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Compaction of Muddy Sediment and Its Significance to Groundwater Chemistry

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Abstract

Muddy sediment is one of the most common aquitards. During the burial compaction of mud, the pressure and temperature of strata increased with depth, in which some complex physical, chemical and biological reactions occurred. Meanwhile, a large amount of porewater, which interacts with microbes, organic matter and minerals in mud, would be discharged into adjacent aquifers. Numerous previous efforts by geologists have put forward some evidences, indicating that a portion of components (such as ions and nutrient) in groundwater are from muddy sediments. This paper provides a brief overview of efforts on different reactions in pore water in which environments change from oxidation to reduction and interfaces between the aquitard and the aquifer. Then, in the view of geological evolution, an idea is proposed that mud provided not only water but also material source for adjacent aquifer during its compaction and burial. In order to further understand the genesis of natural groundwater, especially natural inferior groundwater and brine, the diagenetic reaction and mineralization, water-rock interaction during the compaction of sediment should be considered, which will be of great significance in hydrogeology.

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1. Introduction

Aquitards, which usually accompany aquifers are the important components of the groundwater system. Naturally occurring muddy sediment with unique physical, chemical and biological properties, one of the most common aquitard, is ubiquitous in actual hydrogeology system. Due to its low hydraulic conductivity and widespread occurrence, few special attentions and detailed studies have been given on muddy sediments¹. Actually, muddy

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sediment not merely stores significant groundwater resource, but also dispose waste and protect regional aquifers^{2,3}. In the view of geological evolutionary process, mud is the starting point of aquitard formation, the water-rock interaction in which has large effects on the evolution of natural groundwater, and further diagenesis, mineralization and oil (gas)-generation. Mud is generally rich in water, microbes, carbon and heavy metals. It is a kind of fine, saturated and unconsolidated sediment. Furthermore, it is the sink of regional substance and chemical energy, mostly deposited in the discharge area of groundwater system. Indeed, the compaction and evolution of muddy sediments can be considered as complex water-microbe-organic matter-minerals interactions. Meanwhile, mud releases a large amount of pore water with originally chemical substances enriched in it to adjacent aquifer.

This paper deals with a review on the related studies on compaction of muddy sediment and its significance to groundwater chemistry for laying foundation for future work. In order to have further understanding on the genesis of natural groundwater, especially natural inferior groundwater (such as high arsenic or fluoride groundwater) and brine, the diagenetic reaction and mineralization, and broad prospects in hydrogeology, water-rock interaction during the compaction of mud should be considered, which will be of great theoretical and practical significance.

2. Compaction and burial of muddy sediment

Compaction is the process that pore water released from the compression actions of the sediment through compression caused by the deposition of overlying sediment^{4,5}. As the burial compaction of mud, the pressure and temperature of strata increased with the depth, in which some complex physical, chemical and biological reactions occurred. During the burial process, a large amount of pore water, which interacts with microbes, organic matters and minerals in mud, would be discharged into adjacent aquifers. Two primary processes involved in the compaction of fluid-saturated sediments are physical and chemical processes. The physical process is mainly mediated by pressure. Moisture and porosity of muddy sediment decrease with the increase of formation pressure. The chemical process is mainly dominated by microbes in the shallow burial period⁶, during which diverse microbial communities control various biogeochemistry processes, and by temperature in the deep burial period, during which the thermal maturity of organic matter, diagenesis and mineralization occurred⁷.

3. The effect on groundwater chemistry

In early 20th century, A. C. Lane and W. C. Gorden from America, and N. I. Andrusov from Russia had put forward an idea that groundwater came from initial water in sediments during the deposition and water released into the aquifer due to compaction of clay after the deposition⁸. Then, Vernadsky, modern geochemical founder, paid attention to the research on porewater in sediments, and believed porewater in muddy sediments played an important role in the formation of biogenic ore and mineral and was also the source of groundwater in sedimentary rock⁹.

The relevant studies indicate that aquitards can supply ions and nutrient for adjacent aquifer¹⁰⁻¹³. Several authors¹⁴ determined that approximately $(6-20) \times 10^{11}$ μg of arsenic was removed from near-surface wetland sediments annually by transport to the underlying high arsenic aquifer. Then, a few studies on high arsenic groundwater in Hetao Plain, Jiangnan Plain, Datong Basin, etc. showed that high arsenic groundwater aquifers always accompany with dark silt layers^{15,16,17}. Previous research on contribution of clay layer to the hydrochemistry of underlying confined aquifer in the Pearl River Delta, China demonstrated that the chloride and ammonium concentrations in adjacent aquifers were largely controlled by the chloride and ammonium concentrations in the silt clays¹⁸. It is known that several critical biogeochemical processes, including O_2 reduction, denitrification, methanogenesis, occur near the interface between aquifer and aquitard sediments¹³. The distribution of reaction pathways in the aquifer-aquitard interface depend not only on their relative energy yields, but on the availability of organic matter and terminal electron acceptors¹⁹.

With the development of the theory on groundwater flow system and the deepening of research on groundwater pollution, the retention and secondary release of pollutions controlled by clayey aquitards are being paid more and more attention by scholars^{14,20}. Generally, silt in low-lying areas would carry together a large number of chemical components, among which some would be released into the groundwater directly, and other could transform to new constituents into the groundwater or be attenuated due to adsorption and surface complexation within the silt under the effect of biogeochemical processes^{21,22}.

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