THE NEOPROTEROZOIC AND CAMBRIAN OF THE TETHYAN HIMALAYA: A TEST OF MODELS OF CORE GONDWANAN CONSTRUCTION

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PROJECT SUMMARY: Tectonic reorganization, including breakup of the supercontinent Rodinia and the subsequent assembly of Gondwanaland, is part of the remarkable changes to the Earth, atmosphere, and biosphere that occured during the Neoproterozoic to Cambrian interval. The nature and timing of the assembly of core Gondwanaland remains a matter of vigorous debate. The more traditional view of Gondwanan assembly is that East Gondwana, consisting of India, Australia and Antarctica collided with the combined African cratons (Kalahari and Congo) as one block sometime during the late Neoproterozoic. Estimates of the timing of this collision are range between 700 to 600 Ma. An alternative model suggests that the accretion of East Gondwana to the African craton was a two part process. In this model, India broke off from Australia and Antarctica, swept across the Mozambique Ocean, and collided with the African craton at approximately 680 Ma. This was purportedly followed sometime later by collision of Australia/Antarctica around 550 to 530 Ma.

Our proposed study of the Tethyan Himalaya will test tectonic models of the assembly of core Gondwanaland using a combined sedimentological, macrofaunal and stratigraphic approach. The Tethyan Himalaya was in a critical paleogeographic position to capture a stratigraphic signal of one or more of these proposed tectonic events. It also contains the most complete succession of Neoproterozoic through Cambrian deposits in India. Several predictions should be able to distinguish the two models of core Gondwanan assembly. Of primary importance is the stratigraphic signature of sediment input from adjacent orogenic belts. A record of major increases of siliclastic sediment, with abrupt changes in paleocurrents would accompany orogenesis. Such changes are readily recognizable in the stratigraphic record. A key component of the proposed models is that they have predictable patterns of detrital zircon ages. The collision with the western margin of India would result in deposition of sediment sourced from the pan-African Mozambique Fold and Thrust Belt, with detrital ages generally between 600-700 Ma. The proposed collision along eastern India in the proposed two-stage model would have resulted in deposition in the Tethyan Himalaya of sediment sourced from southwest Australia, which would have been a source of detrital zircons with a wide variety of Precambrian ages including those >3.0 Ga.

A Late Cambrian–Early Ordovician tectonic event is recorded in the Tethyan Himalayas and in other places in East Gondwanaland. The nature of this event is unclear, but two possibilities include: (1) it represents a somewhat delayed expression of the Australia/Antarctica collision in the two-stage model, or (2) it represents the docking of an outboard microcontinent (e.g., the Lhasa Block of Tibet) subsequent to the formation of core Gondwanaland. The biostratigraphic patterns of trilobites provide the basis of testable predictions of these hypotheses. In the first case, we expect to find a stratigraphic increase in similarity in faunas between India and the rest of East Antarctica throughout the Cambrian. If faunal similarity with the rest of East Gondwana was constant throughout the trilobite-bearing Cambrian, we may infer that Gondwanan construction was complete prior to 520 Ma. In addition, if the ~500 Ma tectonic event in the Tethyan Himalaya records microcontinental collision, then the identification of the outboard terrane may be approached through biogeographic patterns established in this study.

As a compliment to detailed sedimentological, macrofaunal and stratigraphic analyses, we will also conduct exploratory carbon isotope stratigraphy of carbonate units, microfossil analysis, and geochronology of volcanic ash samples. Myrow's RUI proposal will involve undergraduates at Colorado College as junior collaborators in all components of the research. This will provide a much-needed opportunity for students to experience scientific research in diverse geographical and cultural environments. A key aspect of this proposal is the close research collaboration with Indian and Chinese scientists.

INTRODUCTION AND STATEMENT OF THE PROBLEM

The Neoproterozoic through Cambrian interval was a time of radical reorganization of tectonic plates with the fragmentation of the supercontinent Rodinia and subsequent assembly of "core" Gondwanaland (comprising South America, Africa, Madagascar, Greater India, Australia and Antarctica). Numerous tectonic reconstructions have been proposed for this reorganization, based in part on emerging paleomagnetic data, which include apparent polar wander paths. It is generally agreed that Rodinia was assembled by 1050 Ma with Laurentia at its core (Bond et al. 1984; Dalziel 1992; Weil et al. 1998; Hoffman 1999). Continental blocks broke off of Rodinia sequentially and moved in a fan-like rotation from both the eastern and western sides of Laurentia towards the African Congo and Kalahari cratons, which had merged by approximately 820 Ma (Hanson et al. 1993; Hoffman 1999). Those fragments that would later make up East Gondwana broke off from western Laurentia and swept across the Mozambique Ocean to collide with the African cratons to form the East African Orogen (Stern 1994). First-order problems remain concerning the nature and timing of accretion of Greater India/Madagascar and Australia/Antarctica with the eastern margin of Africa. The presence of several "outboard" terranes that jostled about the peri-Gondwanan margin during the early Paleozoic (Metcalfe 1993, 1996) further complicates the picture.

This project will focus on latest Terminal Proterozoic and Cambrian rocks in the Tethyan Himalaya of northern India and Tibet as a test of two competing hypotheses for the closure of the Mozambique Ocean and the final stages of core Gondwanan assembly. The more traditional view is that the core of Gondwanaland was assembled when the East Gondwanan blocks of India, Australia, and Antarctica, moving as one, docked against the Congo and Kalahari cratons (Dalziel 1992; Li and Powell 1993). The dates given for the collision of East and West Gondwanaland according to this model vary from 700 Ma (Powell, et al. 1993, Stern 1994) to about 510 Ma (Kaz'min 1988; Li et al. 1993, 1996; Powell, et al. 1993; Trompette 1994). A recent model by Meert and Van der Voo (1997), which is based mainly on paleomagnetic data, reconciles some of these age disparities by proposing that the construction of eastern Gondwanaland was a two-phase process with the initial collision of Greater India with East Africa occurring some 680 Ma ago, followed by the subsequent collision of Australia/Antarctica with India around 550-530 Ma.

The Tethyan Himalaya was in a critical position to record the two proposed stages of East Gondwanan assembly (Meert and Van der Voo 1997) because in tectonic reconstructions the wedge-shaped Indian block forms a juncture with Antarctica (Darling Orogen) and the Congo/Kalahari Craton (Mozambique Belt). Its inferred position places it in proximity to both sutures and so the effects of each proposed tectonic event should be recorded in the sedimentary succession, in part as a two-stage influx of sediment, that records a shift in sediment source provenance and paleocurrents. It is the only region on the Indian subcontinent which preserves a succession of sedimentary rocks with an extensive record of Neoproterozoic through Middle Cambrian rocks. This study will test the competing hypotheses of core Gondwanan assembly with a thorough field-based analysis of stratigraphic sections along the strike of the Himalaya. It will be a major step towards an integrated model of the regional paleogeography and margin development during the latest Terminal Proterozoic through Cambrian.

Within the Tethyan Himalaya there is clear evidence of a major Late Cambrian–Early Ordovician orogenic event. However, the significance of this ~ 500 Ma event is poorly understood. It is unclear whether it is related to the construction of core Gondwana or whether this represents a separate event, such as the collision of an as-yet unidentified outboard continental block with the Tethyan margin.

The project will be an integrated stratigraphic, paleontologic, and sedimentologic analysis. It will provide badly needed chronostratigraphic constraint for a section for which there is a meager biostratigraphic database and almost no information on depositional history, paleoenvironments, or large-scale stratigraphic architecture (including sequence stratigraphic frameworks). The project will specifically focus on sections in Kashmir and Spiti/Zanskar in India, and Nyalam in Tibet. The region is remote and difficult to access so many potentially important outcrops have not yet been analyzed with integrated, modern, stratigraphic approaches. A key aspect of this study is that it will be conducted in close collaboration with geologists from India (Dr. S.K. Parcha, Wadia Institute of Himalayan Geology) and China (Dr. Shanchi Peng, Academia Sinica, Nanjing), both of whom have extensive field experience in the field areas. Drs. Parcha and Peng will be active co-authors in the resultant research, and their involvement will also greatly facilitate implementation of this field-based research program. In addition to their skills as scientists, their institutions have pledged logistic support (Appendix).

OVERVIEW OF HIMALAYAN NEOPROTEROZOIC THROUGH CAMBRIAN GEOLOGY

Whereas various tectonic basins within Peninsular India contain extensive Proterozoic successions, terminal Proterozoic and early Paleozoic sedimentation was largely restricted to the Himalayan region (see Wadia 1975; Naqvi and Rogers 1987). Cambrian rocks are volumetrically the most abundant Paleozoic deposits within the Himalayan region (Wadia 1975; Brookfield 1993). Neoproterozoic to Cambrian rocks are found in two broad zones that are sandwiched between the India/Tibet (Yarlong-Tsangpo) suture zone to the north, and the Indo-Gangetic plain to the south (Fig. 1). The two zones of Cambrian outcrops are separated by highly metamorphosed crystalline complexes of the High Himalaya. Those in the southern zone lie within the Lesser Himalaya of India and the Salt Range of Pakistan. Those to the north lie within the Tethyan Himalayan zone (Fig. 1). At their closest points the Lesser Himalaya and Tethyan zones presently lie approximately 100 km apart, but estimates of crustal shortening suggest that the original distance was at least 500km (Brookfield 1993) . Cambrian deposits within each zone are classified according to the structural/topographic basin in which they occur. For the Tethyan Cambrian deposits, the Kashmir, Zanskar/Spiti, Kumaon, and Nyalam basins occur from northwest to southeast along central Himalayan strike (Fig. 1).

Little is known of the Neoproterozoic history of the Tethyan Himalaya. To the south, in the Lesser Himalaya, initiation of sedimentation in the late Proterozoic was related to a rifting event, the timing and nature of which is poorly constrained. This event is apparently recorded in the Lesser Himalaya by thick basaltic pillow lavas (Raza 1981; Bhat 1987) and block faulting (Brookfield 1993). Rifting was purportedly followed by the establishment of a passive margin in which initially high thermal subsidence led to thick clastic and carbonate deposits (Kumar and Brookfield 1987) (Fig. 3). These events are broadly coincident with that reported on many paleocontinents (e.g., Bond et al. 1984; Hoffman 1991). It is unclear how this rifting event is manifested in the Tethyan Himalaya, in part because of a fundamental lack of basic field data and ages of the Neoproterozoic part of the succession.

Although the NW-SE strike of the central Himalaya roughly parallels the orientation of the paleoshoreline throughout the Paleozoic, Brookfield (1993, p. 7-8) argued that the distribution of Permian basalts and associated sedimentary rocks indicate that present tectonic boundaries cut obliquely across the original facies boundaries of the northern Indian margin. The extent to which lithofacies and biofacies differences among Tethyan deposits of Kashmir, Spiti/Zanskar, and Nyalam, reflect different proximities to the Cambrian margin is unknown at present, and widely divergent opinions have been expressed on this matter.

Reed (1934) suggested, using faunal evidence only, that Kashmir and Spiti belonged to different and isolated sedimentary basins during Cambrian time. Recent faunal revision (Jell and Hughes 1997) has demonstrated that Reed's assessment resulted from the combination of taxonomic misidentifications and the fact that little was known of other Asian Cambrian faunas at the time. In contrast to Reed, Wakhaloo and Shah (1965) considered the Himalayan margin to have been continuous. They interpreted the presence of trilobites in "quartzites, sandstones and limestones" in Spiti to indicate a shallower water setting than that of Kashmir, in which trilobites were found in "muddy shales ... associated with greywackes". The latter were considered representative of a euxinic basinal setting (Wakhaloo and Shah 1965, p.378; Shah 1971). This opinion has recently been reversed, but without any detailed sedimentological analysis to back up these claims. According to Shah and Raina (1989, p. 204), gray and black trilobite-bearing shale units in Spiti represent "a deeper water euxinic kind of setting" whereas Kashmiri Cambrian successions comprise "ferriginous sandy shale and associated carbonates signifying a shallower and more oxygenated condition". Shah (1993) compared the Tethyan Cambrian facies distributions to those of Laurentia. Hence the Kashmir basin is interpreted as an "inner detrital belt" setting with "light colored terrigenous sediments and a carbonate platform", and Spiti interpreted as an "outer detrital belt" comprising dark or black silty and shaly sediments" (Shah 1993, p. 41). Detailed sedimentological and stratigraphic analyses are required in both regions to evaluate which, if either, of these diametrically opposite interpretations is correct. Substantial lateral and vertical lithofacies variations within individual basins should allow for detailed depositional reconstructions. For instance, the Karsha Formation in Zanskar (Figs. 3,4) contains a 300 meter thick dolomite unit with large stromatolite buildups (Garzanti et al. 1986; Fuchs 1987) that correlates 150 km to the NW with interbedded meter-scale dolomite beds and shale in the Spiti section (Hayden 1904; Fuchs 1982; Parcha 1996). Thicker carbonate buildups to the east have been reported in the Nyalam section of Tibet (Zhang 1988)(Fig. 3). At present too little is known to formulate a coherent model for the paleogeographic relationships among Tethyan basins, but paleontological, sedimentological and stratigraphic data will provide a basis for constructing such a model.

Within the Tethyan Himalaya the section from the Precambrian–Cambrian boundary (Hughes and Droser 1992) through early Late Cambrian is generally complete and the Cambrian portion has yielded a surprisingly well preserved trilobite fauna (Jell and Hughes 1997). Sections within the Lesser Himalaya record deposition only up to late Early Cambrian time (Jell and Hughes 1997) because they are overlain by a major unconformity which is followed by Permian and younger deposits (Brookfield 1993). Thus, the post-Early Cambrian Paleozoic history of the Lesser Himalaya is obscure, whereas sections in the Tethyan Himalaya record a significantly greater portion of Cambrian time and are overlain by deposits of Ordovician age. The Tethyan Himalaya therefore offers the greatest potential for constraining the earliest Phanerozoic history of the Himalayan margin, and our studies will focus on this history.

All Tethyan Himalayan sections studied to date have extensive, apparently conformable successions of Neoproterozoic to early Upper Cambrian or late Middle Cambrian strata that are at least 1000 m thick, and in some cases in excess of 4000 m in thickness (Fig. X). Only in Nyalam, Tibet is the basal contact of the Cambrian apparently faulted. Little is known of the stratigraphic details of much of this material, but in Zanskar the Phe Formation (Hughes and Droser 1992) comprises a succession of interbedded siltstone and sandstone over 1500m thick, and the succession is reported to be similar in both the Parahio Valley and in Kashmir, although in these regions it is even more extensive (Kumar 1983; Kumar et al. 1984; Brookfield 1993).

Cambrian–Ordovician Orogenic Event—Tethyan Himalayan deposits contain evidence for a period of regional uplift caused by a major Late Cambrian–Early Ordovician orogenic event. This event was characterized by volcanism (Garzanti et al. 1986; Valdiya 1993; Valdiya 1995), mild metamorphism (Gaetani et al. 1985), and intrusion of granites with high $^{87/86}$Sr isotopic ratios (LeFort et al. 1986). Garzanti et al. (1986) suggest that it records complete development and filling of a foreland basin as a result of subduction, basin closure, and accretion of a terrane to the north, although the identity of this northern terrane was not specified. This was followed by the deposition of pre-middle Ordovician molassic sediment (Hayden 1904; Garzanti et al. 1986; Fuchs 1987). Although this event has been attributed to the “pan-African orogeny” (Gaetani et al. 1986) its specific significance remains entirely unexplained, and it has not been incorporated into regional tectonic models.

The stratigraphic record of this orogenic event is an extensive sub-Ordovician unconformity. The youngest Cambrian faunas occurring below the unconformity are in Kashmir, where overlying deposits with brachiopods (Reed 1934) have recently been reconfirmed to be of earliest Ordovician age (L.R.M. Cocks, personal communication, 1998). This contrasts with the Middle Ordovician age of the earliest brachiopods found along strike in Spiti (Hayden 1904; L.R.M. Cocks, personal communication, 1998). Although the section has not been logged in detail, a marked angular unconformity present in Spiti (Hayden 1904) does not appear to be present in Kashmir, where Cambrian and Ordovician deposits appear to be conformable, even though much of the Upper Cambrian may be missing in Kashmir (Jell 1984). Detailed stratigraphic analysis along the strike of the Tethyan Himalaya will provide a basis for evaluating the paleoenvironmental and tectonic significance of this difference. A regional increase in the deformation and magnitude expressed by the unconformity from west to east may provide clues about the nature of this event.

CRITICAL TESTS OF GONDWANAN ASSEMBLY

First-order uncertainties still exist concerning the position of large continental blocks, the nature of their interactions, and the timing of these interactions for the final assembly of Gondwana during the Neoproterozoic through early Paleozoic. In the Meert and Van der Voo (1997) hypothesis, the first stage of assembly is the East African Orogeny, which formed the Mozambique Belt. In their reconstruction, this orogeny was due to the collision of India, Madagascar, and Sri Lanka with East Africa (Stern 1994) during the closure of the Mozambique ocean. This continent-continent collision was likely to have terminated around 683 Ma, the age of the Mahe granite in the Seychelles (Suwa et al. 1994). The second proposed event was the newly proposed Kuunga Orogeny (550-530 Ma) (Meert et al. 1995; Meert and Van Der Voo 1996) in which Australia and Antarctica complete the assembly of core Gondwana by docking against the previously assembled block of India and West Gondwana. This event, which formed the younger Darling Orogen (Meyers 1990, 1993; Libby and De Laeter 1998; Harris 1994; Harris and Beeson 1993; Wilde and Murphy 1990), is dated at 550-530 Ma (Meert et al. 1995; Meert and Van Der Voo 1997), based on the presence of granulite facies metamorphic rocks of this age in southern India, Sri Lanka, Madagaskar, Mozambique, and parts of East Antarctica (Shiriashi et al. 1994; Unnikrishnan-Warrier et al. 1995; Windley et al. 1994; Kroner 1993; Kroner et al. 1996).

This study is a test of the stratigraphic patterns (e.g., paleocurrents), age relationships, and paleontological patterns which are predictable from the Meert and Van der Voo (1997) hypothesis and earlier one-stage collision hypotheses. The test of these hypotheses has both stratigraphic and paleontological components, each of which is summarized separately below.

Stratigraphic Test of Models—The test of these hypotheses will take the following form:

(A) If older models (e.g., Dalziel 1992; Li and Powell 1993) are correct: (1) a single phase of orogenesis representing closure of the Mozambique Ocean should be a recorded in Tethyan Neoproterozoic strata, (2) all of the sediment recorded in the Precambrian orogenic event should be derived from western sources of the East African orogen, and (3) such sediment sources would be supported by west-to-east paleocurrents and Neoproterozoic (600-700 Ma) detrital zircon ages.

(B) If the model of Meert and Van der Voo (1997) is correct: (1) the terminal Neoproterozoic and earliest Cambrian deposits will record an early tectonic event representing the collision of India with East Africa, (2) these will have western sediment sources of the Mozambique Fold and Thrust Belt with 600-700 Ma detrital zircons, (3) the subsequent Cambrian orogenic event will contain sediment sourced from the Antarctic/Australian tectonic block to the east, (4) these younger deposits will have east-to-west paleocurrents and detrital zircons with a wide range of Proterozoic and Archean rocks including those > 3,000 Ma.

Predictions for paleocurrents and the ages of detrital zircons in the Tethyan Himalayas depend upon tectonic reconstructions of Gondwanaland. There is a general consensus regarding the position of these three continental blocks within the fully assembled Gondwanaland (Fig. X). The eastern edge of southern and central India is placed against East Antarctica and northeast India is contiguous with southwestern Australia (Powell et al. 1988). A critical tie point is provided by the Central Indian Tectonic Zone, which is considered a continuation of the Albany Mobile belt (Harris and Beeson 1993), an orogenic belt just south of the Archean Yilgarn Craton in southwest Australia. Possible sediment sources for Tethyan Himalayan depositional basins during an India–Australia/Antarctica collision would include: (1) the Pinjarra Orogen on the western edge of the Yilgarn Craton, (2) the Yilgarn and Pilbara Cratons, and (3) the Capricorn Orogen (Meyers 1998). The Pinjarra Orogen contains plutonic rocks of the following ages: 2060-2030, 1800, 1100, 650, and 570-550 Ma (Tyler and Thorne 1990; Harris 1994, Meyers 1988, 1993). The Yilgarn and Pilbara Cratons (including the Hamersley Basin) contain much older Archean rocks ranging from 2.4-3.73 Ga (Meyers 1988; Libby and De Laeter 1998). The Capricorn Orogen, which resulted from collision between the Yilgarn and Pilbara cratons, contains potential source rocks of 2200-1600 Ma.

The large areal extent of the Yilgarn and Pilbara Cratons, and the presence of abundant 3.1-3.5 Ga plutonic rocks along the eastern edge of the Indian Craton (e.g., Mishra et al. 1999), would almost certainly result in deposition of > 3 Ga detrital zircons in the Tethyan Himalayas during an Indian–Australia/Antarctica collision. No source rocks of such antiquity would have existed along the Pan-African margin adjacent to northwestern India during its presumed earlier docking with the African Craton because of the considerable width of the Mozambique Fold and Thrust Belt and the considerably large distance to the nearest (northernmost) part of the older Archean Congo Craton (2-3,000 km; Trompette, 1994, fig 1.3). The stratigraphic position marking the introduction of >3Ga detrital zircons is therefore an important part of the test of competing models of Gondwanan assembly. Sedimentary units in the Tethyan Himalaya would contain such older detrital zircons prior to the breakup of Rodinia. However, if the Meert and Van der Voo (1997) hypothesis is correct, from the time India broke off from Antarctica until the final assembly of Gondwanaland (550-530Ma) detrital zircons of this age would become progressively scarcer and likely disappear altogether. A large pulse of sediment from the East-African collision would have been shed during the terminal Proterozoic–Early Cambrian and this would have contained primarily 600-700Ma detrital zircons.

The most fundamental stratigraphic signatures of orogenies include changes in sediment sources and the considerable input of sediment shed from uplifted terranes. Paleocurrents have proven to be remarkably useful indicators of source directions, in that they show surprising consistency over wide regions, and have great utility even in areas of discontinuous outcrop exposure. Neoproterozoic through Cambrian strata in the Tethyan Himalayas contain well-preserved current-generated sedimentary structures. Several studies report paleocurrent readings from rocks of this age in the region, but they are commonly contradictory and consist of generalized results which are not backed up by raw data (i.e., rose diagrams). In addition, such data has been reported without stratigraphic constraint. We are confident that the signatures of orogenesis will be apparent in the field and that paleocurrent readings and facies transitions will allow us to provide the data necessary to test our hypotheses.

The Cambrian-Ordovician orogenic event may be an important component of this debate. If Stratigraphic Hypothesis “B” (above) is correct, then this event may represent the terminal phase of the Darling Orogeny representing the docking of Australia/Antarctica with Greater India and the end of the formation of core Gondwanaland. According to Meert and Van der Voo (1997) collision between Australia/Antarctica and India took place about 550 – 530Ma. This view is based on the ages of granulites found in southern India, southern Madagascar, Sri Lanka, Mozambique and parts of eastern Antarctica. No evidence currently exists for an orogenic event of that age in the Tethyan Himalaya, but so little is known at this point that a thorough examination of this part of the section is imperative. Given that the collision between East and West Gondwana was likely to have been oblique, it is possible that the collision in south India began some tens of millions of years prior to collision in the north.

If Stratigraphic Hypothesis “A” is correct, then this event would most likely represent the docking of an outboard peri-Gondwanan terrane along the northern margin of India. The identity of such a terrane is speculative, but one possibility is that it was the Lhasa block, the southern most of the four major Tibetan terranes (Dewey et al. 1988), which broke away from the Indian craton in the Permian (Gaetani and Garzanti 1991; Sengör et al. 1991; Brookfield 1993; Sengör et al. 1993) or Triassic (Metcalfe 1996). As nothing is yet known of the Cambrian history of any of the four terranes this hypothesis remains speculative.

Faunal Test of Tectonic Models—The distributions of macrofossils yield important information for constraining Phanerozoic paleogeography, particularly in the Paleozoic where knowledge of continental configurations remains incomplete (McKerrow and Cocks 1976; Fortey and Cocks 1992). Sharp changes in Permian faunal and floral characteristics between two of the Tibetan terranes, for example, indicate the position of the intervening suture and also provide information on the degree of separation between the terranes during Permian time (Yin 1997). Cambrian sections within the Tethyan Himalaya have long been known to contain trilobites (Waagen 1889), and previously described specimens from the region have recently been extensively revised and reillustrated in a synthetic monograph by Jell and Hughes (1997), which also includes description of new material. This work provides a regional biostratigraphic framework for the Himalayan Cambrian and a basis for assessing the paleobiogeographic affinities of the region.

Cambrian faunas from the Himalaya can be used to test models of Gondwanan assembly in the following manner:

> If the terminal Cambrian orogenic event in the Tethyan Himalaya represents the delayed closure of an ocean separating India/Africa from Australia/Antarctica, then the affinities of Indian and Australia/Antarctic faunas should rise through the Cambrian, as the distance between the two continents decreased.
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> If this closure had occurred between 550 and 530 Ma, as suggested by Meert and Van der Voo (1997), then there should be a close similarity in Tethyan Himalaya and Australia/Antarctica fauna throughout the Cambrian. The Late Cambrian orogenic event would therefore represent collision of an outboard microcontinent or continents (e.g., Lhasa Block) and faunal comparisons may help with their identification.

Himalayan Cambrian trilobites—Prior to the Jell and Hughes (1997) monograph information about Himalayan Cambrian trilobites was difficult to evaluate because it lacked a modern taxonomic framework. Improved resolution of the effects of tectonic deformation and intraspecific variation on trilobite morphology (Hughes and Jell 1992) has resulted in the synonymy of many previously described Himalayan taxa into a total of 34 identifiable species belonging to 29 genera, with an additional 11 taxa questionably assigned to species or discernible at the generic level only (Jell and Hughes 1997). The diversity of taxa within collections from individual Himalayan horizons is relatively low compared to collections of similar age from other regions (e.g., Zhang et al. 1980; Zhang and Jell 1987). Low diversity may reflect the relatively deep water paleoenvironmental settings (Garzanti et al. 1986), but it is certainly also influenced by the low intensity of sampling of Himalayan deposits. One aim of this project is to substantially increase the size of collections of Tethyan Cambrian trilobites from numerous stratigraphic horizons in different basins, in part to assess the true diversity of these deposits.

Using the revised taxonomy, intraregional correlations have been proposed for three horizons (Jell and Hughes 1997). An informal local biozonation has been established and correlated with the zonal scheme erected for the Chinese Cambrian (Fig. X). These correlations provide a basic biostratigraphic framework that will permit examination of the depositional history and stratigraphic evolution of the trilobite-bearing Cambrian of the Tethyan Himalaya (Fig. 3).

Ninety-seven percent of the genera and 48% of identified species are found outside the Himalaya, indicating faunal affinities with other regions. Most Himalayan Cambrian trilobites have close relatives (or members of the same species) occurring either along the margin of core Gondwanaland, or on adjacent outboard continental fragments. Himalayan faunas also include several species with global distributions (e.g., *Bailiella lantenoisi, Tonkinella breviceps, Lejopyge armata)*. Globally distributed taxa provide important chronological constraints, but taxa with more restricted distributions can be used to assess the paleobiogeographic affinities of the Himalayan fauna, providing an independent, biological test of tectonic models. Data currently available are consistent with India's inferred position within equatorial Gondwanaland (Jell and Hughes 1997; Chang 1998) but biogeographic inferences within the region are questionable due to limited sampling, and are insufficient to evaluate any temporal variations in the faunal affinities with other regions during the Cambrian.

Jell and Hughes's (1997) monograph represents a first step in improved understanding of Himalayan Cambrian trilobites, but significant gaps in knowledge remain. The stratigraphic and paleoenvironmental settings of almost all the trilobite collections are poorly constrained. To date almost all collections have been made in a piecemeal fashion, with little regard to stratigraphic setting. For example, the Middle Cambrian Kashmiri faunas have been ordered pseudo-stratigraphically based on the order of occurrence of similar taxa in South China, rather than on observed stratigraphic occurrence within Kashmir itself. This is because previous Kashmiri collections have not been made with reference to a detailed stratigraphic section. Spiti contains the only section from which trilobite collections have been collected from multiple horizons in stratigraphic order, but even in this case the stratigraphic section was produced in 1904 (Hayden 1904), and thus lacks a detailed sedimentological framework.

While we are confident that our correlations within the Himalaya are securely founded (the stratigraphic positions of these taxa positions are tightly constrained in well documented Chinese sections [Zhang et al. 1980]), additional collecting conducted in a well constrained sedimentological framework will further refine these correlations, and increase the likelihood of establishing additional correlations at other horizons. Given that described Himalayan Cambrian trilobite diversity is relatively low, and estimates of how it will improve as the result of our work can only be approximate, our initial strategy will be to target specific horizons and lithologies were we may best test the competing tectonic hypothesis, based on the predicted occurrence of regionally diagnostic taxa. Diagnostic taxa are distinctive forms that have been demonstrated to characterize specific tectonic blocks within the equatorial Gondwanan region. For example, the distinctive redlichiide family Xystriduridae characterize shelfal settings in Australia/Antarctica (Öpik 1975; Palmer and Gatehouse 1972; Soloviev and Gricurov 1979). The family is also recorded in one of the Hainan Island terranes (Li and Jago 1993; Sun 1963; Zhu and Lin 1978), which was known to be separate from the South China block during the lower Paleozoic (Metcalfe 1996), and in the Junggar block (Xiang and Zhang 1985). Because this family has a narrow paleogeographic range, confined to Australia and structurally contiguous terranes, it was apparently unable to cross open ocean basins. Recovery of xystridurids in the Tethyan Himalaya would suggest a contiguous Australian and India margin in the lower Middle Cambrian, as predicted by the Meert and Van der Voo (1997) model. If found within the Tethyan Himalaya, xystridurids will be found in sandy/silt facies in the upper Maochuangian or basal Hsuchuangian (Fig X), and we will target our searches in these rocks. That this approach may be successful is suggested by recent identification of the distinctive late Early Cambrian dolerolenid *Xela* in the Himalaya (Jell and Hughes 1997), because this taxon is otherwise restricted to Australia (Jell *in* Bengtson, et al. 1990). Other target taxon are the Early Cambrian *Balcorcania* which is restricted to Australia (Pocock 1970) and Antarctica (Palmer and Rowell 1995), *Pararaia* and *Yorkella*, which are restricted to Australia (Jell *in* Bengtson, et al. 1990), and *Australaspis* which is restricted to Antarctica (Palmer and Gatehouse 1972). Recovery of these forms would greatly strengthen the idea of Early Cambrian structural continuity between Australia/Antarctica and India. Target species, as opposed to genera, from the Early Cambrian include Australiasian/Antarctic representatives of *Yunnanocephalus, Hsuaspis,* and of numerous metaredlichiinid genera, Middle Cambrian species of *Mapania, Prohedinia, Dorypyge, Schopfaspis* and *Fuchouia,* and early Late Cambrian species of *Eoshengia, Damesops,* and *Palaeodotes*.

Outboard Microcontinents—In addition to the question of the formation of core Gondwanaland, reconstructions differ markedly in the placement of the numerous "outboard" microcontinents adjacent to the eastern margin of the Gondwanan core such as South China, North China, Tarim, Indo-China, Sibumasu, the Lhasa block, and the Qiangtang block (Fig. 2). Paleogeographic interpretations for the Lower Cambrian to Middle Ordovician of the Himalayan margin and Tibet are wide ranging and include: (1) Middle Cambrian separation of Tibet from the Himalayan margin by an ocean over 5000 km wide (Jell 1974); (2) A large area continental crust, referred to as “Greater India”, situated between the Lesser Himalaya and the ancient continental margin of India some 1000km to the north (this margin was separated from the Tibetan terranes by an ocean less than 500 km wide) (Li, et al. 1996; Metcalfe 1996); (3) Lhasa and Qiangtang blocks situated adjacent to western Australia from the Early Cambrian through the Early Ordovician and completely separated from the Himalaya by an ocean some 1000 km wide (Burrett et al. 1990; Metcalfe 1992; Dalziel et al. 1994); (4) the Tethyan Himalaya forming a microplate separate from the northern margin of India in the Early Ordovician (Cocks and Fortey 1988); and (5) the western end of the Lhasa block adjacent to the Himalaya in the late Cambrian, but the eastern end separated from the Himalaya by approximately 700km (Scotese and McKerrow 1990; Yang and Tong 1993; Rushton and Hughes 1997).

This variety of interpretations is representative of the present confusion in early Paleozoic reconstructions of the equatorial sector of Gondwanaland. Part of this confusion reflects the fact that fundamental questions about the construction of core Gondwana remain unclear. Detailed documentation of the history of the Tethyan Himalaya is key because it can constrain the timing of the construction of core Gondwana. Little substantial progress can be made until the sedimentary and stratigraphic contexts of individual faunas are refined in the manner described above. We already have grounds for rejecting the idea that the Tethyan Himalaya formed a microplate separate from the Indian margin during the Cambrian (Cocks and Fortey 1988), because there is no evidence of a suture zone between the Tethyan and Lesser Himalaya, and because faunal and facies relationships are consistent with a passive margin model. The question of whether the Lhasa block was entirely separate from the Himalayan margin (Jell 1974; Burrett et al. 1990; Metcalfe 1992; Dalziel et al. 1994), or whether it was "anchored" to the western end of India throughout the Cambrian (Scotese and McKerrow 1990; Yang and Tong 1993; Rushton and Hughes 1997) can be addressed through stratigraphic analyses along the Himalayan margin.

Cambrian faunas are not known from the Lhasa Block, nor from any other parts of Tibet north of the Indus suture zone. For this reason it is not currently possible to track whether the Tethyan margin of India and portions of Tibet shared greater progressively greater faunal similarity through the Cambrian. Nor is it possible to evaluate the paleogeographic affinities of the Lhasa block prior to docking with India. We will take advantage of proximity during the Tibetan portion of fieldwork in this project to make a brief reconnaissance trip to Xianza County. This area has a well developed lower Paleozoic succession yielding well preserved Ordovician fossils (Chen and Rong 1992), and is situated north of the suture zone, on the Lhasa block. We hope that Cambrian deposits can be identified in the succession, opening up the possibility of examining events on the northern side of the Indus suture zone.

Cambrian trilobite faunas are well known from several major outboard peri-Gondwanan blocks, such as North and South China. Cambrian trilobite faunas also occur in western Yunnan (Leng 1983), which shows similar basinal lithofacies to that found in the Tethyan Himalaya. This is also structurally part of the Kunlun-Tibet-western Yunnan geosyncline (Zhang 1988), and forms an extension of the Qiangtang terrane (Yin and Nie 1996) and possibly part of the continuous "Cimmerian" continent of Metcalfe (1996)(fig X). Preliminary mapping in the region has recovered trilobites such as *Kunmingaspis* sp., and *Douposiella* sp., which are probably conspecific with Tethyan forms. Details of the sections are scant, but Hughes will travel to western Yunnan with Dr. Peng in June 1999 to conduct initial collecting and lithostratigraphic analysis in this section. It appears that the section is conformable with lower Ordovician deposits (Leng 1983), and there is a good possibility of finding a relatively complete Cambrian succession. Detailed lithological and faunal analysis will provide a basis for comparing the stratigraphic evolution of this region with that of the Tethyan Himalaya, and for assessing whether these areas share the greatest faunal similarity. If western Yunnan collided with the Tethyan margin during the Cambro-Ordovician tectonic event, then we should expect to find the signature of this event in the Yunnan succession. Furthermore, we can predict that the degree of faunal similarity within the two regions should progressively increase stratigraphically in during the Cambrian, refelecting the approaching collision.

BIBLIOGRAPHY

Bhat, M. I. 1987. Spasmodic rift rejuvenation and its role in pre-orogenic evolution of the Himalayan region. *Tectonophysics* 134:103-127.

Bond, G. C., Nickeson, P. A. and Kominz, M. A. 1984. Breakup of a supercontinent between 625 Ma and 555 Ma: new evidence and implications for continental histories. *Earth and Planetary Science Letters* 70:325-345.

Brookfield, M. E. 1987. Lithostratigraphic correlation of Blaini Formation (late Proterozoic, Lesser Himalaya, India) with other late Proterozoic tillite sequences. *Geologische Rundschau* 76:447-484.

Brookfield, M. E. 1993. The Himalayan passive margin from Precambrian to Cretaceous times. *Sedimentary Geology* 84:1-35.

Bureau of Geology and Mineral Resources of Xizheng Autonomous Region. 1993. Cambrian - Chapter 3. *Regional Geology of the Xizheng Autonomous Region, Series 1. Regional Geology, Number 31.* Beijing: Geological Publishing House.

Burrett, C., Jong, J. and Stait, B. 1990." Early - Middle Palaeozoic biogeography of Asian terranes derived from Gondwana." In W. S. McKerrow and C. R. Scotese, ed., *Palaeozoic palaeogeography and biogeography*. pp. 163-174. London: Geological Society Memoir.

Chen, X. and Rong, J.-Y. 1992." Ordovician plate tectonics of China and its neighbouring regions." In B. D. Webby and J. R. Laurie, ed., *Global Perspectives on Ordovician Geology.* pp. 277-291. Rotterdam: Balkema Press.

Cocks, L. R. M. and Fortey, R. A. 1988." Lower Palaeozoic facies and faunas around Gondwana." In M. G. Audley-Charles and A. Hallam, ed., *Gondwana and Tethys.* pp. 183-200. London: Geologica Society Special Publication no.

Dalziel, I. W. D. 1992. Antarctica; a tale of two supercontinents? Annual Reviews of Earth and Planetary Sciences 20: 501-526.

Dalziel, I. W. D., Salda, L. H. D. and Gahagan, L. M. 1994. Paleozoic Laurentia-Gondwana interaction and the origin of the Appalachian-Andean mountain system. *Geological Society of America Bulletin* 106:243-252.

Dewey, J. F., Shackleton, R. M., Chang, C. and Sun, Y. 1988. The tectonic evolution of the Tibet Plateau. *Philosophical Transactions of the Royal Society of London* Series A 327:379-413.

Fuchs, G. 1982. The Geology of the Pin Valley in Spiti, Himachal Pradesh, India. *Jahrbuch der Geologischen Bundesanstalt Wien* 124:325-359.

Fuchs, G. 1987. The geology of southern Zanskar (Ladakh) - evidence for the autochtony of the Tethys Zones of the Himalaya. *Jahrbuch der Geologischen Bundesanstalt* 130:465-491.

Gaetani, M., Casnedi, R., Fois, E., Garzanti, E., Jadoul, F., Nicora, A. and Tintori, A. 1986. Stratigraphy of the Tethys Himalaya in Zanskar, Ladakh. *Rivista Italiana di Paleontologia e Stratigrphia* 48:237-265.

Gaetani, M. and Garzanti, E. 1991. Multicyclic history of the northern India continental margin (northwestern Himalaya). *American Association of Petroleum Geologists Bulletin* 75:1427-1446.

Garzanti, E., Casnedi, R. and Jadoul, F. 1986. Sedimentary evidence of a Cambro-Ordovician orogenic event in the northwestern Himalaya. *Sedimentary Geology* 48:237-265.

Harris, L.B., 1994, Neoproterozoic sinistral displacement along the Darling Mobile Belt, Western Australia, during Gondwanaland assembly: Journal of the Geological Society, London, v. 151, p. 901-904.

Harris, L.B. and Beeson, J., 1993, Gondwanaland significance of lower Paleozoic deformation in central India and SW Western Australia: Journal of the Geological Society, London, v. 150, p. 811-814.

Hayden, H. H. 1904. The geology of Spiti with parts of Bashahr and Rupshu. *Memoirs of the Geological Survey of India* 36:1-121.

Hoffman, P. F. 1991. Did the breakout of Laurentia turn Gondwanaland inside-out? *Science* 252:1409-1412.

Hoffman, P. F. 1999. The break-up of Rodinia, birth of Gondwana, true polar wander and the snowball Earth. Journal of African Earth Sciences 20: 9-27.

Hughes, N. C. 1993. Distribution, taphonomy and functional morphology of the Upper Cambrian trilobite *Dikelocephalus*. *Milwaukee Public Museum Contributions in Biology and Geology* 84:1-49.

Hughes, N. C. and Droser, M. L. 1992. Trace fossils from the Phe formation (Lower Cambrian), Zanskar Valley, northwestern India. *Memoirs of the Queensland Museum* 32:139-144.

Hughes, N. C. and Jell, P. A. 1992. A statistical/computer-graphic method for assessing variation in tectonically deformed fossils and its application to Cambrian trilobites from Kashmir. *Lethaia* 25:317-330.

Hughes, N. C. and P. A. Jell. 1999. The biostratigraphy and biogeography of Himalayan Cambrian trilobites. In A. Macfarlane, R. B. Sorkhabi and J. Quade ed. Himalaya and Tibet: Mountain Roots to Mountain Tops. Geological Society of America Special Paper 328, Boulder, Colorado. pp. 109-116.

Jell, P. A. 1974. Faunal provinces and possible planetary reconstruction of the Middle Cambrian. *Journal of Geology* 82:319-350.

Jell, P. A. and Hughes, N. C. 1997. Himalayan Cambrian trilobites. *Special Papers in Palaeontology* 58:1-113.

Kaz'min, V. G. 1988. Tectonic development of the Mozambique zone: from accretion to collision. Geotectonics 22: 213-219.

Kröner, A., 1993, The Pan-African Belt of northeastern and Eastern Africa, Madagascar, southern India, Sri Lanka and East Antarctica: terrane amalgamation during the formation of the Gondwana supercontinent: Geoscientific Research in Northeast Africa (Abstracts), Rotterdan, Balkema, p. 3-9.

Kröner, A., Braun, I., and Jaekel, P., 1996, Zircon geochronology of anatectic melts and residues from a high-grade pelitic assemblage at Ihosy, southern Madagascar: evidence for Pan-African granulite metamorphism: Geological Magazine, v. 133, p. 311-323.

Kumar, G. 1983. The Precambrian-Cambrian boundary beds, northwest Himalaya, India, and boundary problems. *Proceedings of the Fifth Indian Geophytolological Conference, Lucknow* 98-111.

Kumar, G., Raina, B. K., Bhargava, O. N., Maithy, K. and Babu, R. 1984. The Precambrian-Cambrian boundary problem and its prospects, northwest Himalaya, India. *Geological Magazine* 121:211-219.

LeFort, P., Debon, F., Pêcher, A., Sonet, J. and Vidal, P. 1986. The 500 Ma magmatic event in Alpine southern Asia, a thermal episode at Gondwana scale. *Sciences de la Terre* 47:191-209.

Leng, C.-L. 1983. The discovery of Cambrian and Ordovician system in Jinjiang District, Zhongdian County, Yunnan. *Contribution to the Geology of the Qinghai-Xizhang (Tibet) Plateax* 2:31-36.

Libby, W.G. and De Laeter, J.R., 1998, Biotite Rb-Sr age evidence for Early Paleozoic tectonism along the cratonic margin in southwestern Australia: Australian Journal of Earth Sciences, v. 45, p. 623-632.

Ludvigsen, R. and Westrop, S. R. 1983. Trilobite biofacies of the Cambrian-Ordovician boundary interval in northern North America. *Alcheringa* 7: 301-319.

McKerrow, W. S. and L. R. M. Cocks. 1976, Progressive faunal migration across the Iapetus Ocean. *Nature* 263: 304-306.

Meert, J. G. and R. Van der Voo. 1997, The assembly of Gondwanaland 800-550 Ma.: Journal of Geodynamics 23: 223-235.

Meert, J. G. and R. Van der Voo. 1996, Paleomagnetic and ^{40}Ar/^{39}Ar study of the Sinyai dolerite, Kenya: Implications for Gondwana assembly: Journal of Geology, v. 104, p. 131-142.

Meert, J. G., R. Van der Voo, and Ayub, S., 1995, Paleomagnetic investigation of the late Proterozoic Gagwe lavas and Mbozi complex, Tanania and the assembly of Gondwana: Precambrian Research, v. 69, p. 113-131.

Metcalfe, I. 1992." Ordovician to Permian evolution of southeast Asian terranes: NW Australia Gondwana connections." In B. D. Webby and J. R. Laurie, ed., *Global Perspectives on Ordovician Geology*. pp. 293-305. Rotterdam: Balkema Press.

Metcalfe, I. 1993. Southeast Asian terranes: Gondwanaland origins and evolution. In R. H. Findlay, R. Unrug, M. R. Banks and J. J. Veevers ed. Gondwana Eight: assembly, evolution and dispersal. A.A. Balkema, Rotterdam. p. 181-200.

Metcalfe, I. 1996. Gondwanaland dispersion, Asian accretion and the evolution of eastern Tethys. *Australian Journal of Earth Science* 43: 605-623.

Myers, A. A. and P. S. Giller. 1988. Analytical Biogeography. Chapman and Hall, London. 578 pp.

Meyers, J.S., 1990, Anorthosite in the Leeuwin Complex of the Pinjarra Orogen, Western Australia: Australian Journal of Earth Sciences, v. 37, p. 241-245.

Meyers, J.S., 1993, Precambrian historyof the West Australian Craton and adjacent orogens: Annual Review of Earth and Planetary Sciences, v. 21, p. 453-458.

Meyers, J.S., 1998, Tectonic evolution of the Western Australian shield: Workshop on the Deep Continental Crust of South India, Lunar and Planetary Institute Technical Report, v. 88-06, p. 122-124.

Mishra, S., Deomurari, M.P., Wiedenbeck, M., Goswami, J.N., Ray, S., Saha, A.K., 1999, ^{207}Pb/^{206}Pb zircon ages and the evolution of the Singhbhum Craton, eastern India: an ion microprobe study: Precambrian Research, v. 93, p. 139-151.

Naqvi, S. M. and Rogers, J. J. W. 1987. *Precambrian Geology of India.* Oxford: Oxford University Press, 223p.

Parcha, S. K. 1996. Cambrian sequences in the Tethyan zone of Spiti Himalaya and its boundary problems. *Newsletters on Stratigraphy* 34:3-11.

Peng, S. 1990. New material of *Songtaoia* (Trilobita, Tremadoc) from northwestern Hunan, China. *Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen* 180:97-115.

Peng, S. 1992. Upper Cambrian biostratigraphy and trilobite faunas of the Cili-Taoyuan area northwestern Hunan, China. *Memoirs of the Association of Australasian Palaeontologists* 13:1-119.

Peng, S. and Chen, Y.-A. 1990. Familial position, synonym and new species of *Tamdaspis* Lisogor (Trilobita, Late Cambrian). *Acta Palaeontologica Sinica* 29:637-642.

Peng, S.., Lin, H.-L. and Chen, Y.-A. 1995. New Polymerid trilobites from Middle Cambrian Huaqiao formation of Western Hunan. *Acta Palaeontologica Sinica* 34:277-306.

Powell, C. M., Z. X. Li, M. W. McElhinny, J. G. Meert and J. K. Park. 1993. Paleomagnetic constraints on timing of the Neoproterozoic breakup of Rodinia and the Cambrian formation of Gondwana. Geology 21: 889-892.

Raza, M. 1981. Geochemical clues to elucidate the tectonic environment of the Chamoli Volcanics, Lesser Himalayas, Uttar Pradesh, India. *Lithos* 14:295-303.

Reed, F. R. C. 1934. Cambrian and Ordovician fossils from Kashmir. *Palaeontologia Indica* 21:1-38.

Rupke, J. 1974. Stratigraphic and structural evolution of the Kumaon Lesser Himalaya. *Sedimentary Geology* 11:81-256.

Rushton, A. W. A. and Hughes, N. C. 1997. Biometry, systematics and biogeography of the late Cambrian trilobite *Maladioidella abdita*. *Transactions of the Royal Society of Edinburgh: Earth Sciences* 86:247-256.

Scotese, C. R. and McKerrow, W. S. 1990." Revised world maps and introduction." In W. S. McKerrow and C. R. Scotese, ed., *Palaeozoic palaeogeography and biogeography.* pp. 1-21. London: Geological Society Memoir.

Sengör, A. M. C., Cin, A., Rowley, D. B. and Nie, S. 1991. Magmatic evolution of the Tethysides: a guide to reconstruction of collage history. *Palaeogeography, Palaeoclimatology, Palaeoecology* 87:411-440.

Sengör, A. M. C., Cin, A., Rowley, D. B. and S-Y., N. 1993. Space-time patterns of magmatism along the Tethysides: a preliminary study. *Journal of Geology* 101:51-84.

Shah, S.K. 1971. Palaeoecological studies of the Cambro-Ordovician Formation of Baramulla District, Kashmir. The University Review of the Jammu University. 1971 volume: 1-17.

Shah, S. K. 1982. Cambrian stratigraphy of Kashmir and its boundary problems. *Precambrian Research* 17:87-98.

Shah, S. K. 1993. Cambrian biofacies and faunal provinces of Himalaya. *Journal of the Palaeontological Society of India* 38:37-42.

Shah, S.K. and Raina, A.K. 1989. Significance of *Hundwarella* in the provincial setting of Himalayan Cambrian. *Proceedings of the 12th Indian colloquium on micropalaeontology and stratigraphy*: 203-205.

Shiraishi, K., Ellis, D.J., Hiroi, Y., Fanning, C.M., Motoyoshi, Y., and Kagami, H., 1997, Cambrian orogenic belt in East Antarctica and Sri Lanka: Implications for Gondwana assembly: Journal of Geology, v. 102, p. 47-65.

Speyer, S. E. and Brett, C. E. 1986. Trilobite taphonomy and Middle Devonian taphofacies. *Palaios* 1:312-327.

Stern, R. J. 1994. Arc assembly and continental collision in the Neoproterozoic East African orogen: Implications for the consolidation of Gondwanaland. Annual Reviews of Earth and Planetary Sciences 22: 319-351.

Stutz, E. and Steck, A. 1986. La terminaison occidentale du Cristallin du Tso Morari (Haut-Himalaya; Ladakh méridional, Inde): Subdivision et tectonique de nappe. *Ecologae geolo Helv* 79:253-269.

Suwa, K., Tokieda, K., and Hoshino, M., 1994, Paleomagnetic and petrological reconstruction of the Seychelles: Precambrian Research, v. 69, p. p. 281-293.

Taylor, M. E. 1977." Late Cambrian of western North America: trilobite biofacies, environmental significance, and biostratigraphic implications." In E. G. Kauffman and J. E. Hazel, ed., *Concepts and Methods of Biostratigraphy.* pp. 397-425. Stroudsburg, Pennsylvania: Dowden, Hutchinson and Ross, Inc.

Trompette, R. 1994. Geology of Western Gondwanaland (2000-500Ma). A.A. Balkema, Rotterdam. 350 pp.

Tyler, I.M. and Thorne, A.M., 1990, The northern margin of the Capricorn Orogen, Western Australia—an example of an Early Proterozoic collision zone: Journal of Structural Geology, v. 12, p. 685-701.

Unnikrishan-Warrier, C., Santosh, M., and Yoshida, M., 1995, First report of Pan-African Sm-Nd and Rb-Sr mineral isochron ages from regional charnockites of southern India: Geological Journal, p. 253-260.

Valdiya, K. S. 1993. Evidence for pan African-Cadomian tectonic upheavals in Himalaya. *Journal of the Palaeontological Society of India* 38:51-62.

Valdiya, K. S. 1995. Proterozoic sedimentation and pan-African geodynamic development in the Himalaya. *Precambrian Research* 74:35-55.

Wadia, D., N. 1934. The Cambrian-Trias sequence of north-western Kashmir (parts of Muzaffarabad and Barmula districts). *Records of the Geological Survey of India* 67:121-176.

Wadia, D. N. 1975. *The Geology of India.* New Delhi: Tata McGraw-Hill, 508p.

Wakhaloo, S. N. and Shah, S. K. 1965. Cambrian fauna of Kashmir with special reference to palaeogeography. *Current Science* 34:377-378.

Weil, A.B., Van der Voo, R., Mac Niocaill, C., and Meert, J.G., 1998, The Proterozoic supercontinent Rodinia: paleomagnetically derived reconstructions for 1100 to 800 Ma: Earth and Planetary Science Letters, v. 154, p. 13-24.

Whittington, H. B. 1986. Late middle Cambrian trilobites from Zanskar, Ladakh, northern India. Rivista Italiana di Paleontologia e Stratigrafia, v. 92: 171-188.

Wilde, S.A. and Murphy, D.M.K., 1990, The nature and origin of Late Proterozoic high-grade gneisses of the Leeuwin Block, Western Australia: Precambrian Research, v. 47, p. 251-270.

Windley, B.F., Razafiniparany, A., Razakamanana, T., and Ackermand, D., 1994, Tectonic framework of the Precambrian of Madagascar and its Gondwana connections: a review and reappraisal: Geologische Rundschau, v. 83, p. 642-659.

Yang, J.-l. and Tong, J.-n. 1993. Early Cambrian paleobiogeography and revision of positions of paleocontinents. *Stratigraphy and Paleontology of China* 2:223-234.

Yin, J. 1997. Stratigraphic geology of gondwana facies of Qinghai-Xiang (Tibet) plateau and adjacent areas. Geological Publishing House, Beijing. 206 pp.

Zhang, W. T. 1988. The Cambrian System in Eastern Asia, correlation chart and explanatory notes. International Union of Geological Sciences, 1-81 pp.

Zhang, W.-T., Lu, Y.-H., Chu, C.-L., Qian, Y.-Y., Lin, H.-J., Zhou, Z.-Y., Zhang, S.-G. and Yuan, J.-L. 1980. Cambrian trilobite faunas of southwestern China. Palaeontologia Sinica New Series B, 16. 497pp.

Zhang, W.T and Jell, P.A. 1987. Cambrian trilobites of north China. Science Press, Beijing. 459p.