The Kandra volcanics in Andhra Pradesh: Possible ophiolite?

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The Kandra volcanic belt (~40 km × ~4 km) in the Nellore district of Andhra Pradesh trends in a NW–SE direction and is sandwiched between the Nellore schist belt (NSB) towards east and granitic gneisses belonging to 'unclassified Archaean crystallines' (UAC) towards west. The petrographic and petrochemical characteristics of the rock components of the volcanic belt suggest that they belong to an ophiolite complex designated here as the Kandra ophiolite complex (KOC). The regional rock associations, varied lithological units and metamorphic assemblages in the NSB and KOC, and palaeotectonic regimes of this part of the Precambrian terrain exhibit features mimicking those diagnostic of ophiolite-decorated ancient suture zones. The KOC, in tune with well-established Precambrian ophiolite complexes, is incomplete and imperfect in its magmatic stratigraphy, petrotectonic units and associated mineralization. As there are too many problems in identifying the Precambrian ophiolites, the recognition of their similarities with Phanerozoic ophiolites is more important than establishing their precise sites of origin.

THE Kandra volcanics (Nellore district) occur as a series of sills and dykes [1], and the volcanic suite essentially consists of amphibolites and hornblende schists which are products of metamorphism of basalts, gabbros and dolerites [2]. The metavolcanics are partly spilitic at a few places and display relict pillow structures [3]. The narrow and arcuate Kandra (14° 03′N; 79° 48′E) volcanic belt (~40 km × ~4 km) trends (Figure 1) in a NW–SE direction and is sandwiched between the Nellore schist belt (NSB) towards east and granitic terrain (UAC, unclassified Archaean crystallines) towards west (Figure 2). A clear expression of the belt is strikingly observed in the available aeromagnetic map of the region[4]. This communication aims at interpreting the so-called 'Kandra volcanics' as representing vestiges of a Precambrian ophiolite designated here as the Kandra ophiolite complex (KOC). Ophiolite complexes are important in formulating tectonic scenarios, because they are regarded as slices of ancient metamorphosed oceanic crust and upper mantle tectonically obducted on to the continental margin in subduction zones [5].

A preliminary petrographic study of the randomly collected samples from KOC indicates that the suite contains different members, some of which are thoroughly metamorphosed while others are unmetamorphosed. Further: (i) some flows exhibit amygdoloidal and vesicular structures; (ii) some dykes are fine-grained; (iii) quartzite/metachert bands are associated with the volcanics; (iv) some basic plutonic (gabbroic) members display typical cumulate textures; (v) spinifex-like textured (komatiitic?) rocks are rarely present; and (vi) certain ultramafic slices exhibit thorough metamorphic reconstitution and are now seen as talc–chlorite schists (?in NSB). These features are reminiscent of the characteristics often documented for well-established ophiolite complexes.

Different members of KOC are exposed along the western margin of the schist belt as disconnected outcrops (not shown in Figure 2) in a narrow curvilinear zone (trending NW or NNW) for over 100 km, extending from a few km SE of Kandra to south of Udayagiri; though the members cut across the schistosity [1], they

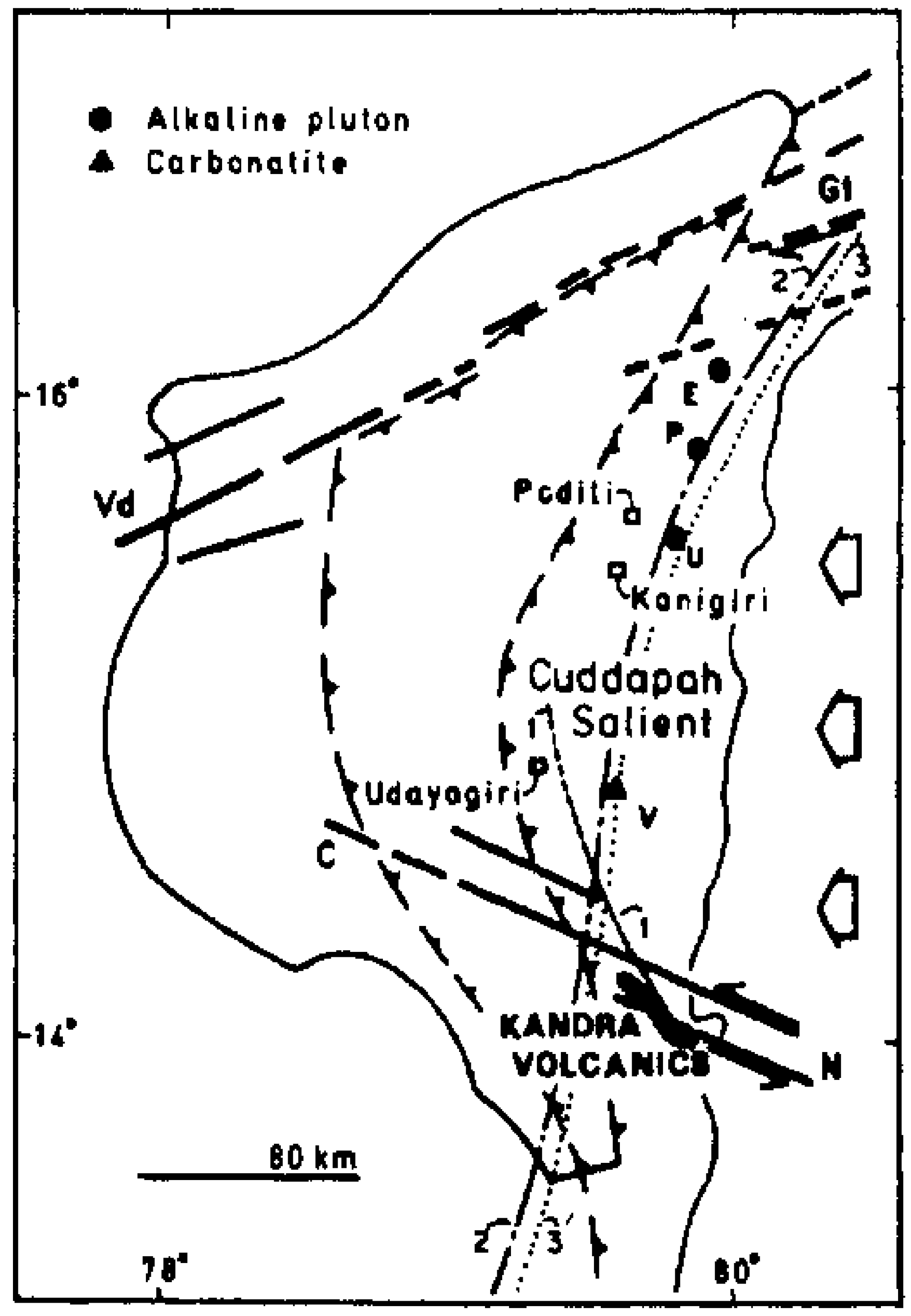

Figure 1. Location of the Kandra volcanic belt with respect to the Cuddapah salient[13] and alkaline plutons of the Prakasam province[18]. 1, Synclinal axis; 2, axis of major Bouguer gravity anomaly areas; 3, basement fracture zone. E, Elchuru; P, Purimetla; U, Uppalapadu; V, Vinjamur. The Cuddapah salient is bounded by the northeast-trending Veldurti–Guntur (Vd–Gt) lateral ramp in the north and the northwest-trending left-lateral Cuddapah–Nellore (C–N) transverse tear fault[13].

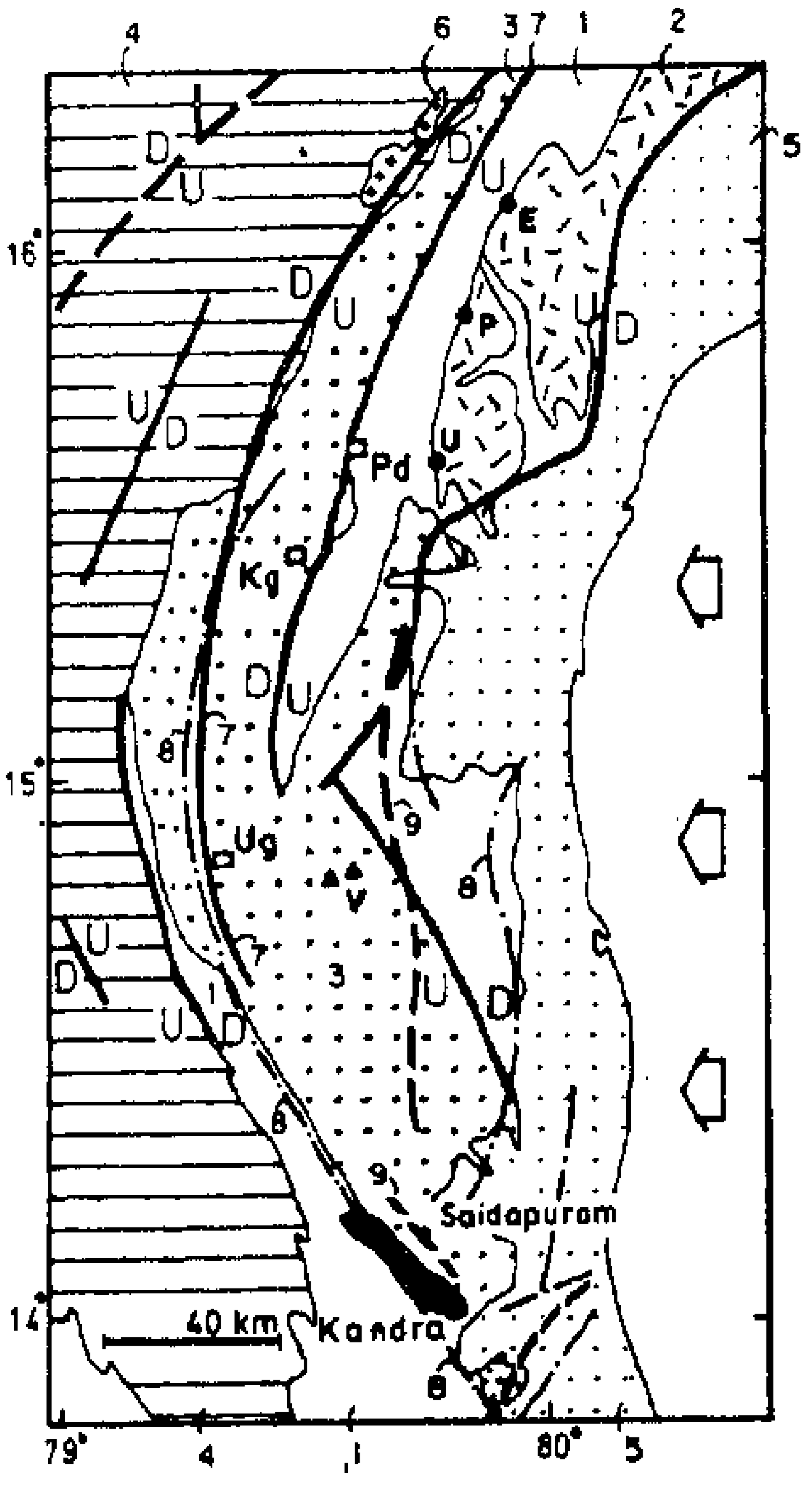

Figure 2. Tectonic map of the Kandra–Elchuru region[11,12]. 1, Unclassified Archaean crystallines; 2, charnockites (and khondalites); 3, Dharwar/Archaean supracrustals; 4, eastern part of the Cuddapah basin; 5, Phanerozoic cover; 6, granite (intrusives); 7, deep fault (D, downthrow; U, upthrow); 8, fault inferred from gravity; 9, axis of gravity 'high'. E, Elchuru; Kg, Kanigiri; P, Purimetla; Pd, Podili; U, Uppalapadu; Ug, Udayagiri; V, Vinjamur.

seem to merge with the schist belt (especially in the central and northern portions) and are virtually indistinguishable from the corresponding members of the schist belt (S. R. Sarma, pers. commun.). The different components which constitute the northern portions of the Kandra volcanic belt and its dimensions are not precisely known.

NSB is comparable to the older greenstone belts of Karnataka (like Holenarasipur and Sargur) and comprises hornblende schists, amphibolites, quartz mica schists, biotite schists, chlorite schists, staurolite kyanite sillimanite schists and quartzites; some of these are garnetiferous[6-10]. The schistose rocks are associated with banded ferruginous quartzites, fuchsite quartzites and crystalline limestones. Pegmatites are confined to NSB and they are characteristically absent in KOC.

The disposition of KOC in conformity (and in apparent continuation) with the highly disturbed (thrusted) eastern margin of the Cuddapah basin at the southern end (Figure 1) is striking. The siting of KOC along a major fault (inferred from gravity data[11]) and close to the boundary between two contrasting terrains (Figure 2) is of paramount significance. This fault coincides with (or is closely parallel to and slightly west of) the already known major synclinal axis, which runs northwards up to 15°N (Figure 1) but extends further in a northeasterly direction to west of Podili; it faithfully parallels (but always ~10 km away from) the eastern margin of the Cuddapah basin (Figure 2). The Udayagiri–Kanigiri sector of this gravity-inferred fault zone virtually coincides with the DSS fault[12] (which separates the Dharwars from Cuddapahs north of Kanigiri) and is worthy of detailed investigations. The Kandra–Udayagiri–Kanigiri fault, inferred from gravity data[11], appears to be far more significant than what meets the eye in the first instance, especially in delineating the northern limit of KOC.

An axis of gravity 'high'[11] running for about 15 km only (Figure 2) and parallel to (and slightly east of) KOC (near Saidapuram) may suggest the possible presence of buried ultramafic rocks with an implication that KOC extends in depth towards east; if so, one may tentatively infer that the NSB block has moved from east (or north-east) to west (or south-west). KOC in this part interestingly lies close to the northwest-trending left-lateral Cuddapah–Nellore transverse tear fault, which buttresses the Cuddapah Salient[13] towards north (Figure 1). The importance and implications of other faults inferred from gravity and of other axes of gravity 'high' in the region[11] (Figure 2) are not presently decipherable.

NSB is separated from KOC by an east-dipping thrust fault[10]. On either side of the thrust boundary between NSB and KOC (Figure 3) lithologic and metamorphic assemblages are markedly different, with contrasting structural styles; the strike–slip regime is dominant, with sinistral sense of movement along the thrust belt (T. R. K. Chetty, pers. commun.). More importantly, the occurrence of large-scale sheath folds and the development of pronounced subvertical stretching lineations (on either side of the thrust belt) at nearly perpendicular directions—NNW in NSB and SW in the adjacent KOC (north of Saidapuram)—serve as strong evidences for the dominant role of thrust and nappe tectonics in the region[10].

NSB exhibits a long and complex evolutionary history involving both continental and marginal-basin environments near a convergent plate margin[8]. The amphibolites of NSB display a dual palaeotectonic setting (with relatively higher degree of volcanic-arc setting and lesser ocean-floor setting) characteristic of marginal (back-arc) basins[8]. The amphibolites of a part of the KOC represent an island-arc volcanism with an impression of ridge magmatism, implying a marginal-basin environment during Proterozoic times[9]. Thus the amphibolites (and hornblende schists) of both NSB and KOC exhibit some similarity in their tectonic settings. The implications of this finding and the relationship between the amphibolites (of NSB and KOC) are yet to be evaluated. Though the terms 'greenstone belt' and 'ophiolite' are not synonymous, ophiolites or ophiolite-like sequences may

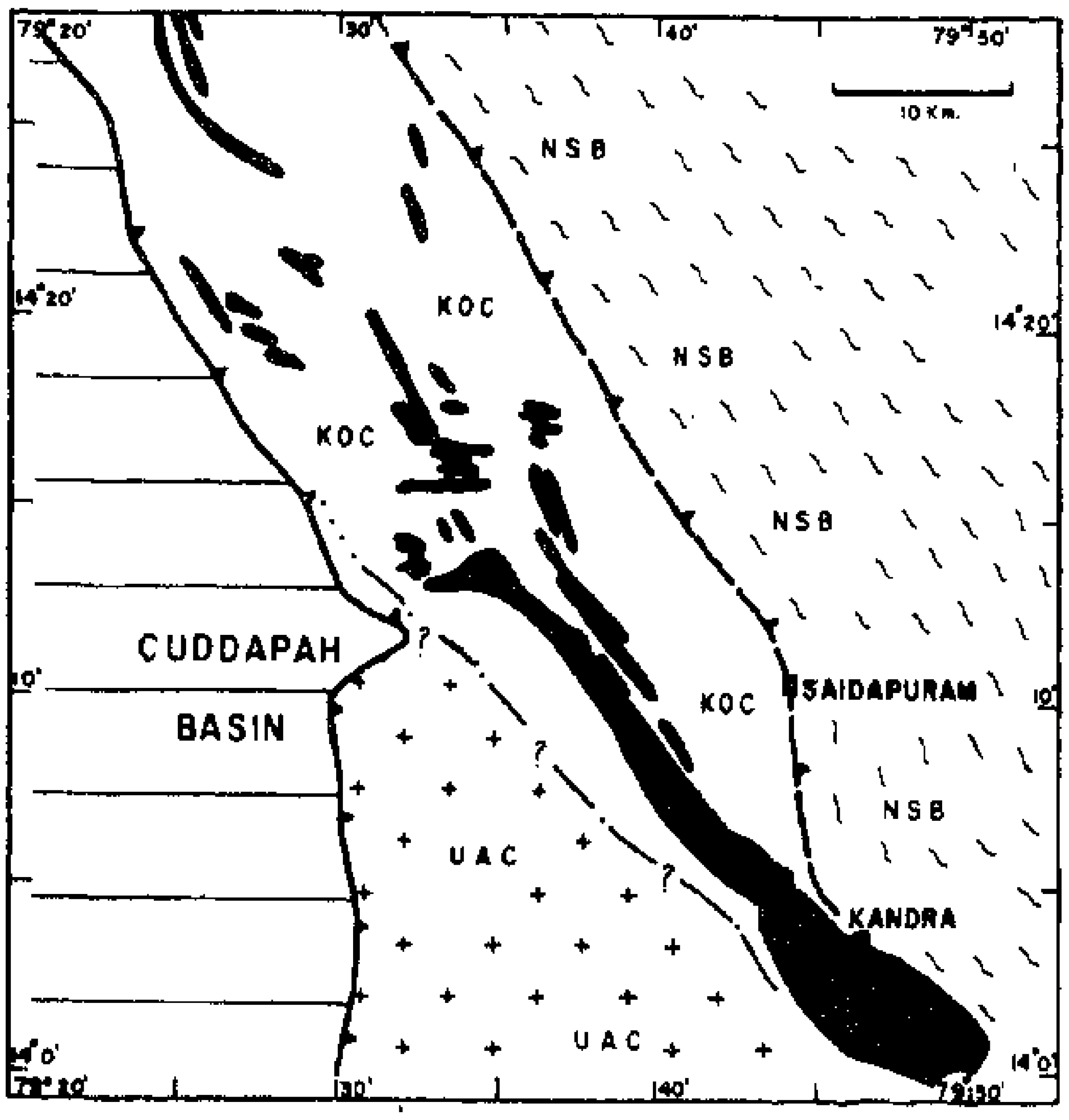

Figure 3. Generalized geological map of the Kandra region (partly adopted from the unpublished maps kindly supplied by T. H. Sastry and the late Y. G. K. Murthy). Basic intrusives and extrusives are shown in black. Granitic patches in the Kandra ophiolite complex (KOC) and unclassified Archaean crystallines (UAC) west of the KOC in the northern portion of the region are not shown. NSB, Nellore schist belt. For other details, see text.

be components of greenstone belts [14]. One can argue that, if plate-tectonic movement has been active since the creation of the earth, then the same types of tectonic processes which form present-day ophiolites also formed Archaean greenstone belts [15]. For example, the Yellowknife and Cameron River 'greenstone belts' in Slave Province, Northwest Territories, Canada, are recognized as back-arc basin 'ophiolitoids' [16].

The Eastern Ghat (coastal) granulite belt (lying east of NSB) is construed as an ancient volcanic arc[17]. The sharp geologic and metamorphic discontinuities between the (cratonic?) schist belt (miogeocline) and the granulite (mobile) belt (eugeocline) are explained in terms of a (? cryptic) suture zone that originated due to collision tectonics[18]; most of the gabbro (-anorthosite) plutons and alkaline complexes in Andhra Pradesh and Orissa[19] occur along this suture zone, a major ductile shear zone with a dextral sense of movement (T. R. K. Chetty, pers. commun.), separating the greenschist–amphibolite facies rocks towards west and granulite facies rocks towards east.

Very little is known about the (UAC) granitic rocks (Figures 2 and 3) west of KOC; they may be (?) similar to those occurring near Podili and Kanigiri. The granitoids of the Podili–Kanigiri region (Figure 2) possess typical characteristics of S-type with a collision-type plate-tectonic setting[20]. Interestingly some of the schistose hornblendic rocks associated with the Kanigiri granites supposedly contain 'glaucophane'[21], a mineral diagnostic of subduction-related (high P/T) metamorphism. Furthermore, the Kanigiri granites [1120 ± 25 Ma; 995 ± 20 Ma (ref. 22)] are enriched in Nb, Ta, Sn, U and Th (ref. 23) characteristic of syn- to post-collision granitic rocks[24]; the pegmatites that infest NSB are additionally enriched in Li and Be (ref. 8), further suggesting collision-related mineralization[24]. West and north of Kanigiri, the western margin of the schist belt is in contact with the thrusted eastern margin of the Cuddapah basin. Though one can suggest that this thrust zone does not represent a plate-collision zone (as the late-Proterozoic ophiolitic assemblages are absent[25]), it can be argued that the absence of ophiolite is due to extreme post-collision elevation resulting in erosion of obducted ophiolite and exposure of deep-level 'roots' of the arc[24]. Evidently, there are different thrust zones between different pairs of terrain in the region; generalizations, at this stage of uncertainty, are likely to compound the already confused issues. Furthermore, the temporal relationships between the tectonic events and emplacement episodes of various rock suites are unclear.

A reference to some of the reported (but not unambiguously proven) ophiolite occurrences in Peninsular India may not be out of place in this context. The Sukinda and Nausahi ultramafic complexes in Orissa are construed as Precambrian analogues of ophiolite complexes[26]. The spilite–tuff and gabbro–norite–anorthosite association in the Simlipal Complex of Mayurbhanj (Orissa) are reckoned as members of a plausible ophiolite suite[27]. The Proterozoic Dalma volcanic belt in Bihar exhibits ocean-floor affinities and is interpreted as an ophiolite belt or a fossil marginal basin[28–31]. The Basantgarh ophiolite in Rajasthan, belonging to the South Delhi fold belt of Late Proterozoic age, is perhaps the most instructive of all the Precambrian ophiolites of Peninsular India, as it not only contains a near-complete ophiolite sequence but also is purportedly associated with 'transitional glaucophane'-bearing blueschist facies metagraywackes[32].

The complete and ideal ophiolite 'stratigraphy' is never expected in ancient complexes as there are many atypical ophiolites even from the Phanerozoic. Significant differences in Proterozoic and Phanerozoic ophiolites may possibly be attributed to the hypothesis that the magmatic oceanic crust was thicker during the period 2500–1000 Ma, perhaps owing to greater amounts of partial melting of a more fertile mantle[33]. It can be argued that oceanic crustal collision may have been a frequent occurrence in the Archaean, and the Himalayas represent a modern analogue for Archaean crustal evolution[34]. A variety of tectonic settings have been suggested on geochemical grounds as viable sites for ophiolite formation[35]. The oceanic lithosphere is constructed not only at mid-ocean ridges, but also in back-arc basins, within or near fracture zones, in a fore-arc setting, and within immature island arcs[36]. It is for this reason that many researchers now believe that most, perhaps all, large sheets of ophiolite incorporated tectonically into the continents are products of arc magmatism, back-arc spreading, or both together, rather than spreading mid-ocean-ridge materials[37].

The problems involved in identification of the Precambrian ophiolites are too well known. The important thing, according to ophiolitologists, is to recognize their probable similarities with Phanerozoic ophiolites than to identify the precise sites (spreading centres, ocean islands, plateaus or island arcs) of their origin[38]. 'The unique patterning of Archaean sheeted dykes will have been obscured in most cases, leaving nothing obvious but mounded lava flows'[39], as witnessed at Kandra. The different lines of evidence, taken in concert, suggest that the Kandra volcanics represent remnants of a possible ophiolite complex which is in no way less convincing than some of the reported ophiolite occurrences[40–42] of Archaean or Proterozoic age.

The ophiolitic interpretation of the Kandra volcanics, as offered in this paper, should be treated as tentative, and has to be tested and established (or discarded) by future studies.

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