MAGMATIC Ti-Fe±V OXIDE DEPOSITS MO4

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IDENTIFICATION

SYNONYMS: Mafic intrusion-hosted titanium-iron deposits.

COMMODITIES (BYPRODUCTS): Ti, Fe

EXAMPLES (British Columbia - *Canada/International*): None in B.C.; *Methuen, Unfravile, Matthews-Chaffrey, Kingston Harbour (Ontario, Canada); Lac-du-Pin-Rouge, Lac Tio, Magpie (Quebec, Canada), Sanford Lake (New York, USA), Tellnes, Egersund (Norway), Smaalands-Taberg, Ulvno (*Sweden*).*

GEOLOGICAL CHARACTERISTICS

CAPSULE DESCRIPTION: Ilmenite, hemo-ilmenite or titaniferous magnetite accumulations as cross-cutting lenses or dike-like bodies, layers or disseminations within anorthositic/gabbroic/noritic rocks. These deposits can be subdivided into an ilmenite subtype (anorthosite-hosted titanium-iron) and a titaniferous magnetite subtype (gabbro-anorthosite-hosted iron-titanium).

TECTONIC SETTING: Commonly associated with anorthosite-gabbro-norite-monzonite (mangerite)-charnockite granite (AMCG) suites that are conventionally interpreted to be anorogenic and/or extensional. Some of the iron-titanium deposits occur at continental margins related to island arc magmatism followed by an episode of orogenic compression.

DEPOSITIONAL ENVIRONMENT / GEOLOGICAL SETTING: Deposits occur in intrusive complexes which typically are emplaced at deeper levels in the crust. Progressive differentiation of liquids residual from anorthosite-norite magmas leads to late stage intrusions enriched in Fe and Ti oxides and apatite.

AGE OF MINERALIZATION: Mainly Mesoproterozoic (1.65 to 0.90 Ga) for the ilmenite deposits, but this may be a consequence of a particular combination of tectonic circumstances, rather than any a priori temporal control. The Fe-Ti deposits with titaniferous magnetite do not appear to be restricted in time.

HOST/ASSOCIATED ROCKS: Hosted by massive, layered or zoned intrusive complexes - anorthosite, norite, gabbro, diorite, diabase, quartz monzonite and hornblende pyroxenite. The anorthosites are commonly emplaced in granitoid gneiss, granulite, schist, amphibolite and quartzite. Some deposits associated with lower grade rocks.

DEPOSIT FORM: Lensoid, dike-like or sill-like bodies of massive ore, or disseminated in mafic host rocks. Some ore is disseminated as layers in layered intrusions. Typically the massive material has sharp, cross-cutting contacts with its anorthositic hosts, forming lenses tens to hundreds of metres wide and several hundred metres long. The massive ore may have apophyses cutting the host rock, be associated with intrusive breccias and contain anorthositic xenoliths. In layered deposits individual layers range in thickness from centimetres to metres and may be followed up to several thousand metres. Lean (disseminated) ore grades into unmineralized host rock. Lac Tio and Tellnes ore bodies are very large examples of the ilmenite subtype. Lac Tio is an irregular, tabular intrusive mass, 1100 m long and 1000 m wide. The Tellnes ore body, which is 400 m thick and 2.5 km long, is part of a 14 km long dike.

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TEXTURE/STRUCTURE: Massive, disseminated or locally in layers. No zoning of ore minerals, but there may be variation in modal proportions of associated silicates. Medium or coarse grained, primary magmatic textures. Exsolution intergrowths of either ilmenite and hemo-ilmenite, or titanomagnetite, titaniferous magnetite or ilmenite in magnetite. Locally the massive ore, particularly near contacts with host rock, contains abundant xenoliths and xenocrysts derived from the associated intrusive.

ORE MINERALOGY (Principal and *subordinate*): Ilmenite, hemo-ilmenite, titaniferous magnetite and magnetite. Proportions of ilmenite and magnetite generally correlate with host rock petrology. Fe-sulphides such as *pyrrhotite, pentlandite and chalcopyrite.*

GANGUE MINERALOGY (Principal and *subordinate*): Silicate minerals, especially plagioclase, orthopyroxene, clinopyroxene and olivine, with apatite, minor *zircon and pleonaste spinel.* Orthopyroxene is rare to absent in the island arc-related titaniferous magnetite deposits.

ALTERATION MINERALOGY: Not normally altered.

WEATHERING: Rarely residual enrichment may occur in weathering zone.

ORE CONTROLS: The key control is the development of a late, separate Ti and Fe-rich liquid from a fractionating magma under stable conditions. Many deposits occur in elongate belts of intrusive complexes emplaced along deep-seated faults and fractures. Ilmenite deposits are associated with lower magnesian phases of anorthositic intrusions. Titaniferous magnetite deposits are commonly associated with magnesian, labradorite phases of anorthositic intrusions or gabbroic phases near the margins of the stock. In layered intrusions the titaniferous magnetite seams are commonly within the upper stratigraphic levels and in marginal zones of complex intrusive bodies.

GENETIC MODELS: Progressive differentiation of liquids residual from anorthosite-norite magmas leads to late enrichment in Fe and Ti. Typically plagioclase crystallization results in concentration of Fe and Ti in residual magmas which typically crystallize to form ferrodiorites and ferrogabbros. Layers form by crystal settling and accumulation on the floors of magma chambers and the disseminated deposits are believed to have formed in-situ. The origin of the discordant deposits, primarily associated with the Proterozoic anorthosites, is not well understood. Two genetic models have been suggested - remobilization of the crystal cummulates into cracks or fractures or emplacement as a Fe-Ti-oxide-rich immiscible melt with little silica.

ASSOCIATED DEPOSIT TYPES: Ni-Cu-Co magmatic sulphide deposits (M02), chromite deposits (e.g. Bushveld Complex), platinum group deposits (e.g. Stillwater Complex, Bushveld Complex), and placer ilmenite, magnetite, rutile and zircon (C01, C02).

COMMENTS: Titaniferous magnetite deposits associated with zoned ultramafic complexes in Alaska and British Columbia, such as Lodestone Mountain (092HSE034) and Tanglewood Hill (092HSE035), are included with Alaskan-type deposits (M05). Some authors would include them with magmatic Fe-Ti±V oxide deposits. In California in the San Gabriel Range occurences of the ilmenite-subtype are hosted by anorthosite and ferrodiorite intrusions within a metamorphic complex composed of gneisses.

EXPLORATION GUIDES

GEOCHEMICAL SIGNATURE: Ti, Fe, V, Cr, Ni, Cu, Co geochemical anomalies.

GEOPHYSICAL SIGNATURE: Magnetic or EM response, although if the deposit is particularly ilmenite-rich it may exhibit either a subdued or a strong negative anomaly. Sometimes the subdued response displays characteristic irregular patterns of negative and positive anomalies that show broad smooth profiles or patterns.

OTHER EXPLORATION GUIDES: Heavy mineral concentrations of ilmenite and titaniferous magnetite in placer deposits. Abundant apatite in some deposits. Association with anothosite and gabbro intrusive complexes along deep fracture and fault zones.

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ECONOMIC FACTORS

GRADE AND TONNAGE: Both grade and tonnage vary considerably. The ilmenite deposits are up to several hundreds of millions of tonnes with from 10 to 75% TiO_2, 32 to 45% Fe and less than 0.2% V. The Tellnes deposit comprises 300 Mt averaging 18% TiO_2. The Lac Tio deposit, largest of 6 deposits at Allard Lake, contains more than 125 mt of ore averaging 32% TiO_2 and 36% FeO. Titaniferous magnetite deposits can be considerably larger, ranging up to a billion tonnes with grades between 20 to 45% Fe, 2 to 20% TiO_2 and less than 7% apatite with V contents averaging 0.25%.

ECONOMIC LIMITATIONS: The economic deposits are typically coarse, equigranular aggregates which are amenable to processing depending on the composition and kinds of exsolution textures of the Fe-Ti-oxide minerals.

USES: Titanium dioxide is a non-toxic, powdered white pigment used in paint, plastics, rubber, and paper. Titanium metal is resistant to corrosion and has a high strength-to-weight ratio and is used in the manufacturing of aircraft, marine and spacecraft equipment.

IMPORTANCE: Apart from placers, this type of deposit is the major source of TiO_2. These deposits were an important source of iron (pig iron) in the former Soviet Union. They have been mined for Fe in Canada, however, the grades are generally lower than those in iron formations and iron laterites. The only current iron production is as a coproduct with TiO_2 in pyrometallurgial processing of ilmenite ore.

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