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PETROGENESIS AND TECTONIC SETTING OF CHROMITE DEPOSITS IN THE SOUTHERN INDIAN CRATON

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Abstract: Chromite deposits within the Southern Indian Craton present a significant resource for understanding the geological processes that have shaped the Indian subcontinent. These deposits, primarily located within ultramafic complexes, provide critical insights into the tectonic evolution of the region and the petrogenetic processes that govern the formation of chromitites. This paper explores the geological setting, mineralogical characteristics, petrogenesis, and tectonic context of these chromite deposits, drawing comparisons with global occurrences to highlight both similarities and distinctions. The study further discusses the economic significance of these deposits and the challenges associated with their exploration and sustainable exploitation. Finally, future research directions are suggested, emphasizing the need for advanced geophysical and geochemical techniques to uncover new deposits in underexplored regions.

Keywords: Chromite deposits, Southern Indian Craton, ultramafic complexes, petrogenesis, tectonic evolution, mineralogy, magmatic differentiation, global comparison

1. Introduction

1.1 Overview of Chromite Deposits in Peninsular India

The Southern Indian Craton, a key geological feature of peninsular India, hosts several significant chromite deposits. These deposits are primarily found within the ultramafic-mafic complexes, such as those in Orissa and Karnataka, and are crucial for understanding the region's geological history. Chromite, an essential source of chromium, is a strategic mineral used extensively in metallurgical, chemical, and refractory industries (Chatterjee, Bhattacharya, & Guha, 2015). The study of these deposits offers insights into the processes of mantle melting, magmatic differentiation, and the tectonic setting of the region, making them of particular interest in geological studies.

1.2 Importance of Chromite in Geological Studies

Chromite deposits serve as valuable indicators of past tectonic and magmatic events. Their formation is closely linked to the dynamics of mantle processes, which are influenced by tectonic settings such as ophiolite complexes, layered intrusions, and supra-subduction zones (Arai & Miura, 2016). The mineralogical and geochemical characteristics of chromite provide essential data on the nature of the source mantle, the degree of partial melting, and the conditions of crystallization. As such, chromite studies are crucial for understanding the petrogenesis of ultramafic rocks and the tectonic evolution of the craton (Barnes & Fiorentini, 2012).

2. Geological Setting of the Southern Indian Craton

2.1 Tectonic Framework and Evolution

The Southern Indian Craton represents one of the oldest and most stable continental blocks in the Indian subcontinent, with a history extending back to the Archean. The craton is characterized by a complex tectonic framework that includes a series of ancient crustal blocks and mobile belts, which have undergone multiple episodes of deformation, metamorphism, and magmatism (Mondal & Mathez, 2016). The tectonic evolution of the craton has been influenced by various processes, including the amalgamation of crustal blocks, cratonization, and subsequent tectonic reactivations during the Proterozoic.

The chromite deposits in the Southern Indian Craton are primarily associated with ultramafic-mafic complexes that were emplaced during tectono-magmatic events related to the stabilization of the craton. These complexes are often found along ancient suture zones and within greenstone belts, reflecting their origin in a supra-subduction zone or rifted continental margin setting (Mukherjee & Dasgupta, 2012).

2.2 Lithological and Structural Characteristics

The lithological framework of the Southern Indian Craton includes a diverse array of rock types, ranging from Archean granites and gneisses to Proterozoic sedimentary and volcanic sequences. The ultramafic-mafic complexes hosting chromite deposits are typically composed of peridotites, pyroxenites, and gabbros, which are intruded into the older basement rocks (Gupta, Mohanty, & Behera, 2012). These complexes exhibit a layered structure, with chromite typically occurring in the lower ultramafic layers, often associated with dunites and harzburgites.

Structurally, the chromite-bearing complexes are characterized by a range of deformational features, including folds, faults, and shear zones, which reflect the tectonic processes that have shaped the craton. The distribution of chromite deposits is often controlled by these structural features, with mineralization occurring in zones of structural complexity, such as fold hinges and fault intersections (Page & Zientek, 2012).

2.3 Major Geological Formations Hosting Chromite

The major geological formations hosting chromite deposits in the Southern Indian Craton include the Sukinda and Boula-Nausahi ultramafic complexes in Orissa, the Nuggihalli and Sittampundi complexes in Karnataka, and the Mayurbhanj Massif in Eastern India. These formations are part of larger greenstone belt sequences that have been subjected to multiple phases of magmatic and metamorphic activity. The chromite deposits within these formations are typically stratiform, occurring as layered or podiform bodies within the ultramafic rocks (Chatterjee, Bhattacharya, & Guha, 2015).

3. Mineralogical Characteristics of Chromite Deposits

3.1 Chromite Mineralogy and Composition

Chromite, a member of the spinel group, is the primary mineral of interest in these deposits. Its composition is typically characterized by high concentrations of chromium (Cr) and iron (Fe), with variable amounts of magnesium (Mg) and aluminum (Al) substituting in the crystal lattice. The Cr
ratio in chromite is a critical parameter that influences its economic value, with higher ratios generally being more desirable for industrial applications (Rollinson, 2010).

The mineralogical characteristics of chromite deposits in the Southern Indian Craton are influenced by the nature of the host rocks and the conditions of crystallization. Chromite from these deposits often exhibits a range of chemical compositions, reflecting the variability in the magmatic processes that generated the host ultramafic rocks. The presence of trace elements, such as vanadium (V) and titanium (Ti), can also provide insights into the petrogenetic history of the deposits (Mondal & Mathez, 2016).

3.2 Associated Minerals and Rock Types

Chromite deposits are typically associated with a range of other minerals, including olivine, orthopyroxene, clinopyroxene, and amphibole, which are common in ultramafic rocks. These minerals occur as major constituents of the host rocks or as inclusions within chromite grains. The mineralogical assemblage of chromite deposits can vary significantly, depending on the composition of the parent magma and the conditions of crystallization (Mukherjee & Dasgupta, 2012).

In addition to the primary minerals, chromite deposits may also contain secondary alteration minerals, such as serpentine, chlorite, and magnetite, which form during post-magmatic processes. The alteration of chromite and associated minerals can provide valuable information on the post-emplacement history of the deposits, including the effects of hydrothermal activity and metamorphism (Zaccarini & Garuti, 2011).

3.3 Textural and Chemical Variations in Chromite Ores

The textural characteristics of chromite ores can vary widely, depending on the mode of occurrence and the geological history of the deposit. Common textures include massive, disseminated, and nodular forms, with chromite occurring as isolated grains, clusters, or continuous layers within the host rock. The texture of chromite ores can provide important clues about the conditions of crystallization, such as the degree of magmatic differentiation and the rate of cooling (Kamenetsky, Crawford, & Meffre, 2010).

Chemical variations in chromite ores are also significant, reflecting the heterogeneity of the parent magma and the processes of crystal fractionation and accumulation. The presence of chemical zonation within individual chromite grains, with variations in Cr, Fe, Al, and Mg concentrations, can indicate complex magmatic histories involving multiple stages of chromite crystallization and re-equilibration (Gupta, Mohanty, & Behera, 2012).

4. Petrogenesis of Chromite Deposits

4.1 Mantle-Derived Processes and Magmatic Differentiation

The petrogenesis of chromite deposits in the Southern Indian Craton is closely linked to mantle-derived magmatic processes. Chromite typically forms in high-temperature, low-silica magmas derived from the partial melting of the mantle. These magmas are often associated with komatiites, picrites, and other ultramafic rock types that are characteristic of Archean and Proterozoic tectonic settings (Barnes & Fiorentini, 2012).

Magmatic differentiation, involving the separation of melt and crystal phases, plays a crucial role in the formation of chromite deposits. As ultramafic magmas cool and crystallize, chromite tends to crystallize early due to its high melting point. The accumulation of chromite crystals in the magma chamber, driven by gravitational settling and other processes, leads to the formation of stratiform or podiform chromite layers within the ultramafic complex (Arai & Miura, 2016).

4.2 Role of Ultramafic Rocks and Layered Intrusions

Ultramafic rocks, such as peridotites and pyroxenites, are the primary hosts for chromite deposits. These rocks are typically part of larger layered intrusions, where chromite layers form as part of a sequence of cumulate layers that also include olivine, pyroxene, and plagioclase. The formation of chromite within these intrusions is controlled by factors such as the composition of the parent magma, the rate of cooling, and the degree of magmatic differentiation (Mondal & Mathez, 2016).

Layered intrusions provide a unique environment for the concentration of chromite, as the repeated injection of magma and the development of magma chambers allow for the accumulation of dense chromite crystals. The stratigraphy of these intrusions, with chromite layers interspersed with other cumulate minerals, provides valuable information on the magmatic processes that occurred during the formation of the deposit (Mukherjee & Dasgupta, 2012).

4.3 Crystallization Processes and Chromite Formation

The crystallization of chromite is a complex process that involves the interplay of several factors, including temperature, pressure, oxygen fugacity, and the composition of the parent magma. Chromite typically crystallizes from a magma that is rich in chromium and iron, under conditions of low silica activity and

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high oxygen fugacity. The early crystallization of chromite, followed by the crystallization of other minerals, leads to the formation of layered chromitite bodies within the ultramafic complex (Gupta, Mohanty, & Behera, 2012).

The formation of chromite is also influenced by the dynamics of the magma chamber, including processes such as magma mixing, crystal settling, and convection. These processes can lead to the concentration of chromite in certain parts of the chamber, resulting in the formation of economically significant deposits. The study of these processes provides important insights into the conditions under which chromite deposits form and the factors that control their distribution and quality (Arai & Miura, 2016).

4.4 Isotopic and Geochemical Evidence

Isotopic and geochemical analyses provide valuable evidence for understanding the petrogenesis of chromite deposits. Isotopic studies, such as those involving oxygen, sulfur, and chromium isotopes, can provide insights into the source of the magma, the conditions of crystallization, and the history of the deposit. Geochemical analyses, including trace element and rare earth element (REE) studies, can reveal the composition of the parent magma and the processes of magmatic differentiation that led to the formation of chromite (Mondal & Mathez, 2016).

Isotopic evidence from chromite deposits in the Southern Indian Craton suggests a mantle origin for the magmas, with contributions from subducted oceanic crust and lithospheric mantle components. The geochemical signatures of the deposits, including high Crratios and specific trace element patterns, are consistent with a supra-subduction zone setting, where mantle-derived magmas interacted with subducted slabs and overlying lithosphere to form chromite deposits (Mukherjee & Dasgupta, 2012).

5. Tectonic Setting and Its Influence on Chromite Formation

5.1 Regional Tectonics and Chromite Distribution

The distribution of chromite deposits in the Southern Indian Craton is closely linked to the region's tectonic history. The craton's tectonic framework, which includes ancient suture zones, greenstone belts, and mobile belts, provides the structural setting for chromite deposition. The chromite deposits are typically found in regions that have experienced significant tectonic activity, such as rifting, subduction, and continental collision (Zaccarini & Garuti, 2011).

The regional tectonics of the craton have influenced the distribution of chromite deposits by controlling the emplacement of ultramafic-mafic complexes and the formation of magma chambers. The tectonic setting also affects the deformation and metamorphism of the chromite deposits, leading to variations in their mineralogy and economic potential (Page & Zientek, 2012).

5.2 Impact of Plate Movements and Cratonization

The tectonic evolution of the Southern Indian Craton, including the processes of plate movement and cratonization, has played a significant role in the formation and preservation of chromite deposits. During the Archean and Proterozoic, the craton underwent multiple episodes of rifting, subduction, and collision, which led to the emplacement of ultramafic-mafic complexes and the formation of chromite deposits (Barnes & Fiorentini, 2012).

Cratonization, the process of stabilizing the craton's lithosphere, has also influenced the preservation of chromite deposits. As the craton became more stable, the chromite deposits were protected from tectonic reworking and erosion, allowing them to be preserved in their current form. The study of these processes provides important insights into the conditions that favor the formation and preservation of chromite deposits in ancient cratonic regions (Arai & Miura, 2016).

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5.3 Tectono-Magmatic Events and Their Role in Chromite Genesis

Tectono-magmatic events, such as mantle plumes, subduction, and continental rifting, have played a crucial role in the genesis of chromite deposits in the Southern Indian Craton. These events lead to the generation of ultramafic magmas, which are the primary source of chromite. The timing and nature of these tectono-magmatic events are critical factors in determining the location, size, and quality of chromite deposits (Mondal & Mathez, 2016).

For example, the chromite deposits in the Boula-Nausahi and Sukinda complexes are believed to have formed during a tectono-magmatic event associated with the rifting and subsequent subduction of an oceanic plate beneath the Indian craton. This event generated a series of ultramafic intrusions that provided the magmatic source for chromite crystallization. The study of such events helps to unravel the complex interplay between tectonics and magmatism in the formation of chromite deposits (Mukherjee & Dasgupta, 2012).

6. Comparison with Global Chromite Deposits

6.1 Chromite Deposits in Other Archean and Proterozoic Terranes

Chromite deposits in the Southern Indian Craton share similarities with those found in other Archean and Proterozoic terranes worldwide. These deposits are typically associated with ultramafic-mafic complexes that were emplaced during tectonic events such as rifting, subduction, and continental collision. The chromite deposits in the Bushveld Complex in South Africa, the Stillwater Complex in the United States, and the Great Dyke in Zimbabwe provide important analogs for understanding the processes that control chromite formation in ancient cratonic settings (Barnes & Fiorentini, 2012).

The comparison of chromite deposits across different cratonic regions reveals common features, such as the association with layered intrusions, the occurrence of stratiform chromitites, and the role of mantle-derived magmas in chromite genesis. However, there are also significant differences in the tectonic settings, magmatic processes, and mineralogical characteristics of these deposits, reflecting the diversity of geological environments in which chromite can form (Arai & Miura, 2016).

6.2 Similarities and Differences in Geologic Processes

The geological processes that control the formation of chromite deposits exhibit both similarities and differences across different regions. Common processes include the partial melting of mantle peridotite, the crystallization of chromite from ultramafic magmas, and the accumulation of chromite in layered intrusions. However, the specific conditions of magmatic differentiation, the composition of the parent magma, and the tectonic setting can vary significantly, leading to differences in the size, grade, and morphology of chromite deposits (Zaccarini & Garuti, 2011).

For example, while chromite deposits in the Southern Indian Craton and the Bushveld Complex share a common association with ultramafic-mafic layered intrusions, the tectonic settings are different, with the former being associated with ancient suture zones and the latter with a stable cratonic environment. These differences highlight the importance of understanding the local geological context in chromite exploration and resource assessment (Rollinson, 2010).

6.3 Implications for Global Chromite Exploration

The study of chromite deposits in the Southern Indian Craton and other global terranes has important implications for chromite exploration. Understanding the tectonic and magmatic processes that control chromite formation can guide exploration efforts by identifying favorable geological settings and predicting the occurrence of undiscovered deposits. The use of geophysical and geochemical techniques, combined with detailed geological mapping, can enhance the efficiency of exploration and reduce the uncertainty associated with chromite resource estimation (Page & Zientek, 2012).

The comparison of chromite deposits across different regions also provides insights into the potential for discovering new deposits in underexplored areas. Regions with similar tectonic and magmatic histories to known chromite-bearing terranes may host undiscovered chromite deposits, offering new opportunities for exploration and resource development (Barnes & Fiorentini, 2012).

CONCLUSION

This paper has analyzed the petrogenesis and tectonic setting of chromite deposits in the Southern Indian Craton, highlighting key aspects such as their association with ultramafic-mafic complexes, mantle-derived magmas, and the significant role of regional tectonics. The study provides valuable insights into the interplay of mantle processes, magmatism, and tectonics in chromite formation, offering guidance for exploration in other cratonic regions. The craton's tectonic evolution, characterized by rifting, subduction, and cratonization, has been crucial in forming and preserving chromite deposits. Future research should focus on further understanding these processes and identifying new chromite resources in the craton.

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