Low temperature susceptibility of manganese ores from the Vizianagaram District, Andhra Pradesh

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We have measured the variation of magnetic susceptibility of manganese ores from the Vizianagaram District between room temperature and the boiling point of liquid nitrogen. In these deposits protores have become enriched to ores by the process of supergene oxidation. The measurements highlight interesting differences in mineralogy, domain states and oxidation states of different ore types. We distinguish samples containing multidomain (MD) ferrimagnetic minerals from samples in which the magnetic minerals have become oxidised to acquire single domain (SD) properties. The domain configurations observed in protore are MD + CD and CD. Ores show broadly two configurations, CD + MD and SD + CD. These configurations imply that smaller grain sizes are present in the ore and result from oxidation. The domain states deduced from the low temperature susceptibility analysis are compatible with the predicted effects of supergene process.

GEOLOGICAL aspects of manganese ore deposits in the Vizianagaram District of Andhra Pradesh have been reported by earlier workers[1,2]. The deposits are in close association with medium to high grade metamorphic assemblages comprising the khondalite suite. The khondalite suite consists of garnet–sillimanite–graphite gneiss, quartzite, calc-granulite and carbonatites. The manganese protores are the metamorphosed products of manganiferous argillaceous, arenaceous and calcareous sediments. The manganese in protores is in the form of oxides, silicates and carbonates with variations in composition among the various localities. In zones of oxidation the protores were subjected to supergene oxidation and enrichment. This secondary enrichment resulted in formation of the ores.

We have studied the magnetic properties of protores and ores in the manganese ore deposits of Vizianagaram District, Andhra Pradesh. Critical aspects of the low temperature susceptibility behaviour of these formations are discussed in this note.

Samples were collected from the manganese ore deposits at Sadanandapuram, Devada, Garividi, Chipurupalle, Garbham, Kottakarra, Avagudem, Gadabavalasa and Bondapalle. They were drilled in the laboratory to obtain cylindrical specimens 2.5 cm in diameter and 2.2 cm in length. Volume magnetic susceptibility of the specimens was measured with a low-field susceptibility meter[3]. To monitor the variation of susceptibility at low temperatures each specimen was cooled to $-196°C$ in liquid nitrogen and quickly transferred to the pick-up coil of the susceptibility apparatus. The very first reading gives susceptibility at about $-196°C$. As the specimen warms up in the pick-up coil the meter is recorded in quick succession until the specimen attains room temperature. Approximately 100 specimens of protores and ores were thus studied.

Magnetic minerals undergo changes in their crystal structure on cooling with associated changes in their magnetic properties. The inverse spinel crystal structure of magnetite changes to an orthorhombic structure below a temperature of $-153°C$. The magnetic susceptibility–temperature curve of magnetite has a discontinuous knee at the temperature of transition. Haematite changes its configuration of magnetic state at about $-15°C$. These transitions are useful for the purpose of mineral identification. They can also be used for magnetic granulometry.

Various types of grains have distinct features in their K–T curves in the temperature range of $-196°C$ to 25°C. The ratio of susceptibilities at $-196°C$ and 25°C (K_{-196}/K_{25} or relative susceptibility, RS) is characteristic of domain state. The reported RS values[4] for samples containing multidomain (MD), cation-deficient (CD), single domain (SD) and superparamagnetic (SP) grains are 0.5, 1.4, 0.4 and 0.1 respectively. For mixtures of two types of grains the suggested values of RS are 0.9 (CD + SD) and 0.25 (SP + SD). The peak value for MD grains will be about 1.4 times K_{25}.

The variation in susceptibility of the manganese ores, under study at low temperature, is suggestive of different domain states. Protores exhibit broadly two types of variation. Similarly the ores also exhibit two different patterns. The four patterns are named as protore-I, protore-II, ore-I and ore-II. They are depicted in Figure 1.

The K–T curves of protore-I display prominent peaks at temperatures slightly above that of liquid nitrogen. Some specimens show susceptibility lows slightly below room temperature. Protore-II is devoid of susceptibility peaks and the curves are strikingly similar to that of cation-deficient grains.

Ore-I is characterized by prominent susceptibility peaks whereas ore-II resembles that of samples containing CD and SD grains, 50% each. The mineralogy of the samples was determined by examination of polished and thin sections and by X-ray diffraction analysis. The minerals identified are bixbyite, braunite, bustamite, haematite, hausmannite, jacobsite, magnetite, pyrolusite, romanechite, cryptomelane, etc. Samples of protore-I, ore-I and II were found to contain the ferrimagnetic minerals jacobsite and magnetite along with other manganese minerals. Some samples of protore-I also contain haematite. Samples of protore-II do not contain ferrimagnetic

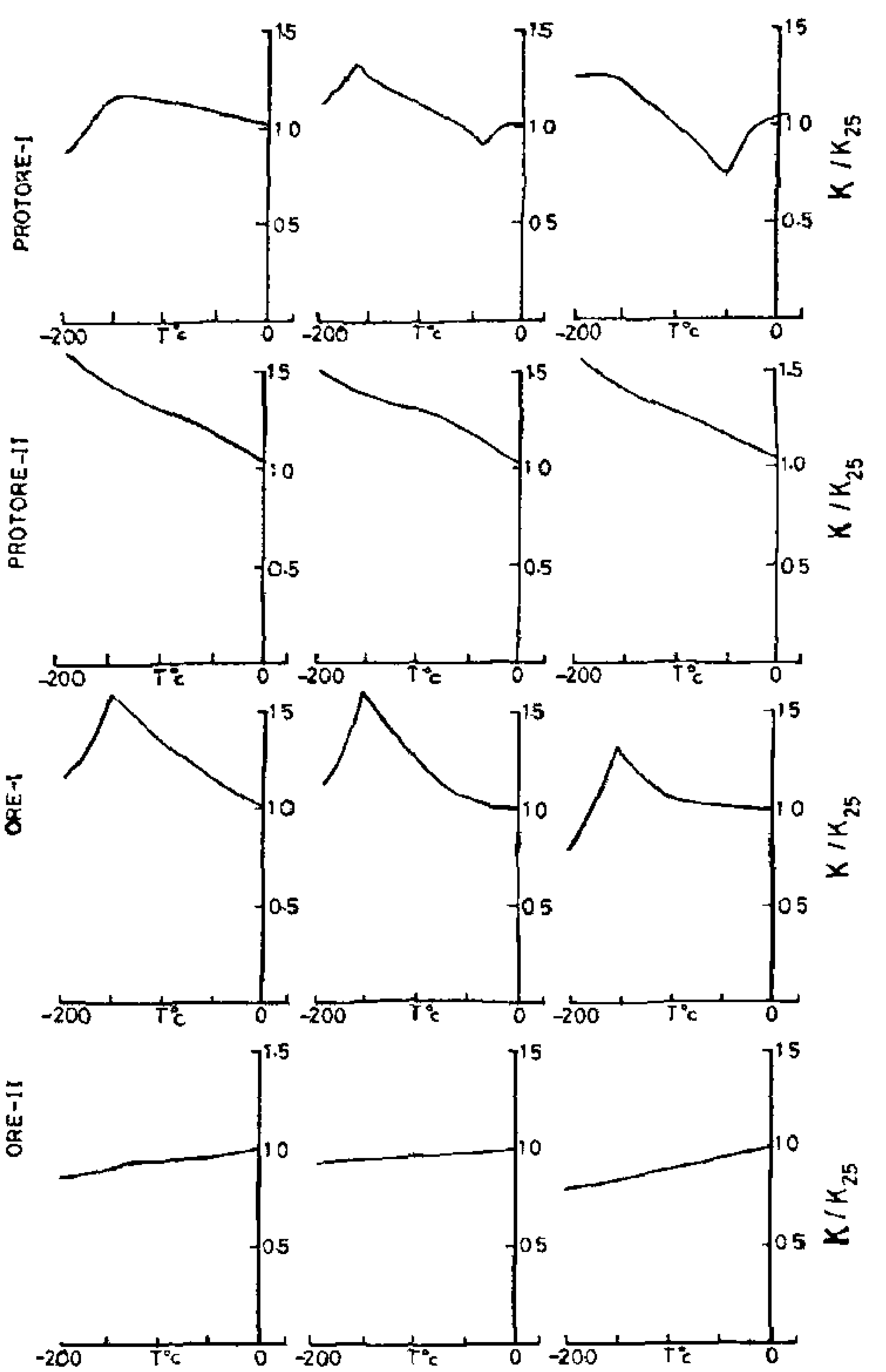

Figure 1. Variation of susceptibility of manganese ores at low temperature (temperature not to scale).

minerals. This was verified by pulverizing some of the samples and separating the magnetic fraction. From samples of protore-I and ore-I and II magnetic mineral content of 1 to 37% by volume was recovered while from protore-II no magnetic fraction could be recovered.

Jacobsite and magnetite belong to the same solid solution series and are isostructural[5]. The K–T relationship of jacobsite can be expected to be similar to that of magnetite because it is structure-dependent. The susceptibility of multidomain titanomagnetite peaks around – 150°C.

The susceptibility peaks of protore-I range from 1.06 to 1.32 while those of ore-I are between 1.23 and 1.6. They are taken to reflect the presence of jacobsite or magnetite, or both, in the multidomain state. The K–T curves of some samples of protore-I displaying susceptibility lows just below room temperature may be indicative of the presence of haematite. Haematite undergoes a transition at – 15°C which is called the Morin transition[6]. Mineralogical examination of these samples by the authors revealed the presence of haematite. Sivaprakash[7] also reported haematite in the protores from this locality (Sadanandapuram).

The RS values of all the specimens measured and the possible domain states are summarized in Table 1. The values of protore-I (0.87–1.11) are indicative of a mixture of MD and CD grains in the samples. RS values of protore-II (0.96–1.56) may be ascribed to the CD state. The K–T relationship of ore-I, with an RS of 0.83–1.17, is suggestive of a CD+MD combination. The pattern of ore-II resembles that of a CD+SD combination and the range of RS is 0.8–0.95.

Cation-deficient states can be developed by low temperature oxidation of Fe^{2+} ions[8]. The presence of CD grains in the manganese ores may be due to the alteration of primary ferrimagnetic minerals by the process of supergene oxidation. The domain states as deduced from the low temperature behaviour of manganese ores are suggestive of the relative oxidation states. The CD state in protore-II may be due to complete alteration of the ferrimagnetic minerals. Though protores are metamorphosed formations they undergo alterations to some extent with their primary textures intact. The presence of relict multidomain ferrimagnetic minerals in ore-I and domain configuration of SD+CD in ore-II are inferred. The critical size of a single domain particle depends on many factors. But, in general, grains which are about a micron in size are single domain particles. Those with grain diameters larger than a micron have multidomain behaviour.

If the degree of oxidation is high the multidomain ferrimagnetic minerals may be absent. Meteoric waters dissolve the manganese minerals and redeposit Mn and Fe ions along with other ions under favourable Eh and pH conditions. The presence of multidomain ferrimagnetic minerals in the ores is possible either due to incomplete oxidation or transportation by meteoric waters. The meteoric waters act along cleavage planes and grain boundaries. As the oxidation progresses the grain size of ferrimagnetic minerals, as also other manganese minerals, is likely to be reduced. The domain states deduced from the K–T relationships are compatible with the

Table 1. Low temperature susceptibility data of manganese ores

Rock type	Peak value range	K_{-196}/K_{25} range	Possible domain state
Protore-I	1.06–1.32	0.87–1.11	MD + CD
Protore-II	–	0.96–1.56	CD
Ore-I	1.23–1 6	0 83–1.17	MD +CD
Ore-II	–	0 8–0 95	SD + CD

process of supergene oxidation operative on the manganese ores.

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Magnetic susceptibility and mineralogical studies of the beach placer deposits, central east coast of India

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Magnetic susceptibility (*K*) and mineralogical studies on the beach placer deposits in three different coastal regions of Andhra Pradesh show that *K* is highest in Hamsaladivi–Manginipudi (HM) placers rich in magnetite and lowest in Visakhapatnam–Bhimunipatnam (VB) placers where ilmenite is abundant. Higher concentration of ilmenite is associated with monazite and not with magnetite. Magnetic susceptibility increases with diminishing mean size. The Eastern Ghats provenance is the major source of ilmenite and monazite, while the Deccan Traps have contributed higher amounts of magnetite.

Heavy minerals have earlier been reported from the beach sands along the Andhra Pradesh coast[1–3]. Since the last two decades, a variety of magnetic parameters have been applied to a number of sedimentological and environmental problems[4–6]. The present study attempts to correlate magnetic susceptibility and mineralogical studies of heavy minerals in three different beaches of Hamsaladivi–Manginipudi (HM), Vasishta Godavari-Upputeru (VGU), Visakhapatnam–Bhimunipatnam (VB) along the coast of Andhra Pradesh (Figure 1) to find

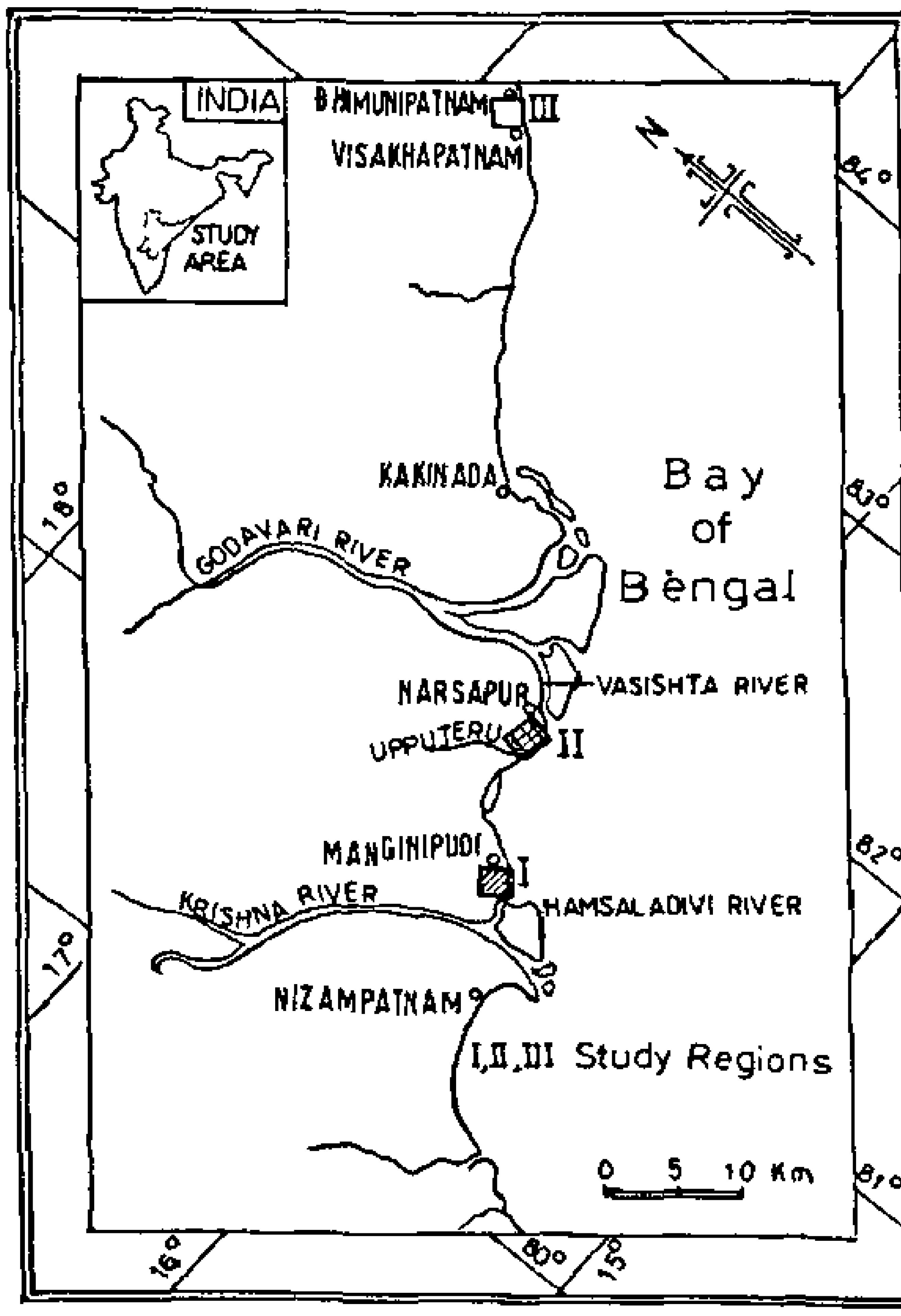

Figure 1. Location map of the study regions.

out exploration tools useful in prospecting for heavy minerals. Gneisses, granites, charnockites and Khondalites form the hinter-land common to the three deposits.

Sixtynine sediment samples were collected from the placers on the back shore beaches and 25 from dunes in December 1989. All the bulk samples were sieved at 0.5 ϕ interval and grain size statistics were computed[7]. Heavy mineral composition of 21 samples, representative of beaches and dunes in the three regions, were determined following standard techniques[3]. Individual heavy minerals are expressed in wt% of total heavies. Volume magnetic susceptibility of the bulk samples as well as 63 (2.0–3.0, 3.0–3.5, 3.5–4.0 ϕ) size fractions of 21 samples were measured in the laboratory with a susceptibility meter[8].

Magnetic susceptibility ($K \times 10^{-3}$ *SI*) *was highest in* beach and dunes in HM (av. 70.5, 59.7), lowest in VB (av. 7.1, 3.7) and intermediate in VGU (av. 37.6, 6.6). In any region, beach placers were characterized by high magnetic susceptibility levels relative to adjacent dunes indicating poorer concentration of magnetite (Table 1). Intra-regional variations in susceptibility level in beach and dune placers were due to dilution of magnetite concentrates by variable amounts of non-magnetic minerals. Inter-region differences are attributed to differences in provenance. The dune hosted magnetite-rich placers in HM are indicated by high magnetic suscep-