Original Research Article

Research on the deformation mechanism of rocks during the process of tectonic evolution

Hailong Chen, *Guanghui Wu*

School of Geoscience and Technology, Southwest Petroleum University, Chengdu, 610500, China

Abstract: This article delves into the mechanism of rock deformation during the process of tectonic evolution. Through a detailed analysis of the basic concepts, influencing factors, and deformation mechanisms of rock deformation in different tectonic environments, the important role of rock deformation in the evolution of Earth's tectonics is elucidated. By combining various research methods such as experimental studies, field observations, and numerical simulations, the complexity and diversity of rock deformation mechanisms have been revealed, providing a theoretical basis for a deeper understanding of internal tectonic activities, mineral resource exploration, and geological hazard prediction in the Earth.

Keywords: Structural evolution; Rock deformation mechanism; Influencing factors; Research method

1. Introduction

As a complex dynamical system,the Earth's internal structural evolution continues.Rock deformation is an important phenomenon in the process of tectonic evolution,which records the changes in the stress field inside the Earth and the tectonic movements during geological historical periods.In depth study of rock deformation mechanisms not only helps us understand the dynamic processes inside the Earth,but also has important practical significance for mineral resource exploration,geological hazard prediction,and other fields.

2. Basic concepts of rock deformation

2.1. Elastic deformation

When rocks are subjected to external forces, their shape and volume will change within a certain limit. Once the external force disappears, the rock can return to its original state, and this deformation is called elastic deformation. Elastic deformation follows Hooke's law, and stress is proportional to strain. In the shallow parts of the Earth, elastic deformation is more common due to the relatively low pressure and temperature on rocks. For example, during an earthquake, rocks are subjected to strong stress for a short period of time, and elastic deformation occurs first. When the stress exceeds the elastic limit of the rock, fracture and other forms of deformation occur.

2.2. Plastic deformation

When the stress exceeds the elastic limit of the rock, the rock will undergo irreversible deformation, namely plastic deformation. Plastic deformation is mainly achieved through mechanisms such as dislocation motion and diffusion creep. Dislocations are a type of defect in the atomic arrangement of crystals. Under stress, dislocations can move within the crystal, leading to plastic deformation of the crystal. Diffusion creep is the deformation of rocks achieved through the diffusion of atoms or ions in crystals, and this deformation mechanism is more significant under high temperature and low stress conditions. In the deep part of the Earth, due to the high temperature and pressure environment, rocks are more prone to plastic deformation.

2.3. Brittle deformation

Brittle deformation refers to the process in which rocks break under stress, forming cracks or faults. Brittle deformation usually occurs under low temperature and high stress conditions, especially in the shallow parts of the Earth. The brittle deformation of rocks is closely related to factors such as their strength, stress state, and internal microstructure. For example, when there are a large number of microcracks or pores in the rock, the strength of the rock will decrease and brittle deformation is more likely to occur.

3. Factors affecting rock deformation

3.1. Temperature

Temperature has a significant impact on the deformation mechanism of rocks. As the temperature increases, the strength of rocks decreases and their plasticity increases. Under low temperature conditions, rocks mainly exhibit brittle deformation; Under high temperature conditions, rocks are more prone to plastic deformation. For example, in the deep mantle of the Earth, where temperatures are high, rocks can adapt to tectonic stresses through plastic deformation. This is because high temperature can promote the movement of dislocations and the diffusion of atoms, thereby reducing the deformation resistance of rocks.

3.2. Pressure

Pressure is also an important factor affecting rock deformation. With the increase of pressure, the strength of rocks will increase, and the trend of brittle deformation to plastic deformation of rocks will strengthen. In high-pressure environments, microcracks and pores inside rocks are compacted, enhancing the continuity of the rock and thus improving its strength. For example, in the deep crust, due to the high pressure on the overlying rocks, the deformation mode of the rocks is more manifested as plastic deformation, and even under greater stress, the rocks are less likely to rupture.

3.3. Rock composition and structure

Rocks with different compositions and structures have different deformation characteristics. For example, rocks rich in quartz are usually more brittle than rocks rich in feldspar because quartz has a higher hardness, a relatively stable crystal structure, and is more prone to fracture under stress. The structure of rocks can also affect their deformation behavior, such as particle size, particle shape, and the bonding between particles. Fine grained rocks usually have better plasticity than coarse-grained rocks because the contact area between particles in fine-grained rocks is larger, and dislocation motion is more easily transmitted between particles, thereby promoting plastic deformation.

3.4. Time

Time also has a significant impact on rock deformation. In a short period of time, rocks may exhibit brittle deformation; Under long-term stress, rocks undergo creep and exhibit plastic deformation characteristics. For example, some ancient mountain ranges have undergone complex plastic deformation of rocks through long-term tectonic movements, forming structural forms such as folds and faults. This is because under long-term stress, dislocations inside the rock can gradually accumulate and move, leading to plastic deformation of the rock.

4. Rock deformation mechanisms under different tectonic environments

4.1. Plate convergence boundary

At the convergence boundaries of tectonic plates, such as subduction zones and collision zones, rocks are subjected to strong compressive stress. In subduction zones, oceanic plates subduct beneath continental plates, and rocks undergo complex deformation processes due to differences in subduction angles and velocities. In the shallow part, due to the low temperature, rocks mainly undergo brittle deformation, forming a series of faults and folds. With the increase of subduction depth, temperature and pressure rise, and the rock gradually undergoes plastic deformation, forming structural rocks such as mylonite. In the collision zone, two continental plates collide with each other, and rocks are subjected to enormous compressive stress, forming large-scale folded mountain ranges and thrust faults. During this process, the deformation mechanisms of rocks include brittle fracture, folding, and plastic flow.

4.2. Discrete boundary of plates

At discrete boundaries of tectonic plates, such as mid ocean ridges, rocks are subjected to tensile stress. At the mid ocean ridge, mantle material surges upwards, forming new oceanic crust. Due to the action of tensile stress, rocks undergo brittle fracture, forming a series of normal faults and rifts. During this process, the deformation of rocks is mainly brittle deformation, accompanied by the intrusion and eruption of magma. As the oceanic crust continues to expand, the rocks gradually cool and solidify, and their deformation mechanisms also change. In areas far from the mid ocean ridge, due to the relatively small stress on rocks, deformation is mainly dominated by plastic deformation and creep.

4.3. Plate conversion boundary

At plate transition boundaries, such as transition faults, rocks are subjected to shear stress. A transition fault is a fault zone that connects two different plate boundaries, with the plates on both sides moving horizontally relative to each other. Near the transition fault, the rock is subjected to strong shear stress, resulting in brittle fracture and plastic deformation. Due to the constantly changing direction of shear stress, the deformation mechanism of rocks is also relatively complex, forming a series of shear structures such as translational faults and goose like folds.

5. Research methods for rock deformation mechanism

5.1. Field geological observation

Field geological observation is the most fundamental method for studying the deformation mechanism of rocks. By observing exposed rocks, one can directly understand the deformation characteristics, structural morphology, and interrelationships between rocks. Field observation can obtain information on the occurrence, fold morphology, fault characteristics, and joint development of rocks, which is of great significance for analyzing the history and mechanism of rock deformation. For example, by observing the shape of folds and the orientation of axes, the stress direction and deformation history of rocks can be inferred; By observing the scratches and steps of the fault, the direction and nature of its movement can be determined.

5.2. Indoor experimental research

Indoor experimental research can simulate the deformation behavior of rocks under different stress, temperature, pressure, and other conditions under controllable conditions. Common experimental methods include rock mechanics experiments, high-temperature and high-pressure experiments, etc. Rock mechanics experiments can determine mechanical parameters such as elastic modulus, compressive strength, and tensile strength of rocks, and understand the deformation characteristics of rocks under different stress states. High temperature and high pressure experiments can simulate the deep environment of the Earth and study the deformation mechanism of rocks under high temperature and high pressure conditions. For example, through high temperature and high pressure experiments, the mechanisms of dislocation movement, diffusion creep, etc. in rocks during plastic deformation can be studied.

5.3. Numerical simulation

Numerical simulation is a method of simulating and analyzing the deformation process of rocks using computer technology. By establishing mechanical and physical models of rocks and inputting different boundary conditions and parameters, the deformation process of rocks in different tectonic environments can be simulated. Numerical simulation can visually display the process and results of rock deformation, providing an important means for studying the mechanism of rock deformation. For example, the finite element analysis method can simulate the deformation and failure process of rocks under complex stress fields. By analyzing the simulation results, we can gain a deeper understanding of the mechanisms and laws of rock deformation.

6. Conclusion

The deformation mechanism of rocks during the process of tectonic evolution is a complex and diverse research field. Rock deformation is influenced by various factors such as temperature, pressure, rock composition and structure, as well as time. Under different tectonic environments, rocks exhibit different deformation mechanisms. Through the comprehensive application of various research methods such as field geological observation, indoor experimental research, and numerical simulation, we have gained a deeper understanding of the deformation mechanism of rocks. However, due to the complexity of the Earth's internal structure and the diversity of rock deformation processes, the study of rock deformation mechanisms still faces many challenges. Future research needs to further strengthen interdisciplinary integration, continuously improve research methods and techniques, to reveal the mysteries of rock deformation mechanisms, and provide a more solid theoretical foundation for the development and practical applications of earth science. In terms of mineral resource exploration, a deep understanding of rock deformation mechanisms can help us better predict the distribution patterns of mineral resources; In terms of geological hazard prediction, the study of rock deformation mechanisms can help us more accurately assess the risk of geological hazards and provide scientific basis for disaster prevention and reduction.

References

[1] Rogowitz A.,Huet B..Evolution of fluid pathways during eclogitization and their impact on formation and deformation of eclogite:A microstructural and petrological investigation at the type locality(Koralpe,Eastern Alps,Austria)[J].Tectonophysics,2021,819.

[2] Engineering-Rock Engineering;New Rock Engineering Study Findings Recently Were Reported by Researchers at University of Science and Technology Beijing(On Anisotropic Fracture Evolution and Energy Mechanism During Marble Failure Under Uniaxial Deformation)[J].Journal of Engineering,2019.