart of the third instruction phase, is to be made easier.

Forms of Work	**Baustein**	
	1	**2**
Mind Mapping		
Concept Mapping		●
Carry out system analysis		●
Develop material flow diagram		
Develop effect diagram		
Observe descriptive elements	●	●
Compare criteria-related elements	●	●
Demonstration experiment		
Student experiment		
Research/ information acquisition		
Graph and work on texts	●	●
Interviews with experts		
Participating in excursions		
Group work		●
Stationary work		
Group puzzle (expert system)		
Project work		
Watch films/animations		●
Work on computer interaction		●
Work on model simulation		
Use the internet		
Write texts		
Hold talks		●
Make posters		●
Make data or interpret from tables, diagrams, graphics etc, data		
Evaluate	●	

Table 1: Forms of Works of the Modules "System Earth" – The basics

For the integration of newly acquired knowledge, the students receive the opportunity to recall which significance the respective systems have which had been worked on for the functioning of system Earth. This way, the students learn to integrate their knowledge which they have acquired in a system model systematically, actively and independently and to use it then for more intensive insights.

The instruction according to the concept "Research dialogue: System Earth" should be finished with student projects (**Phase 3**), through which a model for the climate system (effect diagram) is made (Module 10, Element 9). In individual instruction, the students are busy with literary research, expert interviews and other methods of gathering information on elements of the climate system (e.g. oceans hydrogen cars, regenerative energy, eco-taxes) under the viewpoints of sustainable development. Thereby, ecological, economical and social aspects are researched and compiled in a three-paged text. Each text should contain conclusions to aspects which promote sustainable development. Using these texts, the class should make an effect diagram in group work. This will then be used to identify, respectively develop the most effective measures for sustainable development in the sense of Agenda 21. Additionally, the topic should also be developed so that models, depending on the question, can contain different interpretations.

These effect diagrams are the basis of computer-supported climate system models. Their knowledge places the students in the position of being able to understand and evaluate results from model calculations for the development of planet Earth.

5 Literature

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6 Instruction materials

Element 1: Introduction to the System Concept

Material 1: Introduction to the System Concept (Information)

Material 2: The whole is more than the sum of its part (folio)

Material 3: Robert O' Neill's and his colleagues parable (1986) (Worksheet)

Material 4: Caricature (Worksheet)

Element 2: The Earth as System

Material 1: The Earth as System (Information)

Material 2: Concept mapping of the concept "System Earth" (Information)

Material 3: Interpretation of the concept maps regarding system theory (Information)

Material 4: Sphere rally (Interaction, see CD-ROM "System Earth")

Material 5: Checking learning success

Material 6: Spheres of the Earth (Animation, see CD-ROM, "System Earth")

Material 7: Milestones of the Earth's Development (Information)

Material 8: Drawing Tool (Interaction, see CD-ROM "System Earth")

Further materials

Riedelsheimer, T. (2001): **Andy Goldsworthy working with time: Rivers and Tides. Documentary film on DVD or VHS**. The artist, Andy Goldsworthy, became internationally famous for his fascinating work with natural materials – ice, rocks, leaves, branches and water. The film documents his work over a longer period of time, the creation and fading of his unique and very often short-lived pieces of art. This film offers an artistic access to system Earth. Hereby, Goldsworthy illustrates interrelations of super ordinate subsystems (atmosphere, biosphere, hydrosphere and lithosphere) over a short period of time from the perspective of the history of the Earth.
Source: absolut Medien, Boxhagener Straße 18, 10245 Berlin, Tel. 030-28539870. Internet: http://www.absolutMedien.de

Cassel-Gintz, M. & Harenberg, D. (2002): **Nr. 1 Syndrome des Globalen Wandels als Ansatz interdisziplinären Lernens in der Sekundarstufe. Ein Handbuch mit Basis und Hintergrundsmaterial für Leh-**

rerinnen und Lehrer. Syndromes of global change – behind the circumstantial title, there is an interdisciplinary concept which lays claim to relating and structuring different phenomena such as soil degradation, climate change, technology transfer, migration or also growing environmental awareness among the population. The aim is to recognize a typical pattern of global change, to classify new findings and to be able to assess different possibilities of action. Nr. 24 Unterricht zu den Syndromen des Global Wandels – Umsetzungsbeispiele für die Sekundarstufe I und II. Publication from the series „Werkstattmaterialien" des BLK - Programms „21" – education for sustainable development which can be downloaded from the internet. Source: http://www.Blk21.de/index.php

BLK- Model Experiment: **Steigerung der Effizienz des mathematisch-naturwissenschaftlichen Unterrichts (SINUS und SINUS-Transfer).** The BLK – model experiment program began in the school year of 1998/99. Under scientific guidance, the teachers were responsible for developing their instruction methodology. The groups received a lot of help from the program authorities in the form of further training, didactical materials, handouts and instruction-oriented stimulation. These measures served the purpose, first and foremost, of sharpening didactical awareness and the perception of teaching as well as being able to try out new procedures. Materials and articles can be downloaded from a central server.
Source: http://sinus-transfer.de/ (From the homepage, click on materials/sciences/ article – there you can access a complete list)

BUNDESMINISTERIUM FÜR UMWELT, NATURSCHUTZ UND REAKTORSICHERHEIT, BMU (1997): [Ministry for Environment] Umweltpolitik: Agenda 21. **Documents from the UN Conference for Environment and Development in June 1992 in Rio de Janeiro**. Can be ordered free of charge from the BMU.
Source: The German Federal Environment Ministry, Dep. Public Relations, Pf 12 06 29; D-10178 Berlin, Telephone +49-30 -285 50-0, Internet:www.bmu.de

SCHÄTZING, Frank (2004): ***Der Schwarm***. A novel, which gives a clear picture of the concept of the Earth as an overall system and gives insights into the life of geoscientists. A Peruvian fisherman disappears mysteriously at sea. A Norwegian team of oil developers is suddenly confronted with billions of worms which eat into methane hydrate at a depth of 700m. A freighter becomes infested with mussels, so that it can not manoeuvre and then whales attack the tug that comes to its rescue. Is a catastrophe in the offing?
Source: KIEPENHEUER & WITSCH, Cologne.

Element 1: Introduction to the system concept

Time: 45 minutes

❶ Materials

- Folio: “The Whole is More than the Sum of its Parts” (Module 1, Element 1, Material 2
- Work sheet “Parable from Robert O’NEILL et al. (1986)” (Module 1, Element 1, Material 3)
- Work sheet “Caricature” (Module 1, Element 1, Material 4)

❷ The system concept “The whole is more than the sum of its Parts”

The parable by R. O’Neill and his colleagues illustrates an important historical document in the history of system research. It originates from the debate of ecological research. In this context, it serves as the reason for the interdisciplinary position as well as the system analytic strategy of research. It was argued that a reductionalist research approach, by which every participating scientific discipline only works on a section of the entire system doubtlessly offers valuable insights into the sub-area. However, this does not lead to an insight into the complex structure of relations of the entire system. Today, in this context, the sentence is frequently used: “The whole is worth more than the individual parts”

Reductional research approaches follow the aim of reflecting on elements and relations of a system in detail as isolated as possible from one another. In this way, complex systems are to be analysed at a low complexity level, ultimately, on the level of molecules and atoms.

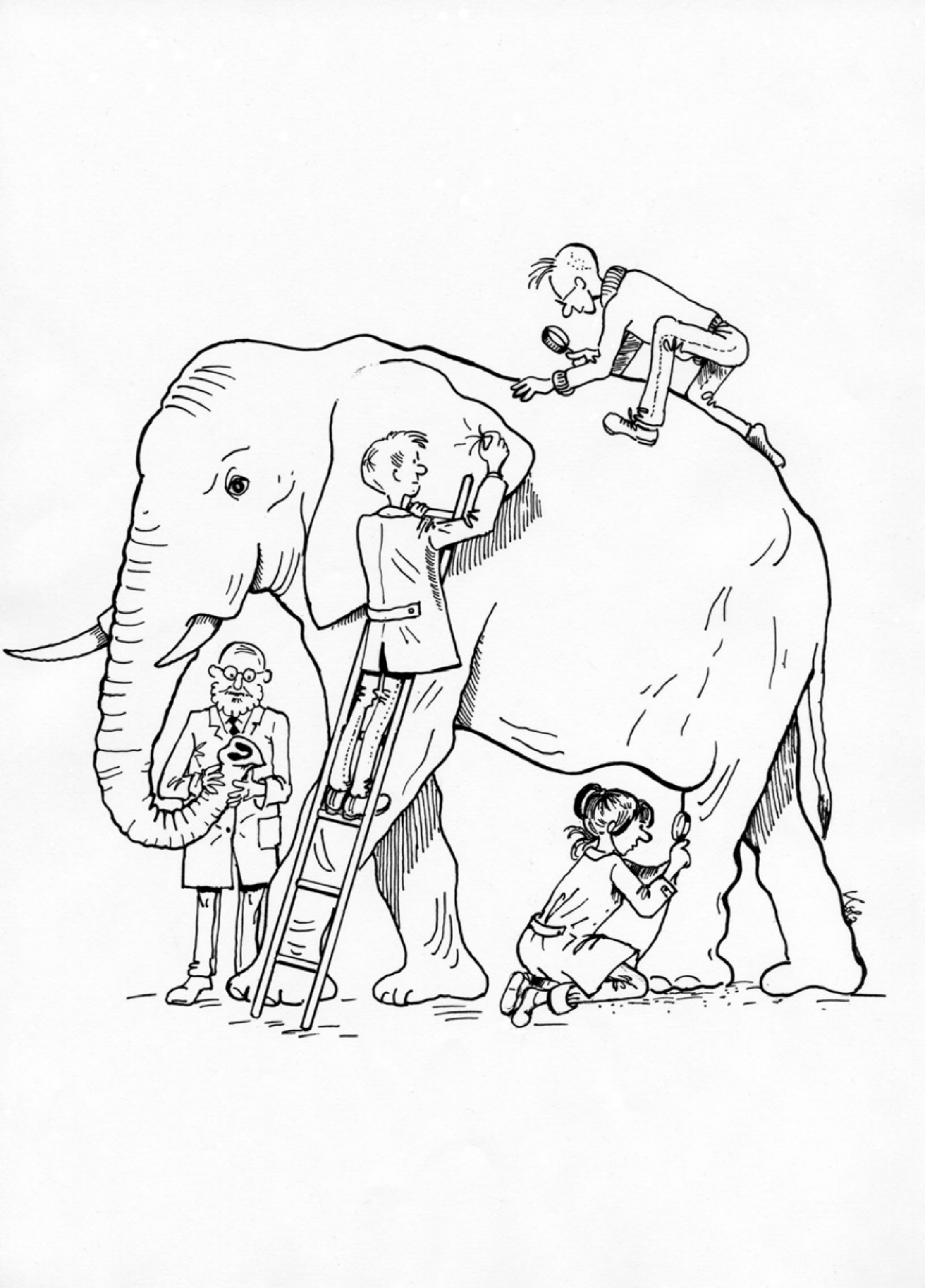
Since the mid-twentieth century, systematic thinking has developed as a new research perspective with the aim of incorporating reductionalist thinking into its procedure.

According to a systematic perspective, the behaviour of the individual elements is observed from a macro-level. This procedure is based on the insight that in the case of a constantly stronger limitation of the object under examination, features of the overall system are lost to view.

❸ Execution

Two work sheets are available (Module 1, Element 1, Material 4) and a folio (Module 1, Element 1, Material 2), which can be used independently of each other, The set of folios consists of five folios: Folio 1: “Research with the magnifying glass”; Folio 2 “Research with ladder”; Folio 3, “Female researcher with magnifying glass”, Folio 4 “Researcher with Beard”; Folio 5; “Elephant”.

The folios are laid upon each other in succession. Please pay attention that the students have sufficient time for describing and interpreting the individual folios. With the help of the folios, the view is directed towards the whole meaning. Each individual examination is only meaningful in context, when it evolves that an elephant is being examined. As an alternative to the folios, the students can be given the parable and/or the caricature (work sheet) for processing.



Element 1: Introduction to the system concept

Parable from Robert O'NEILL and Colleagues (1986)

Robert O'NEILL and his colleagues published the following parable in 1986 in order to promote a new approach to complex systems

Just imagine four scientists, who have set themselves the task of examining certain research objects very intensively using very sophisticated and ingenious instruments: They work on different parts of an elephant's body. However, they are so lost in different details of their respective research object, so that just this single part alone captures their entire interest. If we additionally assume that the elephant in its entirety was not presented to them, then after a long period of examination, the scientists would all come to totally different results. From the completely different conclusions, Scientist A would probably assume, that he probably has to deal with a fire fighter's hose, Researcher B who had concentrated on the right ear of the animal would possibly interpret it as a carpet and scientist C would write a report about the structure of broad walls, whereas the last colleague would interpret the elephant's leg as a typical example for a column. When they apply their isolated, reductionalistically gained individual result to the whole system, they would naturally come to totally different and contradictory conclusions. From the accumulated individual findings, none of the participating researchers can recognize that they are dealing with an elephant.

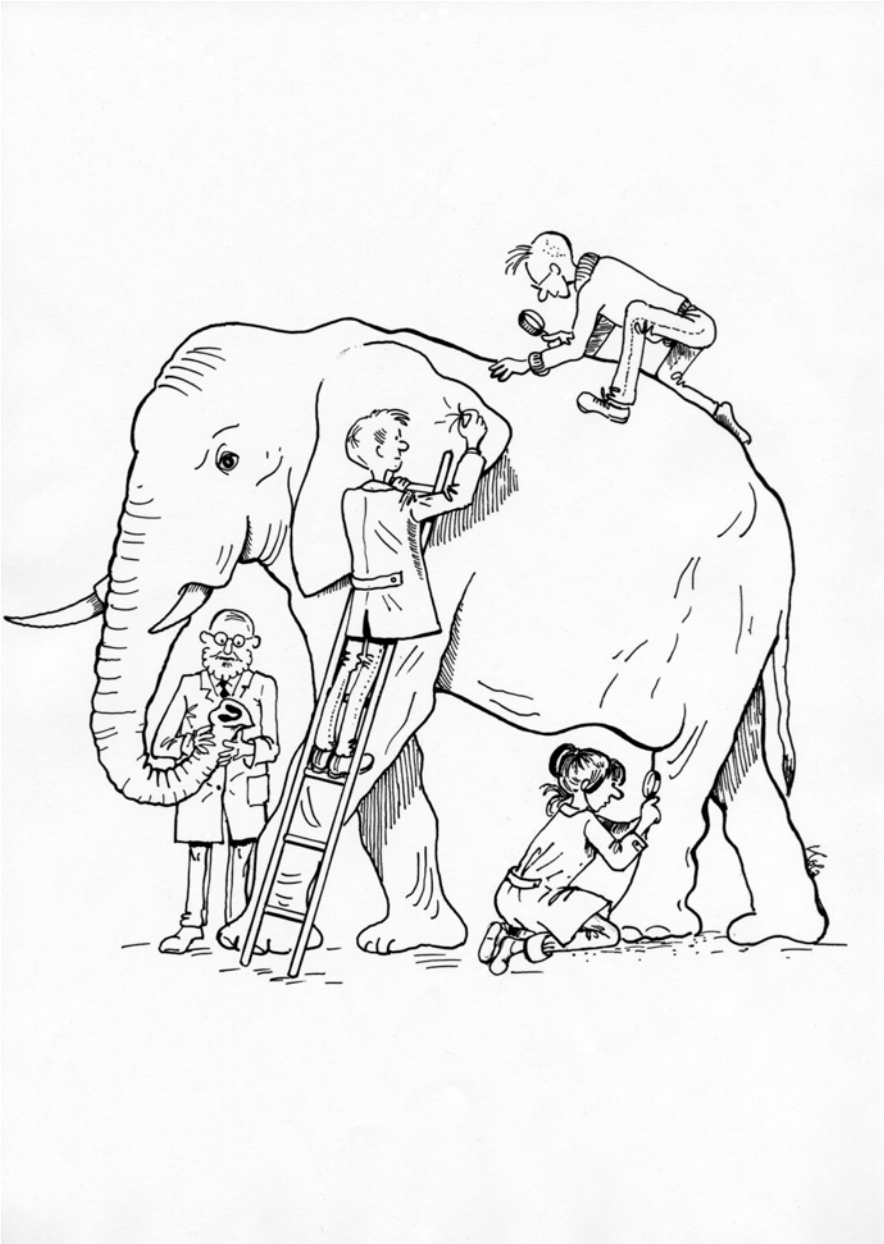
❷ Task:

1) Interpret the parable and formulate the core statement!

2) Which research approaches are referred to in the parable? Describe the methods and discuss their scientific significance.

Element 1: Introduction to the system Concept

Caricature



Tasks:

1) State the interpretation possibilities of the caricature!

2) Which research approaches are referred to? Describe the methods and discuss their scientific meaning!

Element 2: The Earth as a System

Time: About 7 teaching hours

❶ Materials:

- DIN-A5 notepaper and pen for every student
- Paper (DIN-AO) or a piece of carpet with adhesive tape in order to fasten it to the board
- One sheet of paper DIN-A4, yellow adhesive slips of paper and yellow markers
- Commentary to concept mapping (Module 1, Element 2, Material 2)
- Animation resp. interaction of the CD-ROM “System Earth”; “Spheres of the Earth” (Module1, Element 2, Material 6) and Sphere rally” (Module1, Element 2, Material 4), Computer/Beamer or computer room
- Commentary on the interpretation of concept mapping in view of system theory (Module1, Element 2, Material 3)

❷ Execution:

- **Concept mapping: compiling concept maps (2 teaching hours)**

I. The class is to be divided up into groups of maximal seven persons and every student receives a DIN-A5 sheet of paper.

Task: “ Everybody write down ten terms or brief ideas, which occur to you regarding the topic of “System Earth”. You have ten minutes for this task. A glance in the direction of the neighbour will not be encouraged, but it also does not have to be forbidden.

Category	**Exemplary terms named by the students**
Atmosphere	Atmosphere, Earth atmosphere, air, oxygen, ozone, ozone layer, ozone hole, greenhouse effect, climate, weather, wind, wind systems
Biosphere	Biosphere, life, creatures, bio-diversity, rain forest, bacteria, animals, plants, dinosaurs, ground fauna, flora, fossils, human beings, vegetation, biotic factors, ecology, eco-system, evolution, photosynthesis
Hydrosphere	Water, oceans, rivers, lakes, tides, rains weather circulation, dynamic environment (water circulation)
Lithosphere	Lithosphere, rocks, magmatites, minerals, composition of the Earth, core, shell, ground, relief, mountains, circulation of the rocks, earthquakes, earth layers, fossils, mountains, continents, plate tectonics sedimentation, volcano outbreak
Dynamics	Development, transitoriness, exploitation, movement, circulation, origin, time, evolution, tides, seasons, environmental catastrophes, circulation, sedimentation, erosion, destruction, assimilation, warming of the Earth, history of the Earth, earthquakes
Socio-cultural aspects	Human being, feelings, religion, God, politicians/politics, culture, world, States, population, nationalities, globalisation, poles, anthropogenic influences, exploitation, agriculture, farming, raw materials, industry, cars, satellite towns, computer-supported genetic engineering, travel
Nature, -resp. geo-scientific system aspects	System, influence, chaos, solar system, components, spheres (model), effects, influence through unstabile, sensitive relation, function, closed system, equilibrium, instability, circulation, self-regulation, interaction, material exchange, interactions, connections, interaction/living together

Table 1: Response examples from 9 classes to the questions: “What occurs to you regarding the topic of “System Earth”.

II. In each group, a student is sought who collects the terms of the others on the blackboard or on a DIN-A4 sheet of paper. The selected person receives an information sheet on concept mapping (Module 1, Element 2, Material 2). Each group agrees on 20 terms, which are transferred to the yellow slips of paper. Then the student classify, according to the information sheet, and then combine all the paper slips with the terms on the DIN-AO sheet (time ca. 45 minutes) with the arrows and label the arrows (**careful:** each arrow only leads to one term. The labelling should be completed in full).

III. Each group has five minutes for the presentation. After that, there should be some time allotted for questions

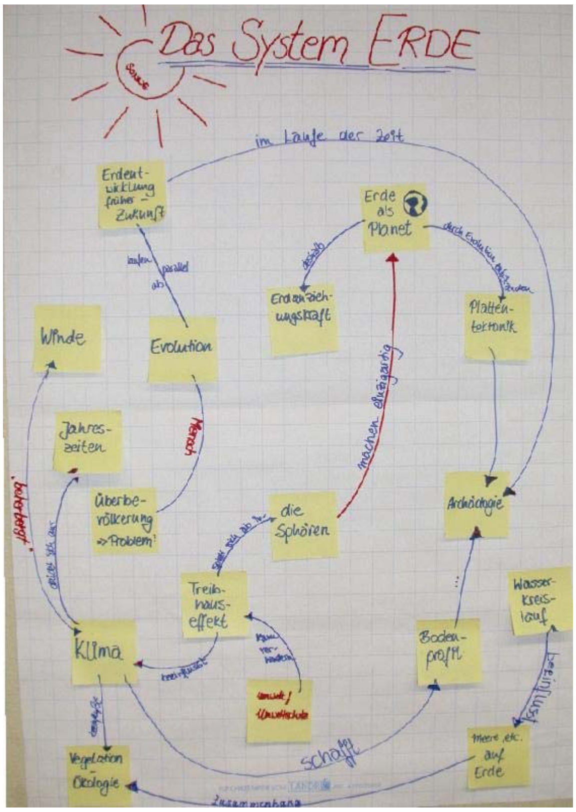


Illustration 1: A possible result for a concept map.

- **Quiz "Sphere rally" (1 hour of instruction)**

I. Present the students with the animation "Spheres of the Earth" (Module 1, Element Material 6) and the preview of the quiz "Sphere rally" (Module 1, Element 2, Material 4) of the CD-ROM "System earth" with a beamer.

II. Divide up the class in groups for answering the questions and choose one student to play quizmaster. Another student writes the scores on the board in a table. Each group has to agree on an answer, note it down on a list and bring it to the front of the class. Only when all the answers have been collected, will the result be written on the board. The quizmaster then answers the question and continues with the game.

- **Evaluation of the concept maps (Four teaching hours)**

After the students have compiled their concept maps and carried out the sphere rally, further concepts can be added, after this these maps have to be reviewed. The students receive an information sheet for this task (Module 1, Element 2, Material 3).

Task 1: Mark all the terms in your concept map according to their classification to the corresponding spheres. The following questions should be able to be answered:

- Which spheres are underrepresented?
- Which terms describe system Earth, which one de-

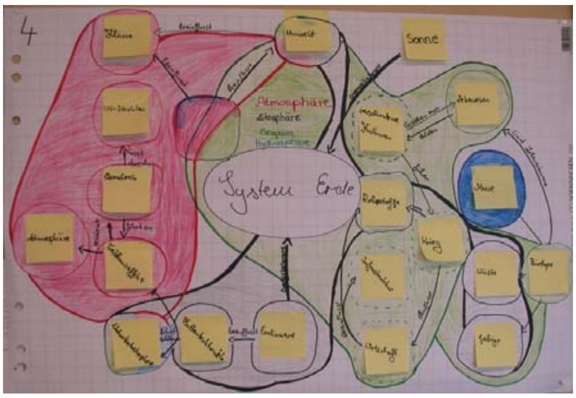


Illustration 2: In this concept map, the spheres were marked in colours and the Sun was entered as an external energy source.

scribes the surroundings of the Earth?

Possible answer: Sun, Moon and other planets describe the more comprehensive solar system.

- What activates the Earth?

  Possible answer: The Sun is an exogenic energy source, e.g. for the weathering and water circulation: The interior of the Earth is an endogenic energy source, which activates the convection current there as well as plate tectonics.

Task 2: Identify in your concept maps an example respectively for material flow and for an effect and make both a material flow and an effect diagram:

Flow diagrams state which materials or energy flow into a system or are transformed: The flows between system elements are illustrated by arrows. The arrows state in which direction the flows or transformations occur. These can be depicted either qualitatively or quantitatively. Of especial interest for the geosciences are biogeochemical material circulations. In a quantitative respect, the arrows mean "flows in the direction of ". "is transformed to "

Effect diagrams show the effect relationships (causal relationships) between system elements by arrows. They run in the direction of the effect and can also be illustrated qualitatively or quantitatively. **In a qualitative respect**, the arrows signify "has an effect on". The effects of individual components in the bio-geochemical circulations are of special interest for the geosciences. The effect diagram in illustration 4 shows qualitative exemplary effects of individual components from the climate systems.

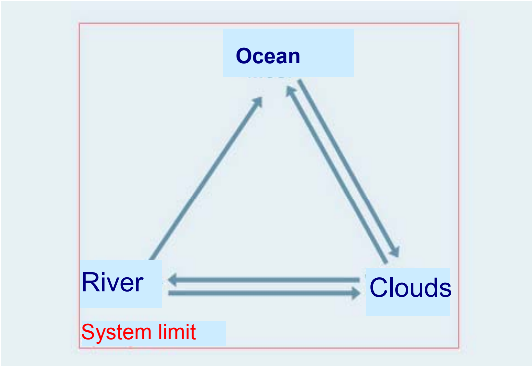


Illustration 3: This section from the circulation of water is an example of a qualitative low diagram: Water molecules from the seas or rivers become a part of the clouds as a result of evaporation and condensation. Due to rainfall, they become part of the seas and rivers again.

- **Checking learning success (One teaching hour)**

To conclude, the students can work on the work sheet "Learning control for the system concept" (Module 1, Element 2, Material 5). The CD-ROM of the project "Research dialogue: System Earth" contains all the information which is required to answer the questions. **Task:** Answer the following questions, for this task you can avail of the CD-ROM of the project "Research dialogue: System Earth"

Task 1: *System definition: A system exists in a system environment. It consists of elements, which stand in a special relationship to each other. A system delimitation separates the system from the system environment. There are relationships between elements of the system and elements of the system environment. Systems are changeable.*

Task 2: *What does the term "state" describe?*

*The state of a system is described by state units (e.g. volume, mass, energy). An individual state **unit of measure** describes the state of a system element.*

Task 3: *Which work steps comprise the system analysis?*

A system analysis comprises the following working steps: Demarking the system from the system environment: Identification (relevant) system elements; identification (relevant) relationships (effects and flows) between the elements; Identification of the system characteristics; identification of the relationships of the system to other systems.

Task 4: *How can systems be depicted?*

Systems can be depicted in the form of illustrations, graphically or mathematically. Graphic system illustrations (flow and effect diagrams) play a significant role here. A preliminary stage of this are the concept maps.

Task 5: *What value is it to you that you have gotten to know the system concept?*

With the system concept, the students get to know an aid for structuring complex, strongly linked contents, which they can apply in other knowledge domains.

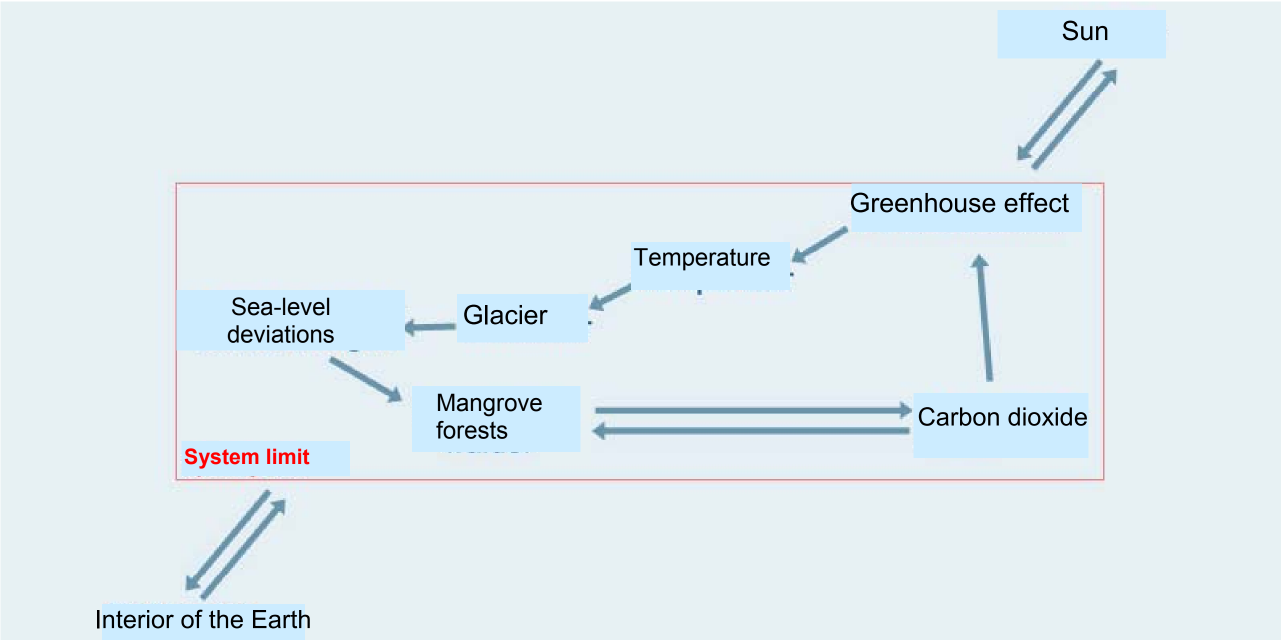


Illustration 4: This section of the climate system is an example of a qualitative effect diagram: mangroves have an effect on the carbon dioxide concentration in the atmosphere, which influences the greenhouse effect and with this the temperature in the atmosphere close to the Earth. The temperature has an effect on the melting or growth of a glacier, which, in turn, has an effect on the sea level.

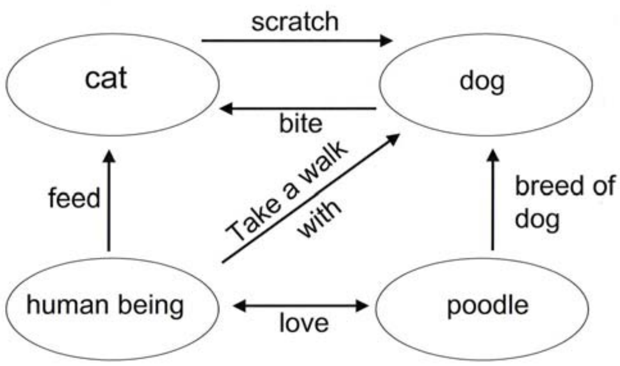
Element 2: The Earth as a system

Concept Mapping on the term „System Earth“

❶ Materials:

- DIN-A5 notepaper and pen for each student
- Table and chalk, alternative flip chart
- Yellow adhesive slip of paper

❷ Execution:



Draw according to your own ideas how concepts on “System Earth” stand in relationship to each other. Use the example of the relationships between the terms, cat, dog, poodle and human being as an orientation. Please take into consideration that there are different possibilities of classifying the terms that belong to each other, which at the same time can also be “correct”. Therefore, the different ideas of the polled persons or groups of people can be recorded and compared with each other with the concept maps.

❸ Task:

1) Draw a map relating to the concept “System Earth” in the following steps:
   - Note “System Earth” as a key concept in the middle of the work sheet;
   - Distribute the concepts, which you have taken a note of on the subject “System Earth” on this work sheet around “System Earth”. Put those concepts closer together which have a connection to each other;
   - Draw lines with arrowheads between the concepts in order to show how they stand in relation to each other
   - Comment on the connection lines in the form of a short note in what way the relationship exists between the concepts.

Tip: There is not a concept map, which is correct in itself. Depending on the choice of concepts, you get different results.

Element 2: The Earth as a System

Interpretation of the Concept Map with regard to System theory

❶ What is a system?

A **system** consists of elements, which stand in relation to each other (see ill. 5). Systems are changeable. If we look out of the window, we see a cross-section of the system Earth at a special point of time, e.g. trees, clouds and water. These are elements of the system, which stand in relation to each other: trees exchange oxygen with the air by means of breathing and photosynthesis as well as carbon dioxide. They absorb water through their roots and emit condensation through their leaves. The view provides a momentary picture of a process of constant changes in the system: trees grow, air movements and water availability constantly change.

With systems, it is frequently meaningful to differentiate the macro- and micro-levels. Under the **macro-level**, the system in its entirety is to be understood (e.g. the entire Earth), whereas individual system elements (e.g. the spheres) are known as the micro-level. The classification of a system to such a level is dependent on the question. The roots of a tree e.g. can constitute a meaningful **micro-level** when observing the combination of cells when absorbing their water and nutrition intake. Roots, however, belong to the micro-level, when you examine the water household of the entire tree.

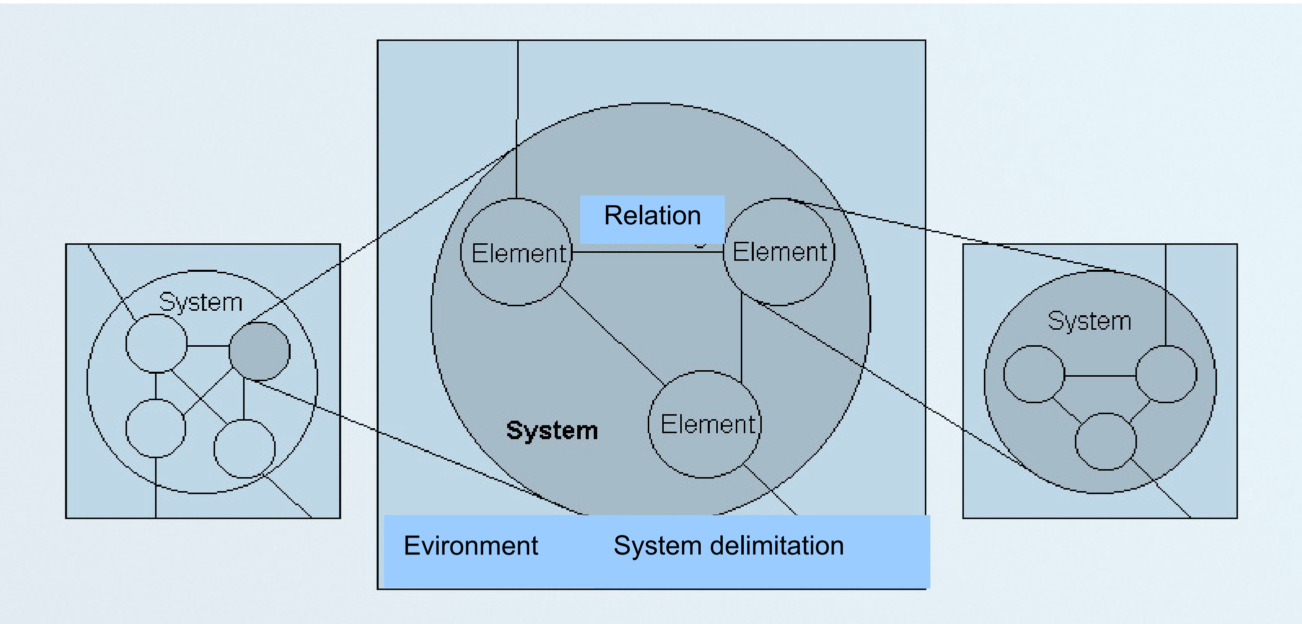


Illustration 1: Schematic illustration of a system. A system exists in a system environment. It consists of elements that stand in a certain relation to each other. System delimitation separates the system from the system environment (input respectively output). The system, which is illustrated in the middle, is on the micro-level in regards to the left illustration, whereas in relation to the system on the right it is on the macro-level.

Phenomena of *self-organisation* belong to the potentially unexpected observations on the *macro-level*. Hexagonal convection cells originate spontaneously in this way, e.g. by warming liquid on the stove under certain conditions (see module "Convection in the Shell of the Earth, Ocean and Atmosphere"). This phenomenon cannot be explained by means of the behaviour of individual molecules of a liquid. It is assumed that the creation of life of such a phenomenon is also self-organisation.

❷ System analysis:

In the case of *system analysis,* the system observer constructs a model. This depicts a selection of elements and relations of the system, which are of relevance for certain questions. For example, a *plastic model* of the wood of a tree only allows statements about the structure of different tissues of the tree and their situational relations, not about the cells from which the tissue is composed. Therefore, a *system model* just depicts a limited picture of the original. It is an idealised and abstractive illustration which makes the structural elements or functioning of the system understandable. With the help of a system model, hypothetic statements can be made about elements and relations of a real existing system, which is not or not yet accessible to direct research. This was true for e.g. the model concept of plate tectonics, when it was developed by Alfred Wegener (see module “Plate Tectonics and Volcanism”). The statements of this model concept could be examined later using geological findings. If positive agreements result from empirical findings, then a model can be used for prognoses about the future development of systems.

A system analysis comprises the following steps:

- Delimitation of the system from the system environment;
- Identification of the (relevant) system elements;
- Identification of the (relevant) relations (effects and flows) between the elements;
- Identification of the system features;
- Identification of the relations of the systems to other systems.

The results of the analysis can be displayed in graphic form, e.g. in the form of concept maps and/or material flows – resp diagrams of effectiveness (see Section 2.3.3 “How can you depict systems?”).

These results are the basis for the modelling of a system and for developing scenarios of future development. Certain models e.g. of climate development serve as the basis for political decisions.

❸ Example: The family as a system:

Using the family as a system, the steps of a system analysis are to be explained. A first step to analysing the system “family” is the identification of the system limitation and the relevant system elements. The point of view under which this system is observed determines the course of the system delimitation. It also determines which elements are regarded as relevant. If, for instance, communication is the key point of observation within the family, then all the people in the family who talk to each other come into consideration. Hereby, the closeness of the relationship is not the sole decisive factor. Therefore, for example, a maid who has been employed for years by the family, who spends everyday with the family is a relevant element in the system family regarding communication. And even the domestic pets can also be important from this perspective for the function of the system family as a communication system. Concerning the issue “inheritance”, the maid is normally not a relevant element in the system family. However, there are perhaps family members who do not play an important role in the system under the aspect of communication, but become relevant system elements when it comes to inheritance. In a further step of system analysis, the identification of relevant relationships is of concern. Between the elements in the complex and strongly linked family system, there are a number of effect relationships and even material flow or supply relationships.

- An example of effect relationships within the family system is stress behaviour. Parental professional stress can have a negative effect on the well-being of other family members. On the other hand, the composure of the children can reduce the mother or father's level of stress, which should then, in turn, increase the feeling of well-being of other family members.
- Money flows between the members of the family are an example for material (supply) flows, which characterize the system family. Money can pass from the parents to the children in the form of pocket money; the grandparents also give the children pocket money now and again. Children lend each other or their parents money. Moreover, using money flows within the family can make the aspect of connection between different systems clear. Therefore, the money, which flows within the family, can be supplied to the system, for example, by the employer. The firms, in which the parents are employed, are connected to the system "family" in this way. Finally, linked systems can be classified in hierarchies. Therefore, both systems "family and firm" as in our example are classified in an economic system, which are hierarchically superior to both systems.

❹ How can you depict systems?

Illustrations of systems reflect the structure i.e., the elements and the relationships between the elements. Visual objects, graphics or mathematical formulas can for example, depict systems. Each of these forms of illustration emphasizes a specific aspect of the system. The selection of suitable forms of illustration depends on the aim which is being pursued with the analysis of a system.

Visual illustrations (flow and effect diagrams) play a significant role. These depiction forms are especially suitable to convey the specific structure of complex systems.

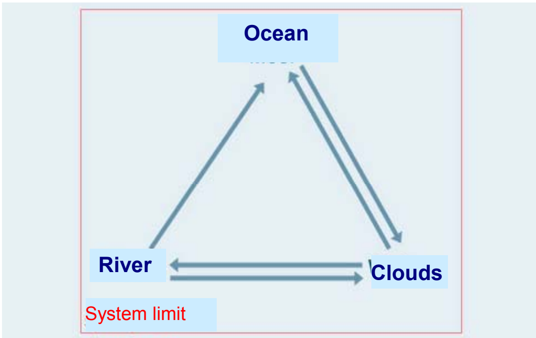


Illustration 2: Visual illustrations (flow and effect diagrams) play a significant role. These depiction forms are especially suitable to convey the specific structure of complex systems.

Flow diagrams state how materials or energy in a system flow or are transformed. Arrows illustrate the flows between system elements. The arrows state in which direction the flows or transitions occur. These can be either qualitatively or quantitatively illustrated. Of especial interest for the geosciences are biogeochemical material circulations (see module "Carbon Circulations" and "Water Circulation and Protection of Drinking Water").

- **From a qualitative view** the arrows mean "flows in the direction of " is transformed to " (see ill. 2)
- **In the case of a quantitative illustration**, special system sizes, so-called state units are classified to system elements (see section 2.3.4 "State of a system"). They serve the purpose of making statements about the state of the system.

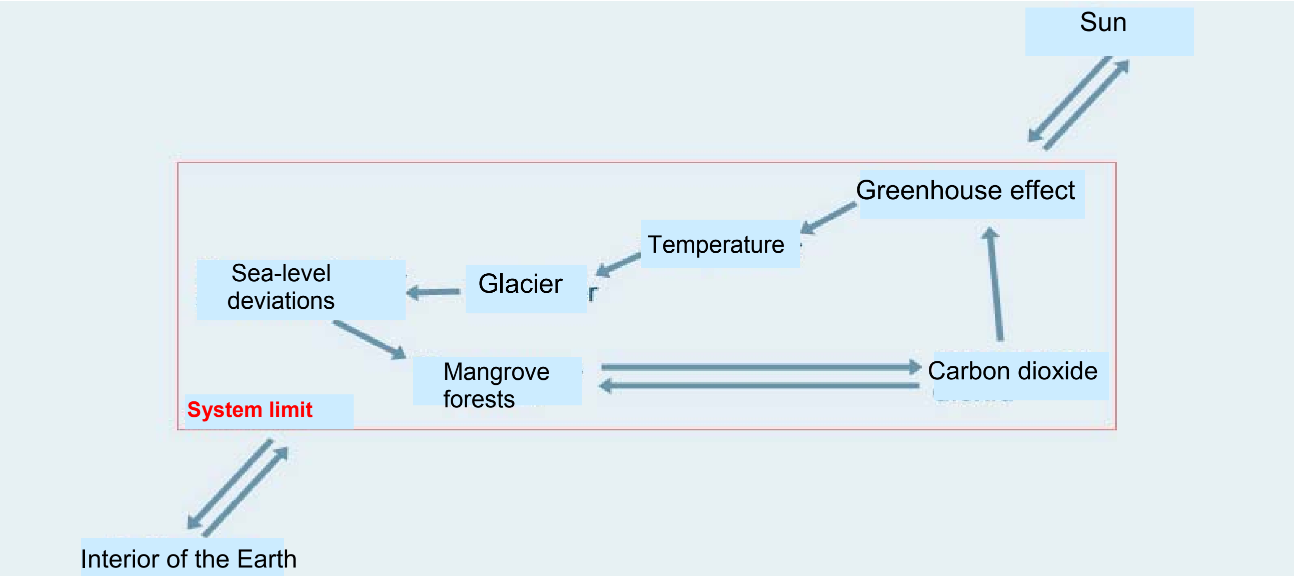
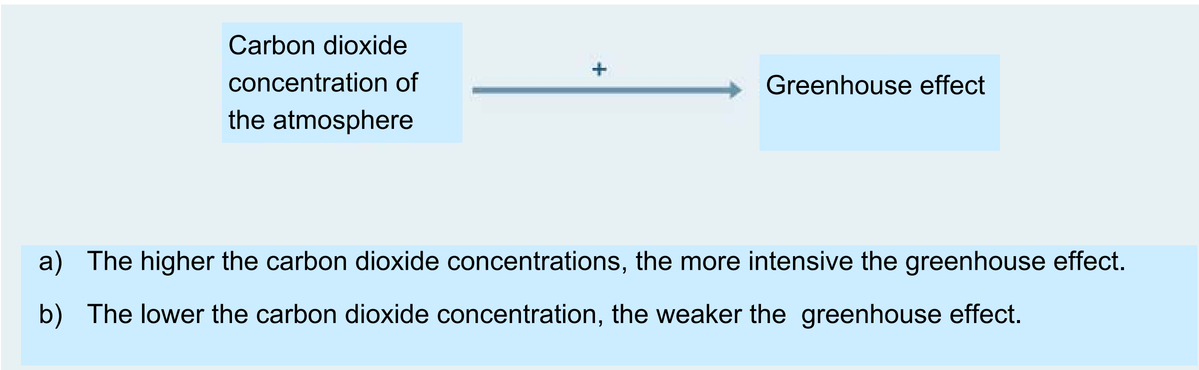


Illustration 3: This section of the climate system is an example for a qualitative effect diagram: Mangroves have an effect on the carbon dioxide concentration in the atmosphere which has an influence on the greenhouse effect and then influences the temperature in the atmosphere close to the Earth. The temperature has an effect on the melting, resp. growth of glaciers, which, in turn, influences the sea level.

Effect diagrams form the effect relationships (causal relations) between system elements using arrows. They run in the direction of the effect and can, therefore, be depicted either qualitatively or quantitatively:

- **From a qualitative point of view**, the arrows mean “effects”. What is of especial interest for the geo-sciences are the effects of the individual components in the biogeochemical circulations. The effect dia-gram in illustration 9 shows qualitative exemplary effects of individual elements on the climate system..
- **In the case of the quantitative illustration**, system elements are classified to state units (see 2.3.4). The correlations between two system sizes can be either positive or negative:
  - Positive correlations are depicted by arrows which are provided with a “+”. The stand for “the more , the more ” and “the less , the less”.



  - Negative correlations are depicted by arrows equipped with a –“. They stand for “the more , the less ” and “the less , the more ”. They are also described as counter meaningful correla-tions (for the illustration in an arrow diagram, see Bayrhuber and Schaefer, 1978)

$$\text{Temperature} \xrightarrow{\;-\;} \text{Glacier}$$

a) The higher the temperature, the smaller the glacier.

b) The lower the temperature, the higher the glacier.

Mathematical forms of illustration of systems occur in the form of equations. They are based on notation rules of mathematical technical language. Equation systems reflect the process characteristics of a system. For this, an exact knowledge of state units is necessary, which frequently can only result from research in the context of geoscientific large projects. These forms of illustration portray the basis of computer-supported models.

❺ Tasks:

1) Colour all the concepts in your concept map in colour according to classification to the respective spheres.

2) Identify your concept map each with an example for a material flow and for an effect, and make both a material flow an effect diagram.

Element 2: The earth as System

Learning check-up System concept

1) What are the most important aspects of a „system“?

2) What does the concept „state“ describe“?

3) Which steps are contained in the system analysis?

4) How can you show system?

5) What advantage is it to have gotten to know the system concept?

Element 2: The Earth as a system

Milestones of the Earth's Development

❶ Milestones of the Earth's development

A slowly rotating cloud of dust and gas – that was probably the origin of our planet system. The dust concentrated to material clouds, which extended much further out into space. About 5 billion years ago, material developed by forming a ball — first of all, the Sun evolved and somewhat later, the planets of the solar system (see ill. 1).

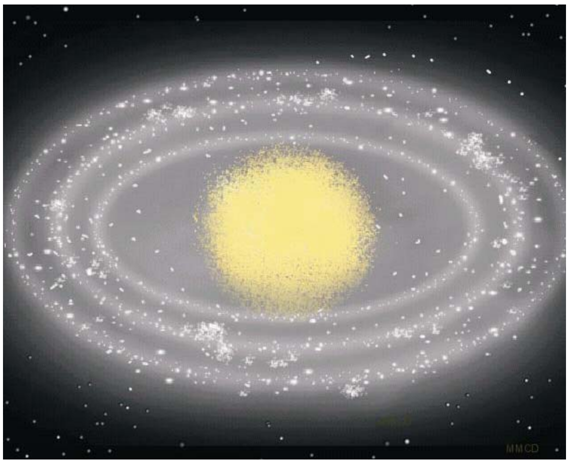


Illustration 1: The Sun in an early stage

Because of gravity the Earth attracted, after its coming to being, a large number of meteorites, which moved freely in the solar system. These fell to Earth as hailstorm in the unimaginably long period of 800m years. Each meteorite released heat energy when it made an impact. Additionally, the radioactive disintegration of elements in the Earth's interior, comparable to a huge nuclear power station, resulted in temperatures rising. For this reason, the Earth became hotter and hotter

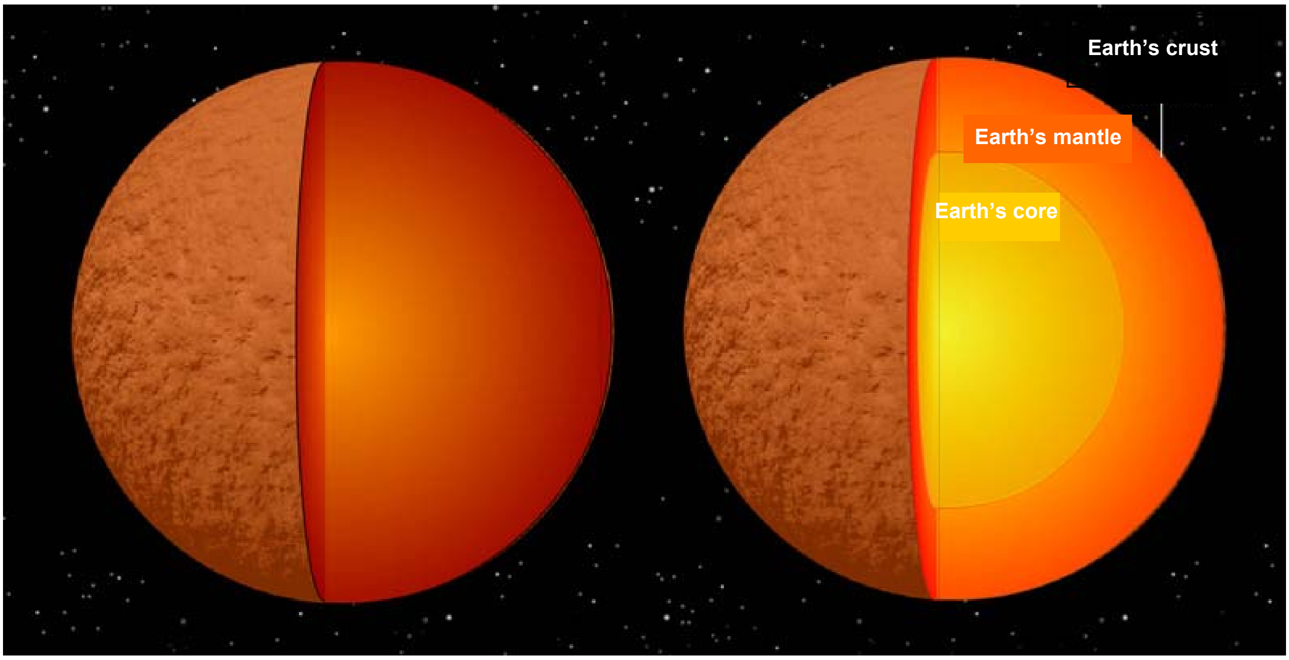


Illustration 2: The Earth formed its composition in the course of its history. The left illustration depicts the homogenic Earth, whereas the illustration on the right shows the later Earth with its core, coat and crust.

The Earth, in an early stage, was probably homogenic and had no continents or oceans (see module "Plate Tectonics and Volcanism"). With increasing temperatures of the Earth's interior, the Earth partially melted and this resulted in a separation of different compositions (see. Ill. 2) Iron sunk down in the central area, and specific lighter material rose to the surface. As a result, an ocean of magna was probably created which covered the entire Earth.

Right from the beginning, the Earth was almost surrounded by a gas cover, the atmosphere,. As far as we know today, the primordial atmosphere was comprised of nitrogen, carbon dioxide and vapour. When the meteorite shower dried up about 3,8 m years ago, the Earth cooled down. The first stones gradually formed and the surface solidified to a solid crust called lithosphere. The oldest stone, which has been found to date, originates from the south coast of Greenland. It is 3,75 billion years old (LAMB and SINGTON 1998).[1]).

After the Earth had cooled down further, the vapour condensed in the atmosphere. The water drops fell to the ground and collected in the depression of the Earth's crust. In those days, very large amounts of water fell in downpours. The water masses, which form the hydrosphere nowadays, for example, the oceans, rivers, lakes and the ground water and the clouds were originally and mainly dispersed as vapour in the atmosphere. Moreover, water was also released from stones.

Thus, three of the four superior subsystems of the system Earth (see. Ill. 3), the *atmosphere*, the hydrosphere and the lithosphere developed one after another. As a *lithosphere*, we describe the Earth's crust and a part of the upper shell of the Earth, which is comprised of rocks (see Module "Rock circulation: Rocks as Documents of the Earth's History" and "Plate Tectonics and Volcanism"). The term *hydrosphere* describes all the regions covered by water such as oceans, rivers, lakes and also ground water in the ground (see Module "Water Circulation and Protected Drinking Water").

Atmospheric gases dissolved in water. For this reason, right from the beginning, the oceans extracted carbon dioxide. In shallow water, organic compounds formed, such as aminoacids, short protein chains and the first molecular elements, which are similar to today's idioplasm (see ill. 4). From this, primordial cells were formed which differentiated themselves from the environment with membranes. As a result of the interaction of the atmosphere, the hydrosphere and the lithosphere, the biosphere developed which consists of bacterial-like archaea, bacteria, unicellular organisms, fungi, plants and animals.

The oldest petrification of organisms is probably 3.5 billion years old (Stanley 1984). These fossils were formed from creatures, which are similar to today's cyanobacteria in their exterior form. They lived in the sea and formed structures, which are called stromatolithes. Nowadays, fossils and other rocks serve as keys to understanding this earlier period (see Module "Origin and Development of Life"). A further 1.5 billion years later, that is 2 billion years ago, different kinds of procaryoten existed on Earth, which all lived in the sea. These were archaea, bacteria-lime creatures.

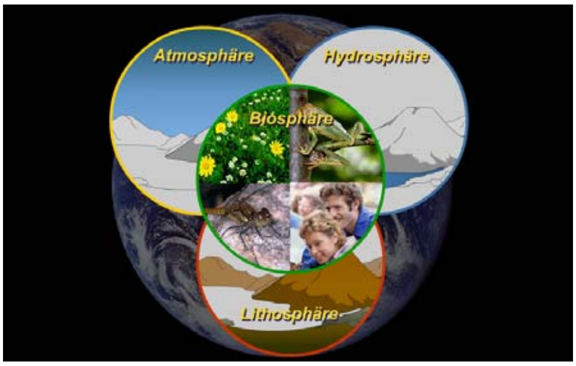


Illustration 3: The atmosphere, biosphere, hydrosphere and lithosphere are the four superior subsystems of system Earth.

[1] Die Quellen finden Sie im Literaturverzeichnis des Moduls „System Erde – Die Grundlagen“ auf der CD-ROM „System Erde“.

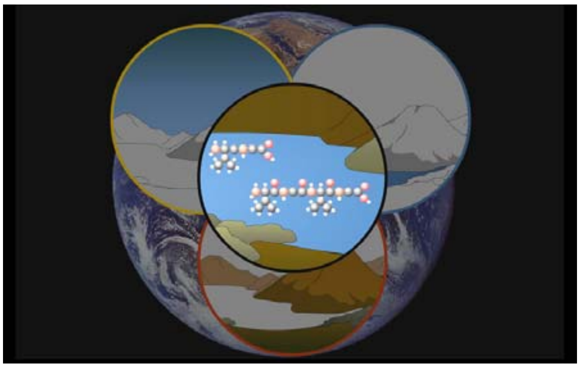


Illustration 4: The biosphere formed from the interplay of atmosphere, hydrosphere and lithosphere.

Photosynthesis was finally developed from bacteria, from which oxygen is released and, which is widely distributed in the plant world. Nowadays, oxygen from photosynthesis reacts immediately in seawater with iron salts to red iron oxide. First, it only penetrated the atmosphere in nominal amounts. Since the majority of iron compounds were oxidised after some time in salt water, oxygen was able to accumulate there. Therefore, the prerequisites for the development of cellular respiration for creatures also existed. In the case of *cellular respiration*, energy is extracted by the oxidation of organic materials with oxygen. However, for some million years, more oxygen was always released as was absorbed by breathing or other processes which sapped oxygen. Therefore, oxygen content of the atmosphere increased from about 0,2 % to 21 %. The value of 21 % adjusted itself gradually following the appearance of land plants more than 400 million years ago.

After the Earth had formed its shell-like structure, it was comprised of the Earth's core, the shell of the Earth and the Earth crust (see Module "Rock Circulation: Rocks as Documentation of the Earth's history"). Probably after about 2 billion years, the lithospheric plates were put into motion. They drifted apart so that huge oceanic pools were formed. As things developed, plates collided with each other and at the edge of the plates high mountain ranges were upfolded.

The energy for this process, which is called plate tectonics, is also responsible today for the disintegration of radioactive elements in the core and in the deep shell of the Earth. (see module "Plate Tectonics and Volcanism"). Due to the difference in temperature between the Earth's interior and surface, convection currents are put into motion in both the shell and in the core of the Earth (see module "Convection in the Shell of the Earth, Ocean and Atmosphere").

The atmosphere is also in constant motion and both winds and temperature differences in the ocean result in huge ocean currents. The energy of the movements in the atmosphere and hydrosphere comes form the Sun.