Andaman accretionary prism: a probable locale for different mineral deposit types

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Crustal growth and stabilization in the Andaman accretionary prism (AAP) occur via accretion of allochthonous crust, fragments of oceanic plateaus, and dismembered juvenile arc and ophiolite sequences. Multiple sutures developed in the AAP, as evidenced from multibeam, magnetic and seismic studies, are envisaged as the first-order structures that determine its distinct metallogenic signature. Furthermore, development of Andaman Back Arc Spreading Centre (ABSC) is attributed to a change from compression to more transgression stress regime as the AAP evolves. This stress regime change generates the first-order conduits for episodes of extensive metalliferous fluid flow via the pathways created by significant lateral displacements along the terrane-bounding multiple sutures. Hence, like many other accretionary orogens, complex association between subduction of the Indian plate and associated accretion, deformation, crustal thickening and melting, metamorphism, burial and exhumation may result in a wide variety of magma types, metal source regions and hydrothermal conduits. In conclusion, the expected deposit types in the AAP are volcanogenic massive sulphide deposits, seafloor massive sulphide deposits, rare earth elements and yttrium deposits and podiform chormite deposits.

Keywords: Accretionary prism, fluid migration, hydrothermal conduits, mineral deposits.

ACCRETIONARY plate margins of all ages host a diverse range of mineral deposit types[1]. These include deposits formed during the arc constructional stage, such as porphyry Cu–Au–Mo and epithermal Au–Ag deposits as well as in more distal settings adjacent to cratonic margins, including intrusion-related, Carlin-type and alkaline epithermal gold and some W–Sn deposits[2]. Above all, orogenic gold deposits typically form on sutures in more proximal to median zones of the orogens after terrane accretion during the orogenic stage[3]. Although debated, giant placer gold, Mississippi Valley-type (MVT) Pb–Zn and unconformity associated uranium deposits are generally considered to form in retro-arc foreland basins inboard of the accretionary system during post-orogenic stage[4]. Hence, a wide array of mineral deposit types can be expected associated with an evolving accretionary system due to ongoing plate convergence and accretion along geometrically complex continental margins. Andaman accretionary prism (AAP) is one such evolving orogen where different types of mineral deposits are expected. Hence considering the broad tectonic set-up of the AAP, the probable occurrence of the principal deposit types associated with it are briefly reviewed here based on the preliminary data available from different cruises on-board *R. V. Samudra Manthan.*

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Geological setting of AAP

The AAP is formed due to the oblique subduction of the Indian oceanic lithosphere below the Eurasian plate along the Andaman–Java trench, from the Cretaceous to the present day[5]. AAP consists of upthrusted and scrapped-off accreted oceanic sediments with highly deformed Cretaceous ophiolites along with older metamorphics which were uplifted during the Oligocene epoch. The top eastern side of the accreted sediments consists of older, deep-sea sedimentary rocks with eastward dipping crustal-scale faults. On the other hand, the western side is represented by progressively younger Quaternary rocks consisting of flysch–sandstone/siltstone and conglomerates along with Mio–Pliocene calcareous sediments[6]. The largely debated Andaman ophiolites are anticipated as upthrust oceanic crust due to subduction continuing since late Mesozoic[5,7], or as the product of collision history of Indo-Burma–Andaman micro-continent that terminated during late Oligocene[8].

AAP in the context of mineralization

Multibeam survey by M&CSD in the AAP region revealed the development of raised topography from west to east, due to the resultant thickening and stabilization of the accretionary prism slices (Figure 1) (unpublished GSI report, 2013). Even the data on reported occurrences of Fe–Mn crusts/nodules by M&CSD indicate their presence in the accretionary prism near the trench axis (Figure 2) (unpublished GSI reports, 2013, 2014). In addition, the surface sediment samples collected from the fore-arc basin have high TiO_2 content, probably indicating the presence of high REE (Figure 3)[9]. A zeolite bearing clay band of 5 cm thickness presumed to be sourced from felsic

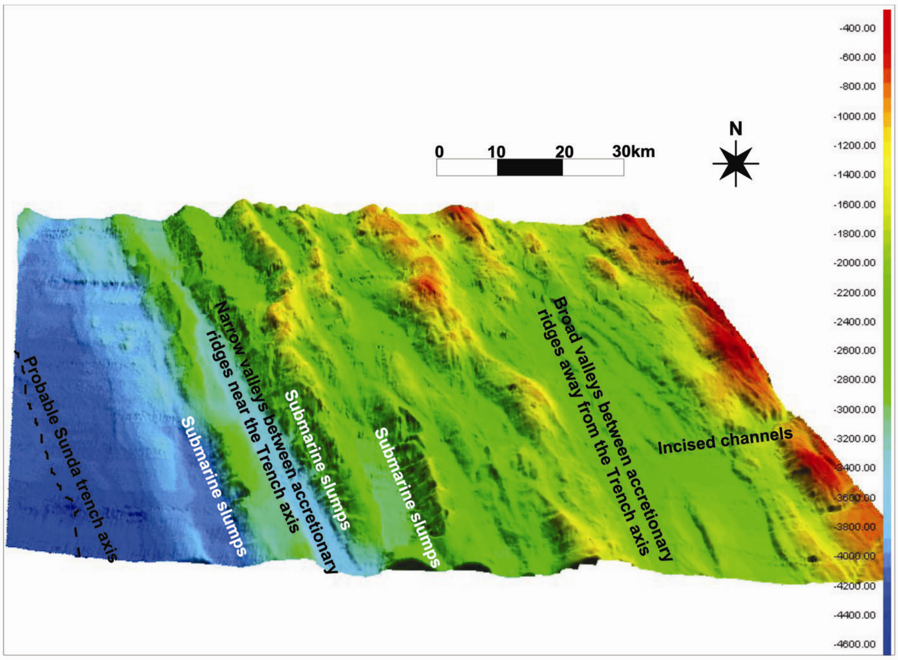

Figure 1. Morphometric set up of the Andaman accretionary prism (AAP) showing the different tectonic elements. Fluid migration along the decollments are also shown.

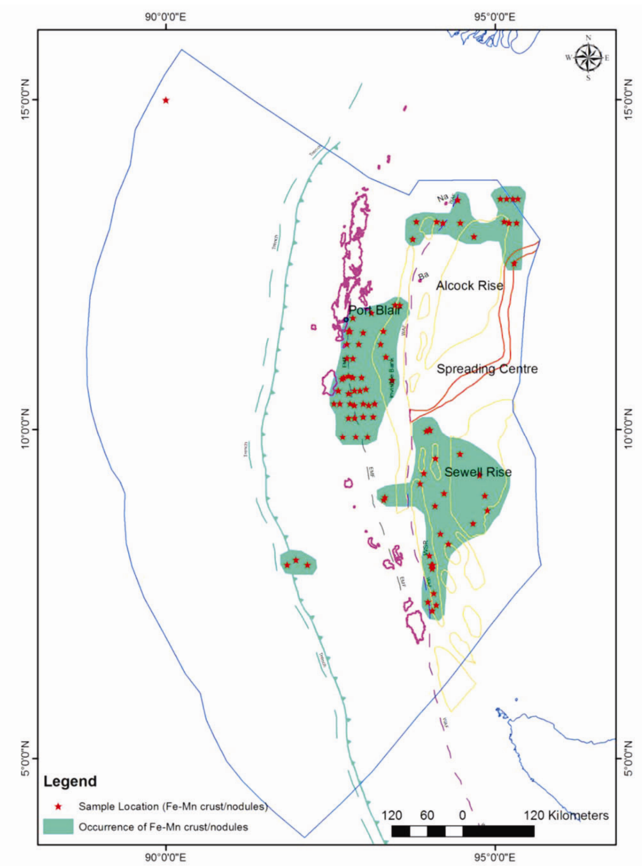

Figure 2. Map showing occurrences of Fe–Mn encrustation and nodules within the exclusive economic zone of India, Andaman region (modified after Curray[5]).

volcanic debris has been reported in a gravity core sample (SM/226/GC/11: 91°43.95′E, 8°20.94′N) from the subduction zone west of Andaman Islands[8] (Figure 4). Zeolite-rich rock pieces along with Fe–Mn nodules were recovered from a grab (SM/46/G-81: 93°18.243′E, 8°55.606′N) in the forearc basin. Moreover, the cores collected from the different parts of the accretionary prism were characterized by an increase in temperature down the sediment column (Table 1). Furthermore, AAP was characterized by numerous aerial and submarine mud volcanoes (Figure 5). In addition, the Burmese microplate was found to contain many N–S trending and right-lateral strike–slip faults with basaltic cores[5]. Presence of multiple sutures developed due to extensive lateral and vertical accretion also characterize AAP[5] (unpublished GSI report, 2013).

Discussion

The AAP underwent one or more episodes of tectonothermal events which occurred during the on-going plate convergence, as inferred from the thickening and stabilization of the accretionary prism slices[5]. Mechanisms of crustal growth and stabilization in the Andaman orogen include accretion of buoyant lithosphere via the accretion of crustal elements such as blocks of allochthonous crust, fragments of oceanic plateaus and ophiolite sequences over-riding the down-going Indian plate. Such occurrence of present-day tectonothermal events and crustal growth

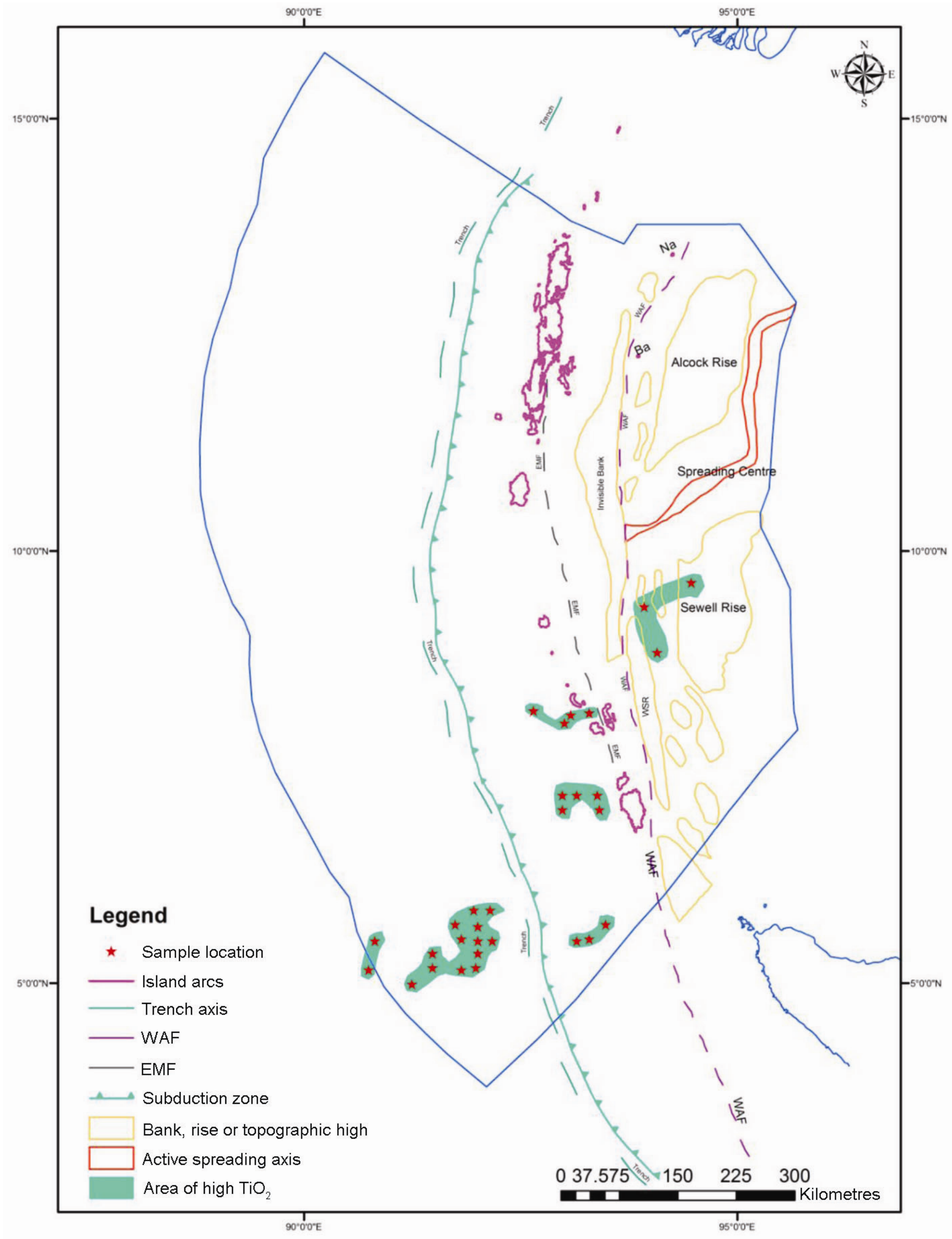

Figure 3. Map showing areas of high TiO_2 content within the EEZ of Andaman region (modified after Curray[5]). WAF, West Andaman Fault; EMF, Eastern Margin Fault.

Table 1. Location of the cores where the temperature increases down the sediment column

Sample no.	Latitude (N)	Longitude (E)	Depth (m)	Temperature (°C)	
				Top	Bottom
SM/104/GC/17	12°59.744′	89°25.884′	3016	8.5	9.5
SM/104/GC/20	12°59.944′	88°59.639′	3041	8.5	9
SM/104/GC/29	13°19.991′	90°30.138′	2958	11	13
SM/104/GC/46	13°39.929′	91°24.897′	2901	7.5	9
SM/214/GC/20	09°33.608′	94°5.597′	2625	14.7	17.8
SM/104/GC/47	13°39.797′	89°07.521′	2959	8.5	10
SM/104/GC/15	12°59.966′	89°42.595′	639	16	18

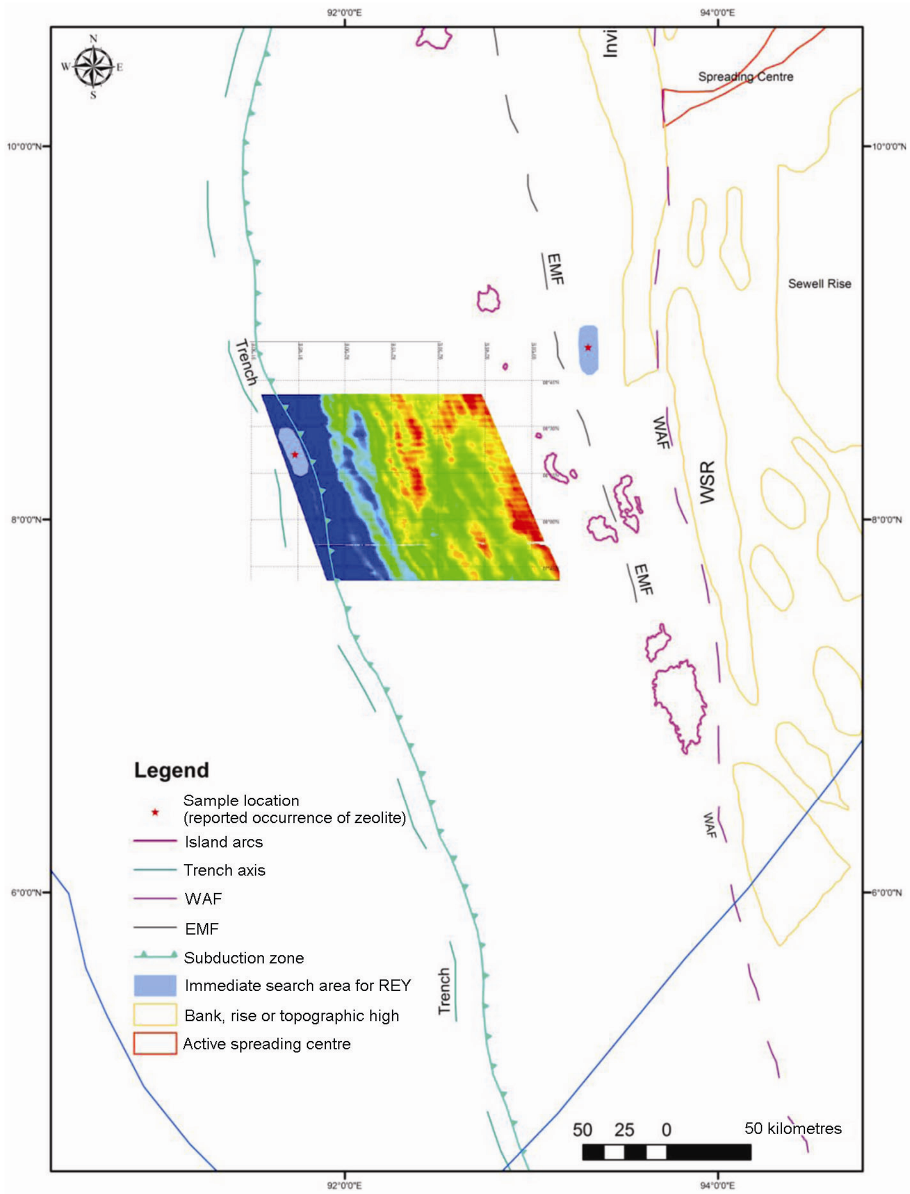

Figure 4. Map showing locations of samples bearing zeolite and OGP area for REY (modified after Curray[5]); Coloured part is the survey area of the cruise SM-226 on-board *R. V. Samudra Manthan* during which zeolite samples were collected. WSR, West Sewell Rise.

indicates that the AAP is at its constructional stage. Furthermore, evidences of constructional stage of AAP are the ongoing subduction of the Indian plate, large-scale earthquake and volcanic activity, development of crustal orthogonal faults, development of sub-volcanic seamounts inboard of acrretionary prism as well as fore-arc basin and the active spreading centre dissected by transform faults[5]. It has been established that during the constructional stage of an accretionary orogen, arc-related mineral deposits (Mesozoic to Cenozoic Porphyry Cu–Au–Mo deposits, epithermal high sulphidation Cu–Au–Ag deposits and low-sulphidation epithermal Au–Ag deposits) were formed[2].

The multiple sutures occurring in AAP are attributed to a change from compression to more transpressional stress regime as it evolves, as suggested by Patchett and Chase[10]. Such regime changes in the Andaman accretionary slices produce significant lateral displacement which is concentrated along the terrane-bounding multiple sutures, thus generating first-order conduits for episodes of extensive metalliferous fluid flow at a crustal scale (Figures 5 and 6). Hence these terrane-bounding sutures are the first-order structures that determine the distinct metallogenic signature of AAP. In addition, presence of Fe–Mn encrustations, zeolite-rich clay layers and zeolite-bearing rock pieces, and rise in temeperature down the sediment column at many places in the AAP point towards the large-scale fluid migration and hydrothermal activity in this region. Constructional stage of AAP also results in the episodic injection of substantial amounts of juvenile material into the outward propagating margin. Such a claim is exemplified by the accretionary orogens through time, including the Archaean Superior Province and Yilgarn Craton, the Proterozoic margin of SW Laurentia and at least the northeastern segment of the Pan-African Orogen, and the Phanerozoic Altaid, Cordilleran and Terra Australis orogens[11–14].

Ray *et al.*[15] have established that the gases and water emitted from mud volcanoes in the AAP are indications of deep-sourced fluid migration along the decollement faults in the Andaman forearc basin (Figure 5). Here, the release of energy is linked to the large-scale earthquakes, whereas the release of fluids is related to the mud volcanoes. All these are closely associated with the east-dipping fault systems[15,16]. It has also been established that the release of energy and fluids is almost certainly in response to the thermal relaxation of geotherms due to accretionary suturing as well as changes in far-field stresses due to anomalous plate geometries[17,18]. These evidences reaffirm the high fluid flux into the overlying mantle wedge due to dehydration of the subducting Indian oceanic slab. Such a fluid influx is associated with the generation of evolved, high-level granitic magmas from the hydrous, metal-enriched basaltic magmas produced by melting of the resultant metasomatized mantle enriched in incompatible elements (Figure 6).

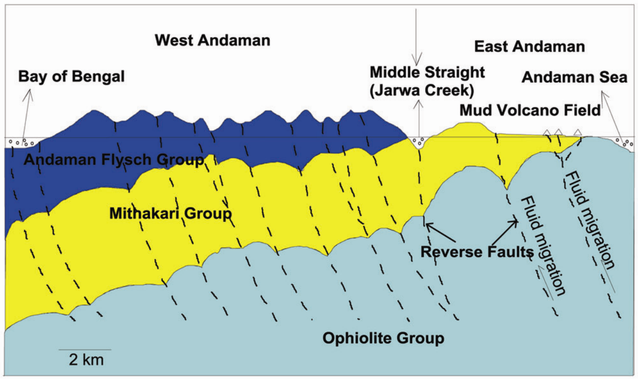

Figure 5. Schematic geological profile inferred from seismic reflection record showing fluid migration along large-scale crustal scale faults.

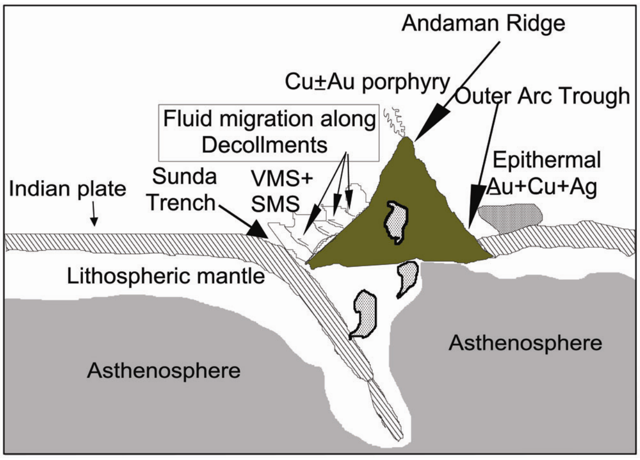

Figure 6. Schematic diagram showing the range of probable deposit types formed in AAP settings.

Hence, the complex interplay between subduction of the Indian plate and associated accretion, deformation, crustal thickening and melting, metamorphism, burial and exhumation may result in a wide variety of magma types, metal source regions and hydrothermal conduits, fluid compositions and pressure–temperature conditions in the AAP dynamic system[19,20]. Like many other accretionary orogens, the above-mentioned parameters operate at a terrane to lithospheric scale and fundamentally control the formation of mineral deposits and metallogenic endowment in the AAP as well[2].

Expected mineral deposit types in AAP

When an accretionary orogen is at its constructional stage, the major deposit formed on the accretionary prism slices is volcanogenic massive sulphide (VMS) deposit. Similarly, long-lived and high-temperature submarine hydrothermal systems that operated in the Indian plate accreted into the AAP like majority of Archaean to Cenozoic preserved VMS deposits formed from a convergent accretionary margin settings[21,22]. The high probable occurrences of VMS deposits in the AAP are due to their preservation after the initial burial and then consequent accretion into the terranes. In addition, the thin or thinned continental lithosphere of the AAP which is at the constructional stage also favours the formation of VMS deposits[1]. The occurrence of present-day equivalents of VMS deposits on the seafloor, seafloor massive sulphide (SMS) deposits, cannot be ruled out in the AAP (Figure 7). Large-scale presence of crustal-scale decollements/faults bounding the accretionary prism slices, associated minor cracks, etc. act as secondary structures for fluid migration and large-scale volcanic activity as reported during various cruises of M&CSD. Presence of major as well as minor igneous bodies <10 km below the seafloor as observed in the magnetic survey confirms the AAP as a major locale for SMS deposits[9]. Although there are no such reports of the occurrence of SMS deposits from AAP area, intense search for the same is recommended in the present study. Further, occurrence of Fe–Mn crusts/nodules at many locales over the accretionary ridges gives us encouragement to recommend intense search for rare earth elements and yittrium (REY). Since zeolite minerals are good adsorbents of rare earth metals from seawater, the zeolitic clay horizon is also worth exploring for REY. Furthermore, Ghosh *et al.*[23] reported the occurrence of alpine-type (ophiolite-hosted) podiform chromitites from the lherzolite dominant mantle sequence of the Rutland ophiolites and North Andaman. It is proposed

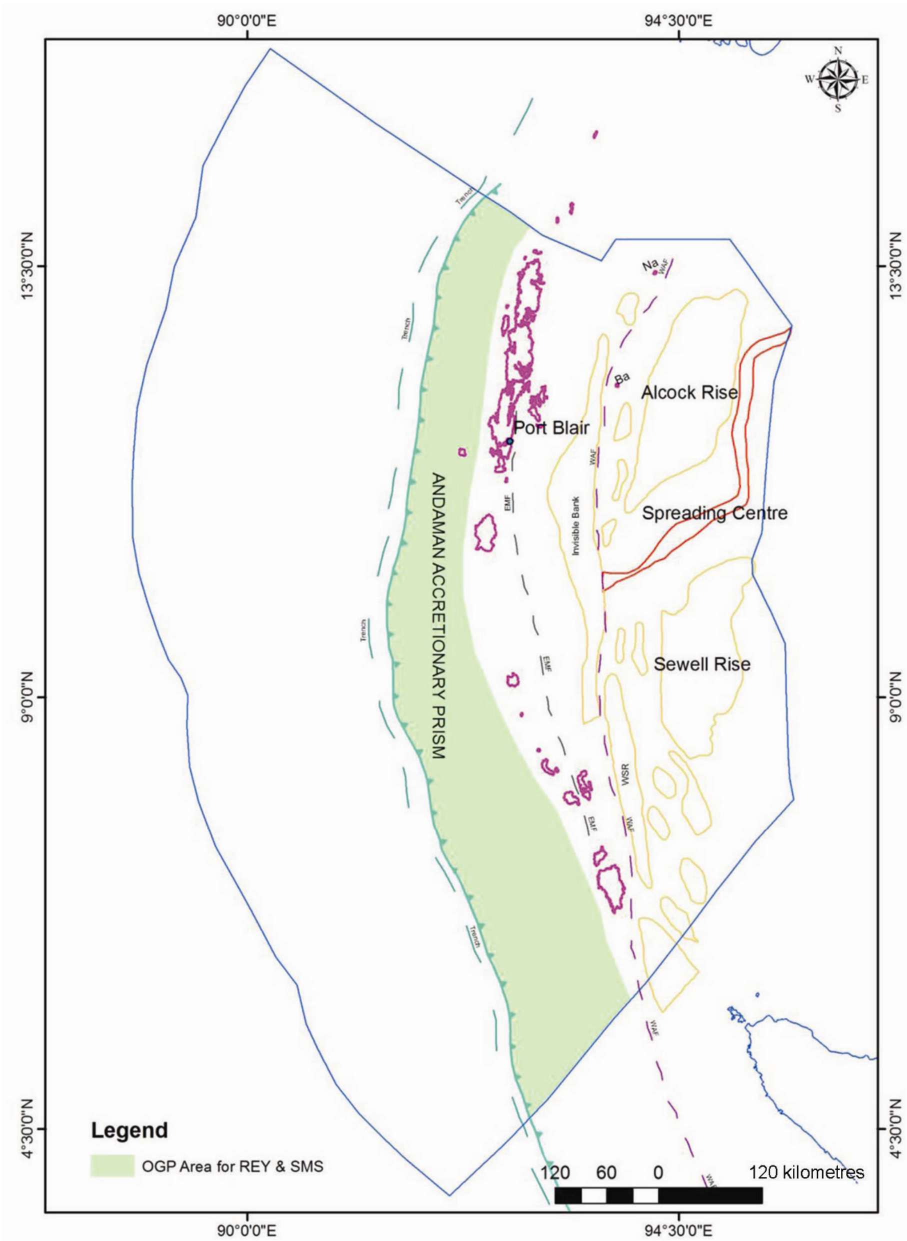

Figure 7. Map showing the OGP area for REY and seafloor massive sulphide in AAP.

that at supra-subduction setting, an oxidizing hydrous fluid derived from subducting slab might have a major influence during the formation of Rutland ophiolite in this part of Burma–Java subduction complex[24,25]. Hence, the AAP is also a suitable locale for chromite deposits.

Conclusion and recommendations

As the preliminary investigation has established the metallogenic significance of AAP, focused mineral studies with the objective to assess the occurrences of mineral deposits in the AAP and to constrain their genetic relationship to the Andaman subduction processes are necessary. Since fluid migration is concentrated along the crustal-scale faults (primary structures) and associated orthogonal faults (secondary structures), a comprehensive exploratory programme comprising seismic, gravity and magnetic surveys may be used to decipher the entire structural set-up and its association to ore deposit formation. Associated sampling and further studies from the ore geology point of view would corroborate the evidence of mineralization by the aforementioned geophysical studies.

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