

Article

Discovery of Environmental Nanoparticles in a Mineral Water Spring from Yiyuan County, Shandong Province, Eastern China: A New Form of Elements in Mineral Water

Rui Liu ^{1,2,3} , Zhiqiang Zhao ^{1,2}, Minghui Lv ^{1,2}, Hongwei Wang ^{1,2}, Lixia Li ^{1,2}, Shenting Gang ^{1,2}, Lei Zuo ³, Peng Zhang ³, Yaqin Wang ³, Changsuo Li ^{1,2,*} and Qianqian Lu ^{1,2,*}

¹ 801 Institute of Hydrogeology and Engineering Geology, Shandong Provincial Bureau of Geology & Mineral Resources (Shandong Provincial Geo-Mineral Engineering Exploration Institute), Jinan 250014, China; liurui@sdu.edu.cn (R.L.); zhaozq1979@126.com (Z.Z.)

² Shandong Engineering Research Center for Environmental Protection and Remediation on Groundwater, Jinan 250014, China

³ School of Resources and Environmental Engineering, Shandong University of Technology, Zibo 255000, China

* Correspondence: lics120@163.com (C.L.); 15964526321@163.com (Q.L.)

Abstract: Environmental nanoparticles are known to be present in various aquatic environments, exerting significant influences on water quality, particularly in water distribution systems. However, there has been a notable dearth of research on the presence and impact of environmental nanoparticles in mineral water, a unique water resource. In this study, we employed Nanoparticle Tracking Analysis (NTA) and conducted High-Resolution Transmission Electron Microscopy (HRTEM) to address this research gap. This groundbreaking study represents the first comprehensive exploration of environmental nanoparticles within natural mineral water from Zibo City, Shandong Province, China. The results of the NTA showed that the concentration of the particles was 5.5×10^5 particles/mL and the peak diameter of the size distribution was 180 nm. The HRTEM showed that the nanoparticles were granular, pinniform, rodlike, and flakey in shape, and some of the nanoparticles existed in aggregation. The energy-dispersive spectrometry results showed that most of the nanoparticles contained O, Mg, Ca, Si, Fe, Ti, and P, and some of them also contained F, V, S, and Mn. When combined with the characteristics of the selected area electron diffraction pattern, the nanoparticles were confirmed to be Ca-bearing nanoparticles, attapulgite nanorods, MnO₂ nanosheets, and TiO₂ nanoparticles. These findings shed light on a novel manifestation of elemental compositions in mineral water. Furthermore, considering the chemical and physical attributes of both the nanoparticles and mineral water, it is highly plausible that these environmental nanoparticles result from the weathering of minerals. The presence of these nanoparticles within mineral water offers a unique opportunity to advance our comprehension of nanoparticle behavior across diverse systems. Significantly, the realm of environmental nanoparticle science holds paramount importance for ongoing endeavors in ensuring water safety, enhancing treatment processes, and facilitating effective remediation procedures.

Keywords: water quality; nanoparticle tracking analysis; high-resolution transmission electron microscopy; weathering byproducts; water safety



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1. Introduction

Mineral water is typically characterized as naturally occurring, uncontaminated groundwater that originates from deep subterranean sources or is deliberately accessed. It possesses inherent mineral salt content, trace elements, and occasionally includes dissolved carbon dioxide gas [1]. Distinguished by its unique fusion of mineral and water resource features, mineral water exhibits attributes such as recoverability, fluidity, distinct elemental composition, and relatively stable dynamic properties. Moreover, being a premium water source, it serves as a naturally beneficial beverage with positive implications for human health [2].

Prior research has effectively illustrated the pervasive occurrence of nanoparticles in diverse aquatic settings, encompassing groundwater, lakes, and rivers [3]. Despite constituting less than 1% of the Earth's overall water reserves, these water resources are paramount for human existence, serving indispensable roles in drinking-water supplies and agricultural irrigation. However, the mounting global population places escalating demands on these resources [4–6]. Nevertheless, as far as our current knowledge extends, no investigations have been conducted concerning the presence of environmental nanoparticles in natural mineral water resources.

The allure of nanomaterials lies in the unique characteristics they exhibit when at least one spatial dimension is confined within the nanoscale size range [7]. This remarkable phenomenon has been the driving force propelling the rapid advancement of nanotechnology, as evidenced by the multitude of industrial applications of synthetic Fe-oxide nanoparticles [8–10]. However, it is worth noting that nature, over the course of billions of years, has also given rise to its own iron oxide nanoparticles. These natural nanoparticles serve as carriers for elements and compounds within rivers and groundwater, facilitating their transportation over extensive distances. Moreover, they assume a critical role in the functioning of the critical zone, a fundamental component responsible for diverse dynamic environmental processes such as soil formation, elemental cycling, and the maintenance of water quality [3].

This study was undertaken with the objective of ascertaining the presence of environmental nanoparticles in natural mineral water and delving into the mineralogical traits of these nanoparticles. These nanoparticles exhibited not only a significant presence of major elements such as O, Mg, Ca, Si, Fe, Ti, and P, but also a notable content of trace elements including F, V, S, and Mn. Furthermore, we conducted a comprehensive investigation into the morphological and structural attributes of these nanoparticles within the mineral water. Our exploration extended to elucidating the sources and potential directions for further research on environmental nanoparticles in mineral water.

2. Materials and Methods

2.1. Sampling Location and Geological Background

The mineral water samples were obtained from well YY17 in Yiyuan County, Shandong Province, eastern China. Yiyuan County is in the central part of Shandong Province (Figure 1), and there are three types of landforms (low mountains, hills, and mountain plains) in this area. The altitude of this area ranges from 150 to 300 m. The study area is located in a warm-temperate zone with a semi-humid continental monsoon climate. It experiences four distinct seasons throughout the year. In spring, the climate is characterized by dry and windy conditions. The summer is characterized by high humidity, hot temperatures, and frequent rainfall. The autumn is typically sunny, with pleasant weather. The winter is cold and dry in this region. The average annual temperature is 13.6 °C, the average precipitation (1971–2017) is 724.90 mm, and the average annual evaporation is 1578.9 mm.

The strata in the study area are mainly composed of Cenozoic Quaternary Strata (clay and gravel sand), Ordovician Strata (limestone, dolomite, and siltstone), and Cambrian Strata (limestone, marl, dolomite, siltstone, and shale). The basement in this area is composed of the Neoproterozoic Taishan group (amphibolite). The fault structures in the region are extremely developed, with the northeast-trending faults being the most developed. Several springs in the region are also distributed in this direction. The intrusive rocks in the region are also relatively developed. Furthermore, the formation age is mainly Neoproterozoic, and the lithology is mainly amphibolite, hornblende quartz diorite, syenogranite, and monzogranite.

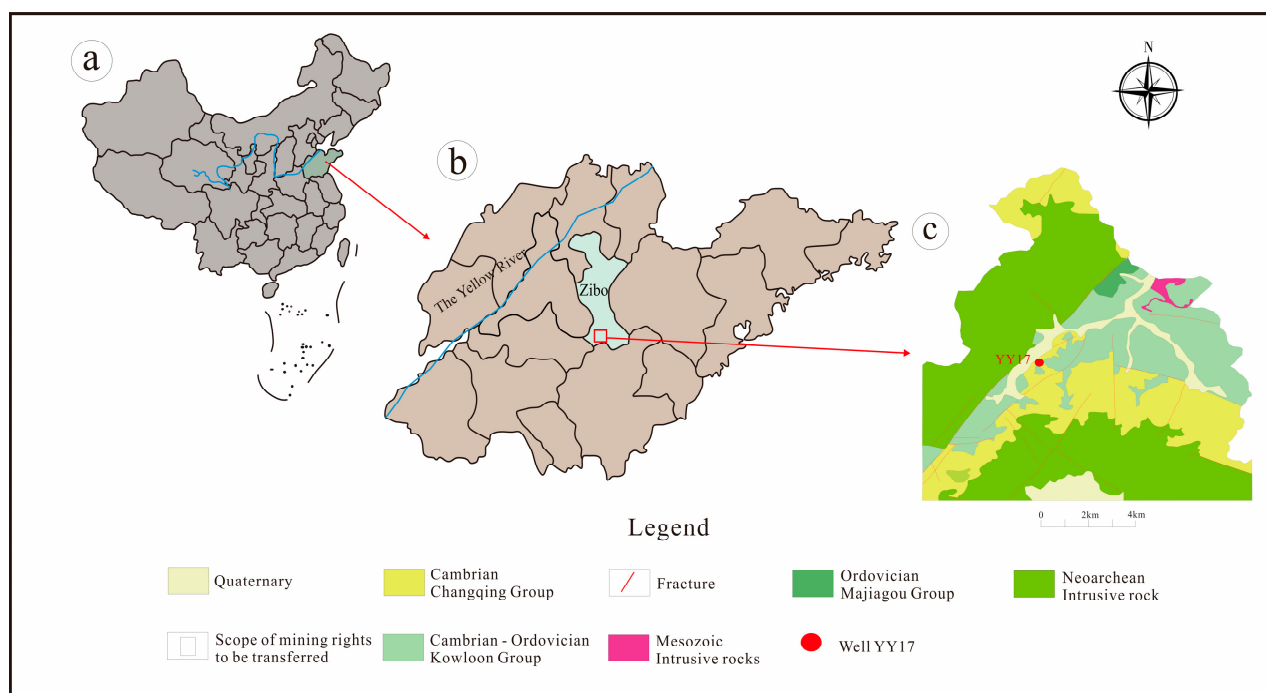


Figure 1. Location and geological sketch map of the study area. (a) The location of Shandong Province in China. (b) The location of Zibo City in Shandong Province. (c) A geological sketch of the study area.

2.2. The Occurrence and Hydrochemistry Characteristics of the Mineral Water

Well YY17, which contained natural mineral water, was located in the limestone and siltstone in the Cambrian Strata, and the roof and floor were impermeable shale in the Cambrian Strata and Neoproterozoic amphibolite, respectively. The hydrochemistry characteristics of the mineral water are shown in Table 1. The strontium content of the well YY17 mineral water was 2.64–3.01 mg/L, with a chromaticity of less than five degrees and a turbidity of less than 2 NTU. The volatile phenol content of this mineral water was <0.002 mg/L and the cyanide content was <0.002 mg/L. The anionic synthetic detergent content of the mineral water was <0.050 mg/L and the mineral oil content was <0.005 mg/L. The nitrite (NO_2^-) content ranged from 0.0172 to 0.054 mg/L, and the total content of the radioactivity β was 0.06–0.1032 Bq/L. There was no odor or objects in the water. In addition, the test result for coliform bacteria, fecal streptococci, *Pseudomonas aeruginosa*, and *Clostridium perfringens* was 0 [11]. These results indicated that the well YY17 natural mineral water was high-quality strontium-type natural mineral water.

Table 1. The results of hydrochemistry characteristics of the mineral water [11].

Sampling Times	Sr (mg/L)	K ⁺ (mg/L)	Na ⁺ (mg/L)	Ca ²⁺ (mg/L)	Mg ²⁺ (mg/L)	Cl ⁻ (mg/L)	SO ₄ ²⁻ (mg/L)	HCO ₃ ⁻ (mg/L)	NO ₃ ⁻ (mg/L)	TDS (mg/L)
25 December 2016	2.638	1.28	5.84	68.0	35.0	4.97	54.4	309	5.74	493
23 May 2017	3.01	1.19	4.93	67.6	35.9	8.75	59.3	314	5.67	507
22 September 2017	2.64	1.32	5.39	67.0	36.0	4.86	54.4	312	5.36	496
	3.01	1.25	5.16	69.4	36.4	5.25	59.6	317	5.49	509
	2.89	1.25	6.36	68.5	36.5	4.76	61.4	314	5.53	499
19 December 2017	3.00	1.14	5.07	70.8	37.8	5.60	60.6	314	6.03	510
	2.89	1.30	6.31	70.7	37.1	5.12	62.2	318	4.05	511

2.3. Sampling and Analytical Methods

2.3.1. Sampling

We chose clean and sterile 500 mL polyethylene bottle for sampling. We selected a sampling location that could represent the source of the mineral water accurately, and avoided areas with potential sources of contamination, such as sewage or chemical runoff.

The bottles were held beneath the surface of the water and filled slowly to minimize splashing. We allowed the water to run for a few minutes to flush out any stagnant water in the bottles, to ensure that the sample is representative of the current water quality. We filled the container to its capacity and labeled each bottle with essential information such as the sampling location, date, time, and any other relevant details. Then, we sealed the bottles tightly and transported them to the laboratory as soon as possible. The samples were kept at a cool and stable temperature during transportation to preserve their integrity.

2.3.2. Nanoparticle Tracking Analysis

Ten samples were diluted in phosphate-buffered saline (PBS) to a final volume of 1 mL. The optimal measurement concentrations were determined by pre-testing the ideal particle per frame value (140–200 particles/frame). The default software settings provided by the manufacturer for the nanoparticles were selected accordingly. Each measurement involved three cycles, scanning 11 particle positions and capturing 60 frames per position (video setting: high), under the following settings: focus, autofocus; camera sensitivity, 92.0; shutter, 70; scattering intensity, 4.0; and cell temperature, 25 °C. Subsequently, the videos were analyzed using the built-in ZetaView Software 8.02.31 (Particle Metrix Inc., Meerbusch, Germany), employing the following analysis parameters: maximum particle size, 1000; minimum particle size, 5; and minimum particle brightness, 20. An embedded laser (40 mW at 488 nm) and a CMOS camera were employed in the experiment. The number of completed tracks in the nanoparticle tracking analysis (NTA) measurements was always greater than the proposed minimum of 1000 to minimize skewed data based on single large particles [12].

2.3.3. Characteristics of the Nanoparticle Analysis

The mineral water samples were pre-treated before being analyzed using high-resolution transmission electron microscopy (HRTEM). The pre-processing of these samples followed the procedures described by Li et al. (2016) [13]. To ensure even dispersion of nanoparticles in the aqueous solution, the collected water samples were lightly shaken before being transferred onto the HRTEM grid using a pipette. This shaking procedure was repeated four to five times. All grid samples were tested at the Sinoma Institute of Materials Research (Guangzhou, Guangdong, China) Co. Ltd. using an HRTEM facility (Tecnai G2F20) equipped with energy-dispersive spectrometry (EDS) at 200 kV. The HRTEM had a dot resolution of 0.20 nm and a linear resolution of 0.102 nm. The maximum magnification for HRTEM and scanning transmission electron microscopy was 1 million and 2.3 million times, respectively. The elemental composition of nanoparticles was determined via EDS-analysis.

3. Results

3.1. The Number and Size Distribution of the Environmental Nanoparticles in the Well YY17 Mineral Water

The NTA of the well YY17 mineral water showed the size distribution with a peak diameter of 180 nm (Figure 2), and the concentration of the particles was 5.5×10^5 particles/mL (Figure 2).

3.2. Characteristics of the Environmental Nanoparticles in the Well YY17 Mineral Water

According to the morphological map of the nanoparticles (Figure 3), it can be observed that these nanoparticles exhibit various shapes and sizes. Specifically, the samples consist of granular, pinniform, rodlike, and flakey nanoparticles. Furthermore, some of the nanoparticles are observed in the form of aggregates, while a few are present as monomers. Among these nanoparticles, the smaller ones were only 50×60 nm in size, while the larger ones reached 300×500 nm in size. Moreover, the elemental compositions of these nanoparticles varied, and the elements included O, Mg, Ca, Si, Fe, Ti, P, F, V, S, and Mn. Among them, the representative nanoparticles are discussed below.

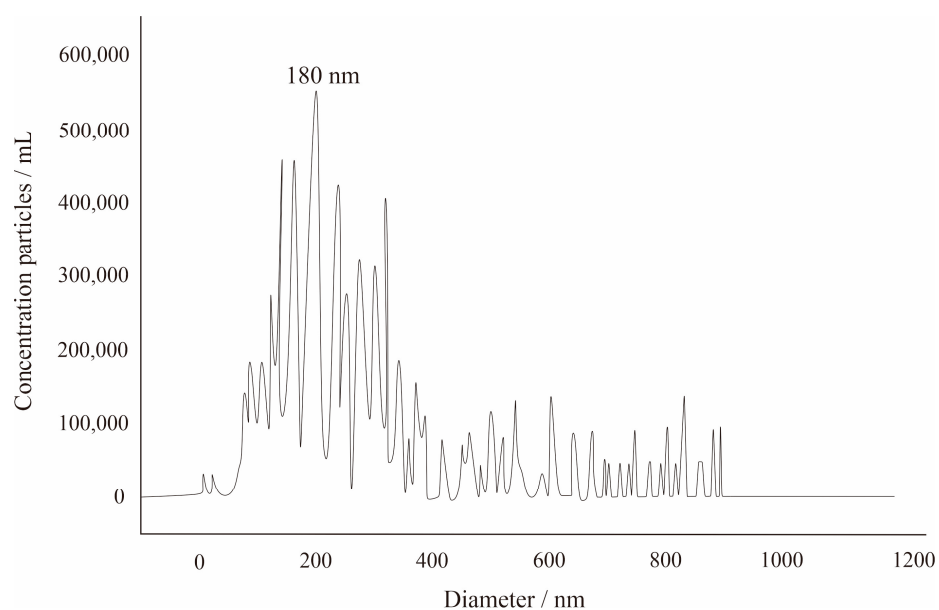


Figure 2. The size distribution and concentration of the particles in the well YY17 mineral water analyzed using nanoparticle tracking analysis.

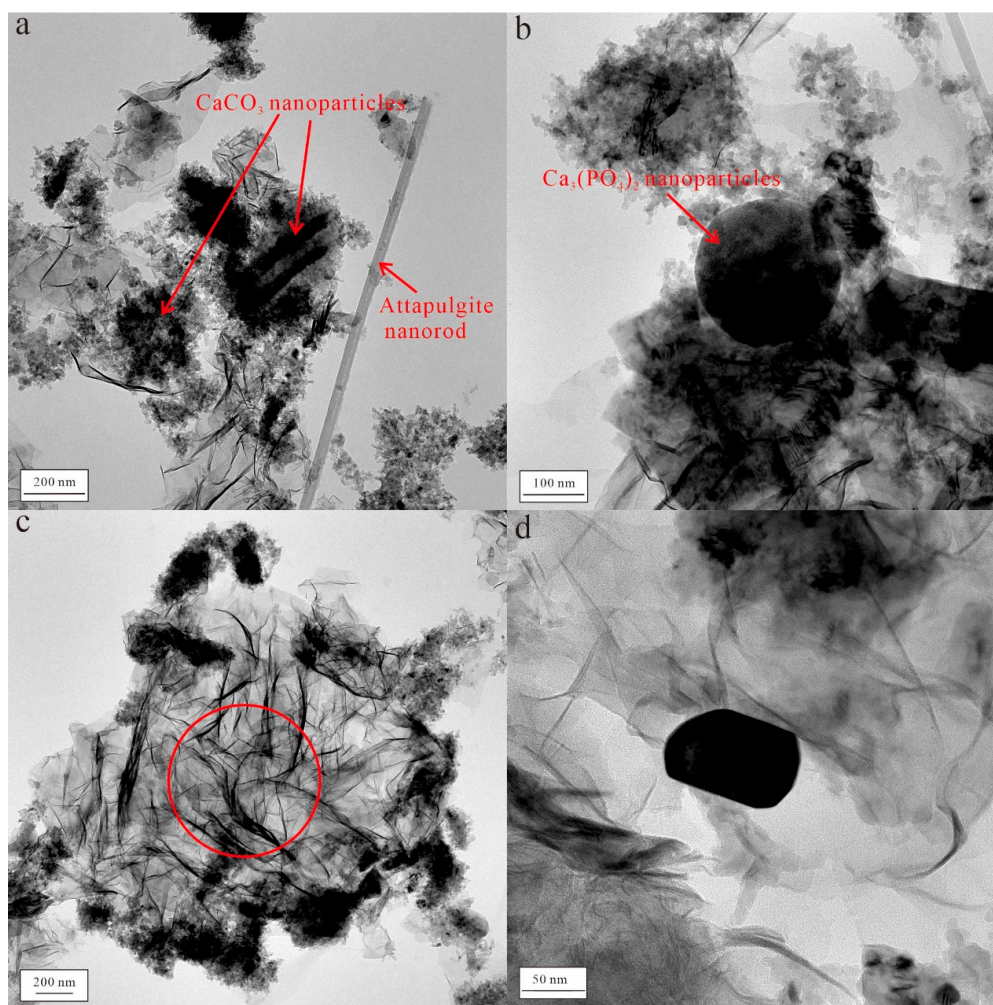


Figure 3. The morphological map of the representative nanoparticles in the well YY17 mineral water. (a) CaCO_3 and attapulgite nanoparticles. (b) $\text{Ca}_3(\text{PO}_4)_2$ nanoparticle. (c) MnO_2 nanosheet. (d) TiO_2 nanoparticle.

3.2.1. Ca-Bearing Nanoparticles

As shown by the topography (Figure 3a,b), the Ca-bearing nanoparticles mainly occurred as aggregates. According to the results of the TEM-EDS, the Ca-bearing nanoparticles mainly included two types: Ca-O-C nanoparticles and Ca-O-P nanoparticles. The Ca-O nanoparticles mainly occurred as irregular shapes that were 100 to 400 nm in size, and the Ca-O-P nanoparticles were spheres that were 200 nm in diameter. The selected area electron diffraction patterns of the Ca-bearing nanoparticles contained no obvious diffraction spots (Figure 4), indicating that they were amorphous. Based on the composition of these nanoparticles, the Ca-O-C and Ca-O-P nanoparticles were CaCO_3 and $\text{Ca}_3(\text{PO}_4)_2$ nanoparticles, respectively.

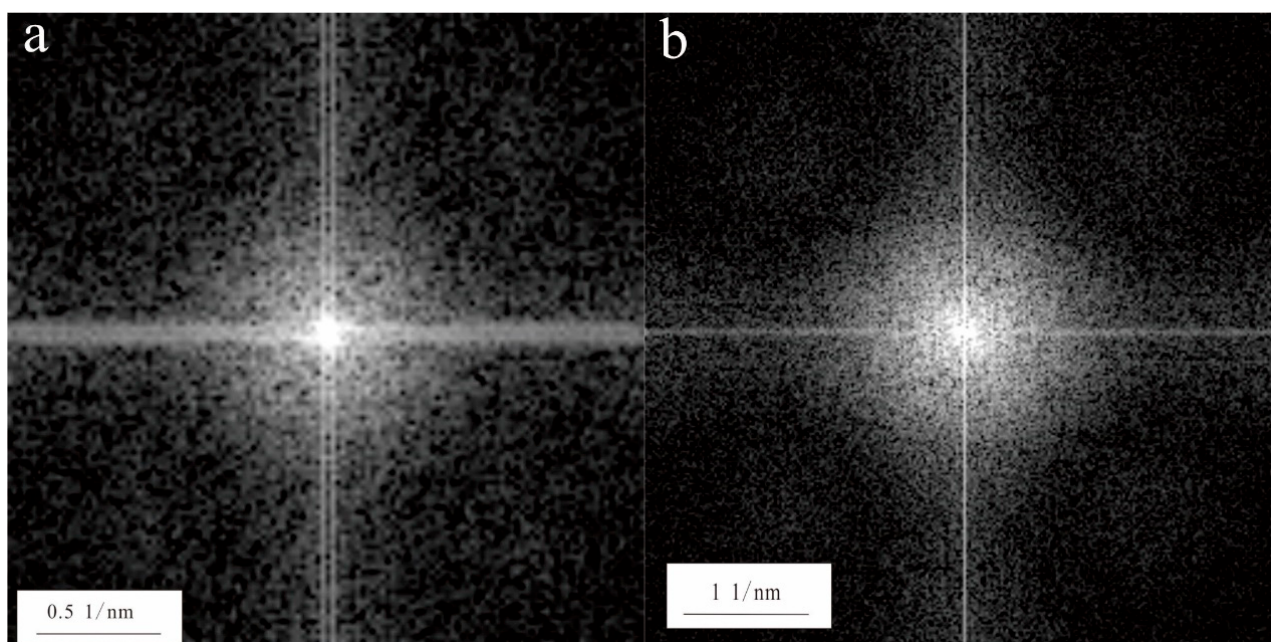


Figure 4. The selected area electron diffraction patterns of the Ca-bearing nanoparticles. (a) CaCO_3 nanoparticle. (b) $\text{Ca}_3(\text{PO}_4)_2$ nanoparticle.

3.2.2. Attapulgit Nanorod

The particle with a rodlike shape in Figure 3a mainly contained Si, Mg, and O, indicating that the nanorod may be attapulgit. The nanorod had two dimensions that were about 30 nm in diameter and 1–3 μm in length. The selected area electron diffraction pattern of the attapulgit nanorod contained no obvious diffraction spots (Figure 5), indicating that it was amorphous.

3.2.3. MnO_2 Nanosheets

In Figure 3c, there are many nanosheet aggregates in the mineral water. Based on the EDS (Figure 6), the nanosheets mainly contained Mn and O. The HRTEM image showed that the lattice of this nanosheet was 0.303 nm (Figure 7a,b). In addition, the selected area electron diffraction pattern had obvious diffraction spots, which were characterized by 110 ($d = 0.303$ nm) main reflections (Figure 7c). These results indicated that the nanosheet was pyrolusite (MnO_2).

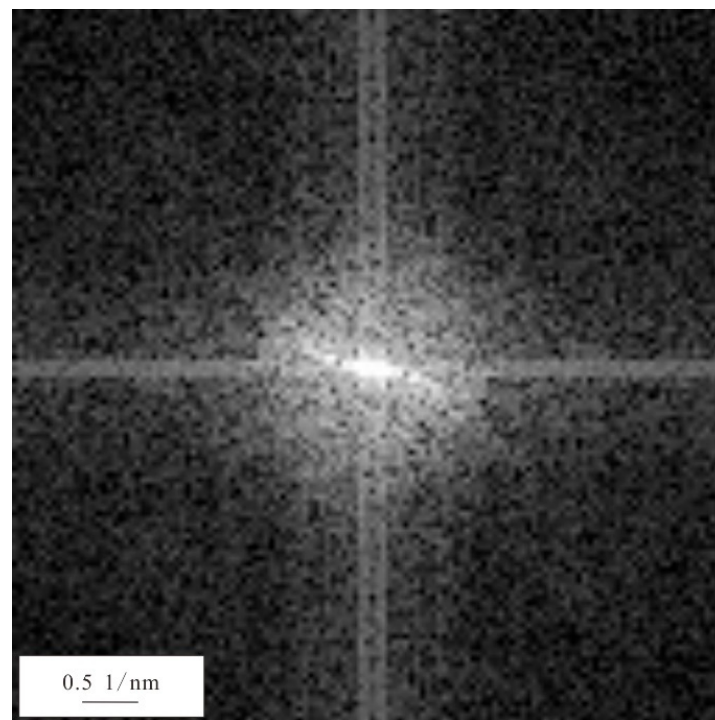


Figure 5. The selected area electron diffraction patterns of the attapulgite nanorod.

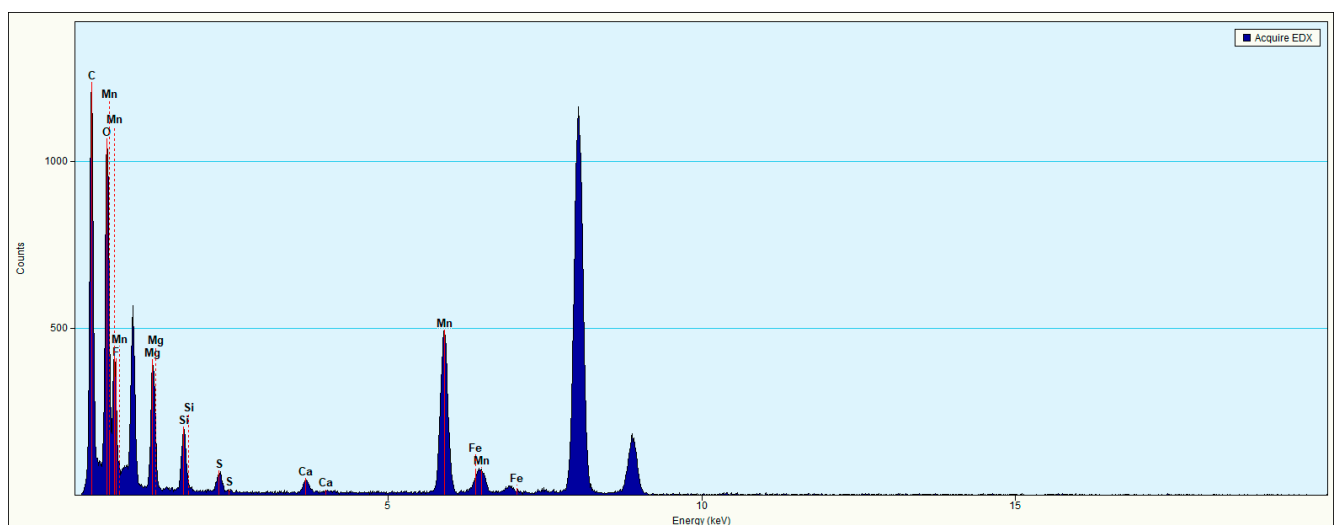


Figure 6. The EDS of the MnO₂ Nanosheets.

3.2.4. TiO₂ Nanoparticle

Figure 3d shows a nanoparticle with a composition of mainly Ti and O. The high-resolution transmission electron microscopy (HRTEM) image shows the ordered arrangement of the atoms with a lattice spacing of 0.352 nm (Figure 8a). In addition, the selected area electron diffraction pattern showed some diffraction spots that were characterized by 120 main reflections ($d = 0.352$ nm; Figure 8b), indicating that this nanoparticle was crystalline. When combined with the results of the EDS, this suggested that this nanoparticle was a TiO₂ nanoparticle.

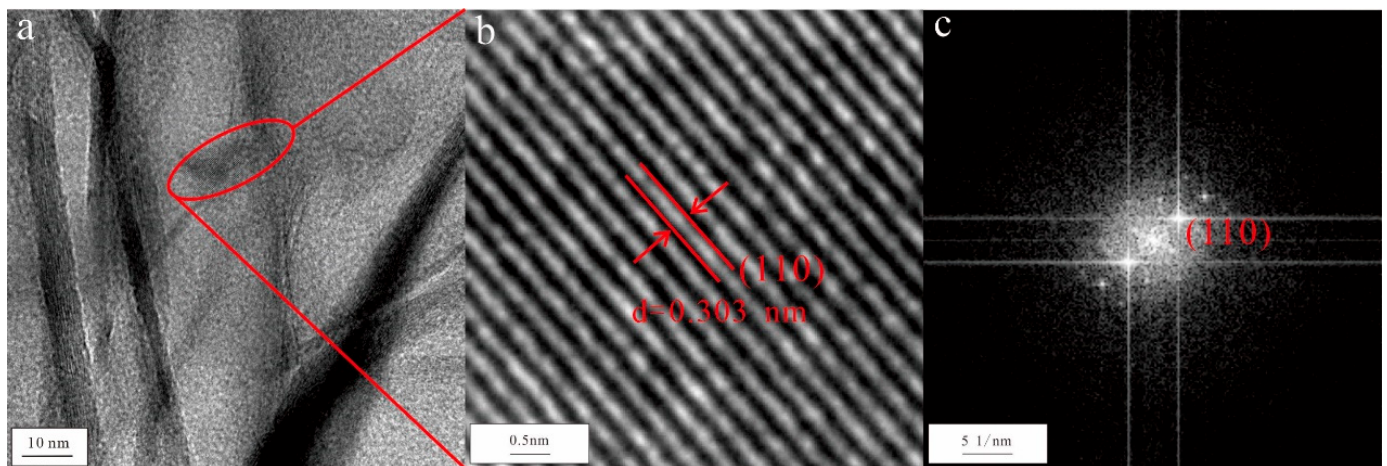


Figure 7. (a,b) The high-resolution transmission electron microscopy image and (c) the selected area electron diffraction pattern of the MnO₂ nanosheet.

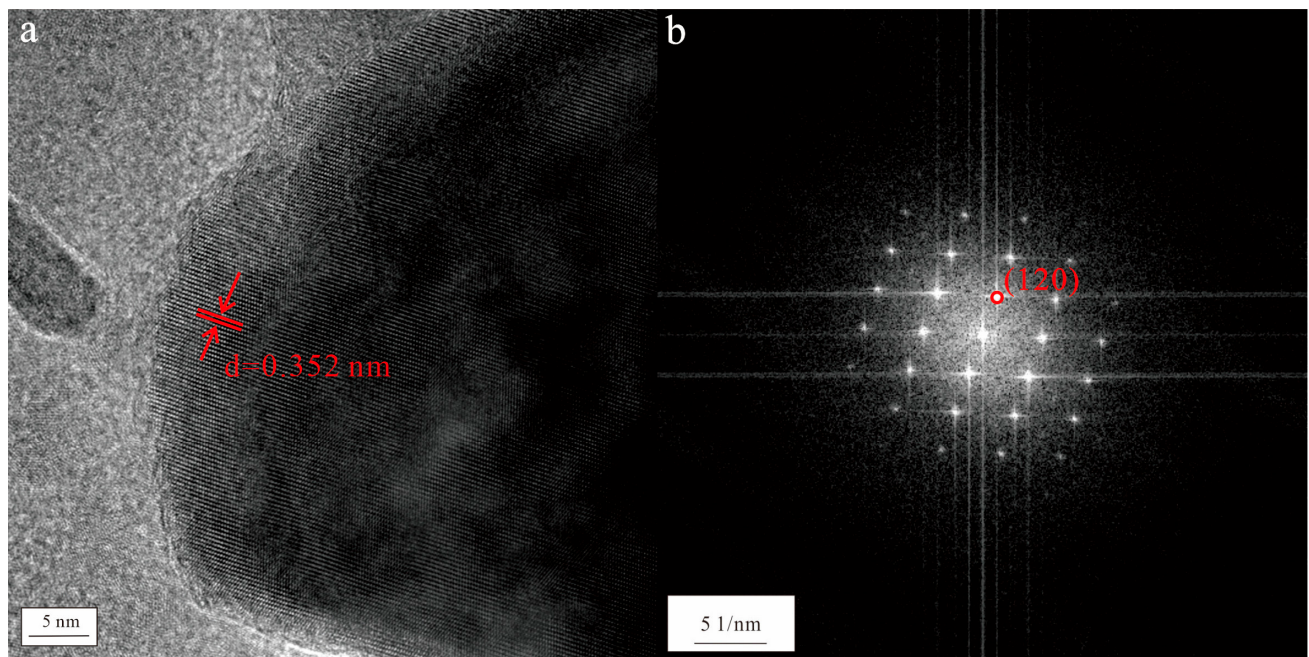


Figure 8. The high-resolution transmission electron microscopy image (a) and the selected area electron diffraction pattern (b) of the TiO₂ nanoparticle.

4. Discussion

4.1. A New Form of Elements in Mineral Water

For elements in groundwater, most researchers have only focused on the ionic forms, such as Ca²⁺, Mg²⁺, K⁺, Na⁺, Cl[−], SO₄^{2−}, HCO₃[−], and NO₃[−]. However, researchers are now discovering that naturally occurring environmental nanoparticles can exist stably in natural waters [3]. In addition, nanoparticles can play a crucial role in determining important chemical properties and overall water quality in natural environments. In this study, numerous nanoparticles were found in mineral water, which had a concentration of about 5.5×10^5 particles/mL. These results indicate a new form of elements in mineral water, especially Ca, Si, and Mg. The findings also confirm that natural nanoparticles can exist stably in mineral water and the elements can be transported in a nanoparticle form. The nanoparticles may also serve as one of the primary constituents of mineral water and element cycling [3].

4.1.1. Natural CaCO_3 Nanoparticles in Mineral Water

Calcium carbonate (CaCO_3) is one of the most abundant biominerals in the Earth's crust, ranking fifth in terms of abundance [14]. It is a crucial substance that can be found in geological sources such as limestone, chalk, and marble [15], as well as in biological organisms including corals, pearls, mollusk shells, and eggshells [16]. Biogenic calcium carbonate can take on six different forms: three anhydrous crystalline polymorphs (calcite, aragonite, and vaterite) [17], and three hydrated forms (amorphous calcium carbonate, calcium carbonate hexahydrate [$\text{CaCO}_3 \cdot 6\text{H}_2\text{O}$], and calcium carbonate monohydrate [$\text{CaCO}_3 \cdot \text{H}_2\text{O}$]) [18]. In this study, we also found that the CaCO_3 nanoparticle occurred in the mineral water. These particles were amorphous and usually occurred as an aggregation, indicating that the aggregation-based growth of the CaCO_3 nanoparticle may exist in this water system. In addition, the occurrence of the CaCO_3 nanoparticle in mineral water also confirmed that it is widely distributed in the environment.

4.1.2. Natural $\text{Ca}_3(\text{PO}_4)_2$ Nanoparticles in Mineral Water

The most abundantly produced phosphate mineral is carbonated hydroxyapatite, and it is closely associated with bones and teeth [19]. Amorphous calcium phosphate ($\text{Ca}_3(\text{PO}_4)_2$) is often found during the formation of calcium phosphates in aqueous systems. It is believed to be a precursor to hydroxyapatite [20,21]. In addition, the research on $\text{Ca}_3(\text{PO}_4)_2$ nanoparticles mainly focuses on its application in medicine for biomaterials (e.g., bone regeneration and tooth substitutes) and drug delivery vehicles [22].

In natural water systems, the occurrence of phosphorus mainly exists as dissolved phosphorus (PO_4^{3-}) and particulate phosphorus (>450 nm; [23]). Moreover, $\text{Ca}_3(\text{PO}_4)_2$ is the precipitation of corrosion products and is the one of most costly design and operating problems in water recycling systems [24,25]. Therefore, either in natural water systems or in industrial water systems, there has been a lack of studies on $\text{Ca}_3(\text{PO}_4)_2$ nanoparticles. Our findings could indicate an important occurrence of phosphorus in water systems.

4.1.3. Natural Attapulgite Nanorods in Mineral Water

Attapulgite has gained significant attention in recent years due to its unique properties such as its large specific surface area, nanochannel structure, exchangeable cations, ultra-high adsorption capacity, and colloidal properties [26]. Its versatile applications include being used as nanofillers [27,28] in clay nanocomposites, to support high-performance catalysts [29,30], in sensor devices [31], and for clay–biological interfaces in tissue engineering [32]. Attapulgite is a naturally occurring crystalloid hydrated magnesium–aluminum silicate clay, which is classified as part of the sepiolite family in mineralogy due to its similar microscopic structure and morphology [33]. It has been observed that natural attapulgite mainly consists of laths, rods, and bundles ([34–36]).

The nano attapulgite in the mineral water occurred as rods (two-dimensional), indicating that the attapulgite nanorod may be relatively widespread in the environment. In addition, the attapulgite nanorod also demonstrated a new occurrence of a clay mineral in mineral water. As clay is widely available on Earth, a rock–water reaction commonly occurs between the groundwater and the clay layer. Therefore, there are likely a lot of clay minerals entering the groundwater, and our findings provide strong evidence that numerous nano-scale clay minerals may occur in groundwater.

4.1.4. MnO_2 Nanosheets in the Mineral Water

Manganese is abundant in the crust (ranked No. 10), and it is the most common transition element that is second only to iron [37]. The migration of Mn(II) that is generated by rock weathering is prevalent, and it is oxidized into a variety of manganese minerals after entering the surface and water environment. As a natural oxidant and catalyst, manganese oxide minerals are widely involved in the oxidation–reduction and catalytic reactions of various organic and inorganic compounds in nature [38–42]. In addition, due to the formation of manganese oxide minerals at the interface between the lithosphere, hydrosphere,

atmosphere, or biosphere, they are the products of interactions between these layered systems. Their formation and transformation carry rich environmental information and are potential indicators of system evolution [37]. Therefore, the formation of manganese oxide minerals has important significance in the environmental geochemical cycle of organic and inorganic compound migration and transformation. Additionally, due to its large specific capacitance and environmentally friendly nature [43–45], MnO_2 has attracted interest for applications related to low-cost and green energy storage devices. Therefore, artificial MnO_2 materials (e.g., MnO_2 nanosheets) are very common in the industrial field.

In this study, the MnO_2 materials also occurred in the mineral water. These MnO_2 materials mainly existed in the form of nanosheets, similar to the MnO_2 materials that are synthesized in industry. In composition, there were other elements (e.g., F, Mg, Si, S, and Fe) occurring in these MnO_2 nanosheets, indicating that the MnO_2 nanosheets can act as carriers of elements in the mineral water. In addition, MnO_2 nanosheets are widely distributed in mineral water and thus can be considered one of the key components in groundwater. Their presence in groundwater plays a significant role in dynamic environmental processes such as soil formation, element cycling, and water-quality regulation.

4.1.5. TiO_2 Nanoparticles in the Mineral Water

TiO_2 nanoparticles are widely used in various industries such as paints, ceramics, rubber, plastics, cosmetics, and water purification [46,47]. Although there have been numerous studies on the safety and characteristics of engineered nanoparticles due to their increased usage and discharge, research on naturally occurring nanoparticles is scarce [48]. Given that Ti is one of the most abundant elements in the Earth's crust, it can be speculated that TiO_2 nanoparticles, predominantly composed of TiO_2 , are naturally distributed in the environment through natural processes. Furthermore, several studies have estimated the environmental concentration of nanomaterials, with TiO_2 nanoparticles consistently showing the highest levels in all regions [49–53]. Despite this, research on naturally formed TiO_2 nanoparticles has been limited.

Naturally formed TiO_2 nanoparticles were found to be widely distributed in the mineral water in this study, which also provides strong evidence that TiO_2 nanoparticles can be produced in nature. Additionally, the TiO_2 nanoparticles were found to be present alongside other common elements found on the Earth's surface, including Mg, Al, and Si. This coexistence suggests that during the formation and movement of the TiO_2 nanoparticles in the natural environment, they interacted with various elements present in the mineral water. These interactions led to the aggregation of these elements with the TiO_2 particles, resulting in a more complex chemical composition for the overall particle.

4.2. The Origins of Environmental Nanoparticles in Mineral Water

As discussed above, many nanoparticles can be synthesized in industry, such as CaCO_3 nanoparticles, MnO_2 nanosheets, and TiO_2 nanoparticles. Therefore, these nanoparticles are considered to be engineering nanoparticles. However, regardless of the preparation methods used, the engineering nanoparticles exhibited consistent granular size and pure chemical composition, with a narrow range of size distribution. In contrast, the nanoparticles investigated in this study displayed varying diameters and compositions, indicating that they were not artificially produced.

Environmental nanoparticles are often generated through three main processes: weathering of minerals, biogenic products of microbial activity, or as growth nuclei in supersaturated fluids [3]. Some of the nanoparticles (e.g., Ca-bearing nanoparticles and MnO_2 nanosheets) in the mineral water existed as irregular shapes. As the nanoparticles that are formed as biogenic products of microbial activity are usually regular shapes, such as a sphere with smoothed edges (e.g., [54]), nanoparticles with irregular shapes cannot be products of biogenesis. In addition, the concentration of microorganisms (e.g., coliform bacteria, *Enterococcus faecalis*, *Pseudomonas aeruginosa*, and *Clostridium perfringens*) in the mineral water was low [11]. Therefore, the nanoparticles in the mineral water were unlikely

to have been formed by organisms. Moreover, all the mineral (e.g., anhydrite, aragonite, calcite, chalcedony, chrysotile, dolomite, and gypsum) concentrations did not reach saturation, indicating that these minerals were unsaturated in this mineral water. Therefore, the nanoparticles were also unlikely to have formed as growth nuclei in super-saturated fluids.

We suspect that these environmental nanoparticles in the mineral water are the weathering byproducts of minerals. The well YY17 mineral water mainly existed in limestone and siltstone, and the roof and floor were shale and amphibolite, respectively. Therefore, strata and igneous rocks can be a source of Ca, P, Ti, Mn, Mg, and Si elements in mineral water during water–rock reactions. These findings also indicate that elements can be transported as nanoparticles during water–rock reactions, which may be an important form for element cycling between water and rocks.

4.3. Perspectives on the Advancement of Environmental Nanoparticles in Mineral Water

4.3.1. The Opportunity to Understand the Long-Term Stability and Transport Mechanisms of Nanoparticles

As discussed above, the nanoparticles that occurred in the natural mineral water were also found in other systems, such as $\text{Ca}_3(\text{PO}_4)_2$ and CaCO_3 nanoparticles in vivo and TiO_2 nanoparticles and MnO_2 nanosheets in engineered systems. However, the research on their long-term stability and transport mechanisms is relatively limited. Although the system in this study is different from in vivo and engineered systems, the behavior of nanoparticles may be the same in these systems due to the surface effect of nanoparticles [7]. Thus, the findings of this study can assist with understanding the long-term stability and transport mechanisms of nanoparticles in nature and in vivo and engineered systems.

4.3.2. Environmental Nanoparticles in Drinking Water Systems

Particulate species in drinking water are defined as particles larger than $0.45\ \mu\text{m}$. Colloids, on the other hand, range in size from 0.1 to $0.45\ \mu\text{m}$. Soluble fractions, which are also known as dissolved substances, have a size smaller than $0.1\ \mu\text{m}$, equivalent to $100\ \text{nm}$. This study has presented compelling evidence that nanoparticles can be found in mineral water, which is renowned for its high quality. Furthermore, other investigations have demonstrated the presence of environmental nanoparticles in various natural aquatic systems, ranging from subsurface aquifers to surface lakes and rivers [3]. Therefore, this supports the theory that nanoparticles occur widely in drinking water systems. Based on this study, the nanoparticles in drinking water systems should be varied, and some of these nanoparticles have potential environmental risks, such as being associated with toxic elements. Therefore, the presence of environmental nanoparticles in water distribution systems may have an impact on water quality and the efficacy of drinking-water-treatment processes. Thus, the safety of drinking water for human consumption should be considered when environmental nanoparticles are present in treated waters, and treatment methods to remove the environmental nanoparticles should also be considered. Consequently, this study provides a foundation for understanding the behavior of nanoparticles in drinking water systems.

4.3.3. Environmental Nanoparticles Science in Drinking Water Systems

Recently, billions of dollars have been invested in nanoscience and technology research and development around the world [3]. There is also considerable commercial funding in this field. However, the attention given to environmental nanoscience is only a small fraction of the total research conducted. As a result, the progress in environmental nanoscience has significantly fallen behind other sub-disciplines in the field of nanoscience. Nevertheless, it is anticipated that the environmental and health implications of nanoscience and technology will become increasingly significant as their potential costs become apparent.

Based on significant advancements in the field of nanoscience over the past few decades, it has been observed that nanoparticles exhibit properties and reactivity that vary depending on their size. These characteristics can have a considerable impact on the

aqueous chemistry of both natural and engineered waters [3]. Therefore, it is crucial to conduct fundamental research on the variability of physical properties and chemical reactivity of environmental nanoparticles as they relate to their size. Furthermore, comprehensive studies on the impact of environmental nanoparticles on aqueous chemical processes are also necessary. The behavior of materials changes as they transition from bulk material to a molecular state, and the rates of reaction measured vary significantly depending on the size of the nanoparticles. As a result, environmental nanoparticle science has expanded beyond conventional boundaries of aqueous colloid science, and these disciplines are becoming increasingly integrated. Additionally, environmental nanoparticle science should be prioritized as a new research direction for continued advancement in the areas of water safety, treatment, and remediation.

5. Conclusions

This study employed NTA and HRTEM techniques to investigate the properties and composition of environmental nanoparticles in mineral water from Zibo City, Shandong Province, eastern China. The concentration of the nanoparticles was 5.5×10^5 particles/mL, and the peak diameter of the size distribution was 180 nm. The shapes of these nanoparticles were granular, pinniform, rodlike, and flakey, and some of the nanoparticles were aggregated. The composition of these nanoparticles mainly included O, Mg, Ca, Si, Fe, Ti, and P. In addition, F, V, S, and Mn were also found in some of the nanoparticles. It was confirmed that there were Ca-bearing nanoparticles, attapulgite nanorods, MnO_2 nanosheets, and TiO_2 nanoparticles in the mineral water, indicating a new form of elements in the mineral water. The chemical and physical characteristics of the mineral water suggested that these environmental nanoparticles are byproducts of mineral weathering. This knowledge can serve as a foundation for understanding the behavior of environmental nanoparticles in natural aquatic environments and can be applicable to various systems. Moreover, the field of environmental nanoparticle science holds significance for drinking water systems, and further research is warranted to advance our understanding of water safety, treatment, and remediation in this context.

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