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THE ORIGIN OF ALLOCHTHONOUS TERRANES: Perspectives on the Growth and Shaping of Continents[1]

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INTRODUCTION

In recent years new theories of continental growth have focused on the idea that the crust of the North American continent has grown through the accretion of discrete allochthonous fragments of oceanic and continental material at active margins. Though the processes by which materials are added to continental margins are still poorly understood, we can at least identify the distinct accreted blocks that compose the new margins. This identification and characterization is a major step in understanding the growth and shaping of continents.

The early division of continents into cratonal, miogeosynclinal, and eugeosynclinal areas offered a framework for theories of continental growth by peripheral accretion. Various forms of growth through collision of continental blocks and subduction-related accretion, volcanism, and tectonism (e.g. Dewey & Bird 1970) were proposed in later plate-tectonics models. More detailed work revealed complexities in active margins that could not be explained by assuming that the present spatial relations of tectonic domains within the margins imply original genetic and geographic relations. A growing body of geological and geophysical evidence demonstrates that large translational and rotational displacements have occurred within and between tectonic provinces of the eugeosynclinal belt. A natural outgrowth of plate-tectonics theories—the concept of terrane analysis—recognizes that the diverse fragments of vastly differing geologic histories cannot be assumed to have genetic relationships in time and space and

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DOESN'T PUT A CONSTRAINT ON OUR THINKING therefore are "suspect." These fragments are termed *suspect tectonostratigraphic terranes* (Figure 1).

The terrane concept, as now applied to the North American Cordillera, originated in the Klamath Mountains of northern California as a direct outgrowth of the investigations of W. P. Irwin (1960). He first subdivided the Klamaths into four arcuate belts, each representing a unique package of rocks characterized by particular ages and lithic assemblages. This fourfold subdivision was later modified (Irwin 1972) when he subdivided one belt into three "subbelts," which he termed "terranes." The term "terrane," as used by Irwin (1972, p. C103), "refers to an association of geologic features, such as stratigraphic formations, intrusive rocks, mineral deposits, and tectonic history, some or all of which lend a distinguishing character to a particular tract of rocks and which differ from those of an adjacent terrane." In the same year, the terrane concept was applied to rocks in southern Alaska by Berg et al (1972), who recognized several terranes as discrete, fault-bounded tectonic units. The Alaskan terranes were later described in more detail by Berg et al (1978) in the first terrane map prepared for the northern part of the North American Cordillera. The definition used on this map emphasized the fault-bounded nature of terranes and also introduced the concept of composite terranes formed by preaccretionary amalgamation (see below). These pioneering efforts have now become standardized, as explained in Jones et al (1983) and below, and as portrayed on more recent terrane maps of the Cordillera (Jones et al 1981, Blake et al 1982a, Campa & Coney 1983, Silberling et al 1983).

One of the earliest indications that terranes might be far travelled came from work by Monger & Ross (1971), who recognized tectonically displaced, fault-bounded faunal provinces in the Canadian Cordillera that had more affinity to the Tethyan realm than to North American realms. Many later workers have identified other displaced terranes of oceanic

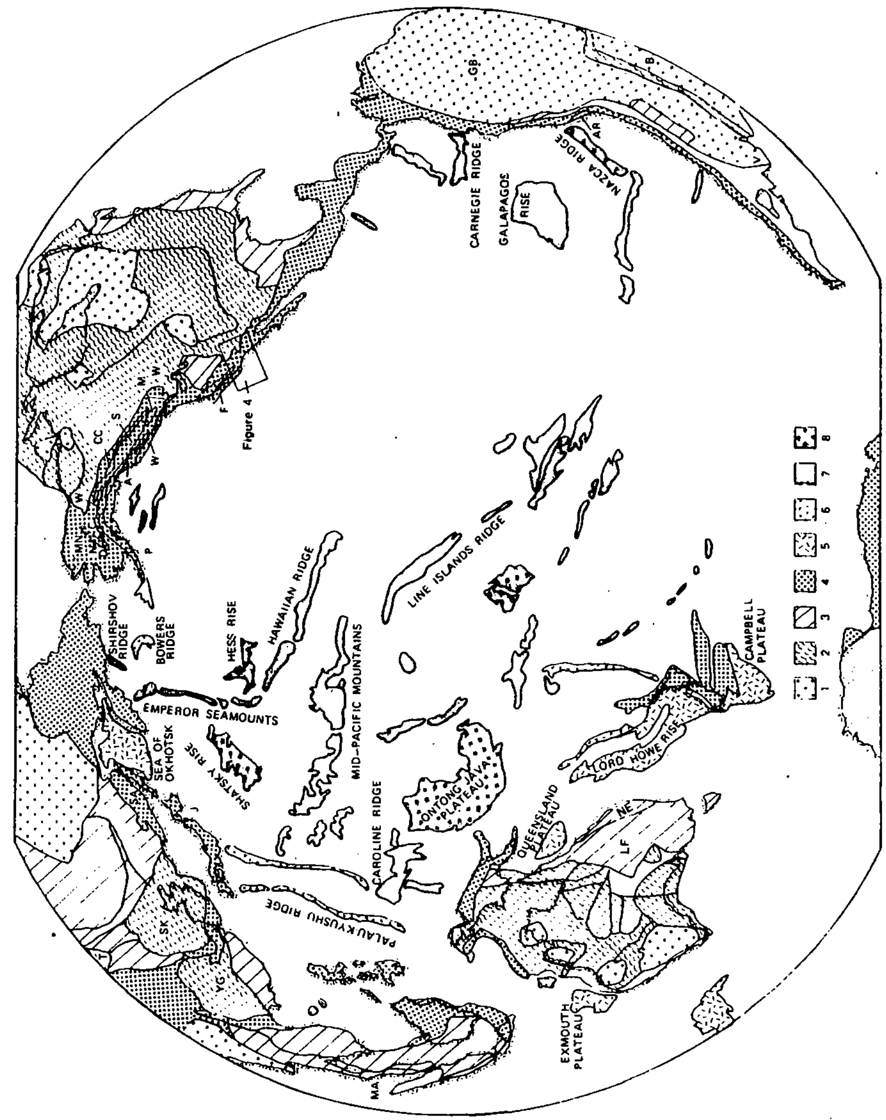

Figure 1 Highly generalized map of circum-Pacific tectonostratigraphic terranes. Explanation of symbols: (1) Archean cratonal blocks; (2) Proterozoic orogenic belts and cratonal blocks consolidated during the Proterozoic; (3) Paleozoic orogenic belts, composed of terranes accreted during the Paleozoic; (4) Mesozoic-Cenozoic orogenic belts and accreted terranes; (5) continental fragments; (6) remnant volcanic arcs; (7) oceanic islands and seamounts, including hotspot tracks; (8) mixed origin—oceanic with anomalously thick, continental-like structure. Abbreviations of terranes and localities mentioned in text (clockwise from Alaska): P = Peninsular; D = Dillinger; N = Nixon Fork; C = Chulitna; MN = Manley; W = Wrangellia; A = Alexander; CC = Cache Creek; S = Stikine; M = Methow; F = Franciscan; GB = Guyana and Brazilian shields; AR = Arequipa; B = eastern Brazilian shield; V = Sierra de la Ventana; NE = New England fold belt; LF = Lachlan fold belt; MA = Malaysia; YG = Yangtze; SK = Sino-Korea; T = Tarim; J = Japan; SA = Sikhote Alin.

rocks containing exotic faunal communities throughout the Cordillera of western North America (Monger 1977, Nestel 1980, Nichols & Silberling 1979, Tozer 1982). Early paleomagnetic work seemed to support the idea that several terranes of the Cordillera were exotic (e.g. Irving & Yole 1972, Packer & Stone 1972, 1974), but the interpretations of the data were not widely accepted until 1977, when combined geophysical, stratigraphic, and paleobiogeographic data gave strong support for thousands of kilometers of displacement of the Wrangellia terrane of Alaska (Hillhouse 1977, Jones et al 1977). Since that time, increasing numbers of paleomagnetic studies have provided evidence for large amounts of translation and rotation for terranes throughout western North America (e.g. Beck & Cox 1979, Alvarez et al 1980, Champion et al 1980, and many others).

It is now becoming apparent that terrane accretion is not limited to North America, but has occurred since at least Proterozoic time throughout the circum-Pacific region. This review briefly summarizes the principles of terrane analysis as discussed in Coney et al (1980) and Jones et al (1983) and presents an application of terrane analysis for the circum-Pacific region. Additional background material for terranes of western North America can be found in these two articles.

TERRANE ANALYSIS

Terrane Definition

A tectonostratigraphic terrane is a fault-bounded geologic entity of regional extent that is characterized by a geologic history different from that of neighboring terranes (Coney et al 1980, Jones et al 1983). Terranes can be classified as stratigraphic, metamorphic, disrupted, or composite. Stratigraphic terranes are composed of coherent sedimentary and igneous sequences. They may include a complicated array of lithofacies reflecting one or more depositional environments, e.g. continental, oceanic, and/or island-arc basins. Metamorphic terranes are represented by fault-bounded blocks that have a regional penetrative metamorphic fabric that obscures and is more distinctive than original lithotypes. Disrupted terranes are characterized by blocks of heterogeneous lithology and age that are set in a matrix of foliated graywacke or serpentinite. Composite terranes consist of two or more terranes that amalgamated prior to their accretion to a continental margin.

TERRANE BOUNDARIES Terranes are by definition fault-bounded, implying that there is at least some movement between adjacent terranes. Commonly the boundaries are suture zones or cryptic faults that are inferred because of the juxtaposition of differing lithologies. Ophiolite belts and blueschist are

good evidence for the location of a subduction zone and closure of an ocean basin. However, a terrane boundary need not be marked by ophiolite or ophiolitic mélange; in fact, most terrane boundaries are not, indicating that they probably represent (*a*) accretion via strike-slip or overprint by later consolidation and dispersion processes (Figure 2; see below); (*b*) closure of only relatively small marginal basins rather than entire oceans; and/or (*c*) most of the oceanic crust is either subducted or not exposed due to the structural complexities intrinsic to accreting margins. Worldwide, ocean basins have been destroyed several times during the Phanerozoic, yet ophiolite is only rarely exposed in continental masses. This fact, combined with the observation that terranes are commonly detached from their substrata, suggests that even the closure of an entire ocean basin leaves scant evidence of oceanic crust. Some terranes appear intact with their basement rocks [e.g. Wrangellia on an arc basement and Chulitna on an ophiolite basement (Figure 1; Jones et al 1977, 1980)], but many more are flakes of sedimentary and volcanic strata that occur either as fault-bounded nappes or as coherent blocks embedded in a matrix of foliated graywacke. With rare exceptions, terranes are not equivalent to microplates, as the latter term implies discrete lithospheric blocks.

Plate Tectonics and Terrane Analysis

The fact that petrotectonic assemblages, such as volcanic arcs, forearc basins, and subduction complexes, may be extensive along a continental margin does not in itself prove that these assemblages formed in their present position. Detailed examination of tectonic and stratigraphic relations and paleomagnetic and paleobiogeographic indicators, as has been done for terranes throughout the western North American Cordillera, has demonstrated that parts of these assemblages may be allochthonous. Therefore, one must be cautious in applying plate tectonics models that assume that tectonic domains that are presently spatially juxtaposed are

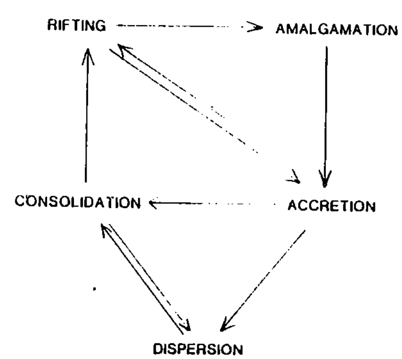

Figure 2 Diagram showing how the various kinematic states of terranes are affected by the complex interrelationship of movement processes, resulting in either the breakup or the welding together of terranes and continental masses.

genetically related. Separation of fact from interpretation is essential here; one does not define a terrane because it fits or does not fit a model but because of its distinctive stratigraphy and geologic history. The genetic linkages and paleogeographic history must be determined by rigorous analysis of geologic and geophysical data. Where tectonostratigraphic sequences are not unequivocally correlative, we take a conservative stance and treat them as separate terranes. This taxonomic splitting permits a variety of palinspastic interpretations and reconstructions once pertinent data are gathered. The skepticism about genetic relationships that is inherent in terrane analysis allows for more objective collection and interpretation of data; as facies relationships must be proven before they serve as the basis for a model.

Unfortunately, the inappropriate application of many popular models to the specifics of orogenic belts has led to error and confusion about these highly mobile, diverse regions. In several ancient orogenes, the typical model of arc, forearc, and subduction complex belts arranged in parallel along an active margin fails when examined in detail. For example, in New Zealand, the tectonic belts from west to east consist of (*a*) middle to late Paleozoic sialic crust and continental strata of the Tuhua terrane, (*b*) Permian to Mesozoic ensimatic island-arc rocks of the Hokonui terrane, (*c*) Paleozoic and Mesozoic(?) volcaniclastic graywacke of the Caples terrane, and (*d*) Permian to Cretaceous quartzo-feldspathic graywacke of the Torlesse terrane (Figure 3; Howell 1980). The continentally derived strata of the Torlesse terrane are spatially separated from their expected source area (the Tuhua terrane) by a coeval, entirely ensimatic assemblage. Similarly, in California, Jurassic quartzo-feldspathic strata of the Franciscan assemblage are separated from their expected continental source to the east by coeval ensimatic igneous and volcaniclastic rocks at the base of the Great Valley sequence (Figure 4; Blake & Jones 1981).

Because of the dynamics of environments within active continental margins and because a given region may pass from one plate tectonic regime to another in both time and space, a plethora of lithofacies may occur within any given terrane. The key to terrane analysis is to distinguish between diverse lithologic packages that are linked in time and space and lithofacies units that are genetically unrelated and thereby reflect juxtapositioning of two or more allochthonous terranes.

Tectonostratigraphic Analysis of Terranes

The stratigraphy of a terrane is probably the most important key to unraveling its origin; however, this stratigraphy commonly reflects a diverse geologic history. This situation is largely a result of both the tectonic and eustatic dynamics along continental margins and on islands and

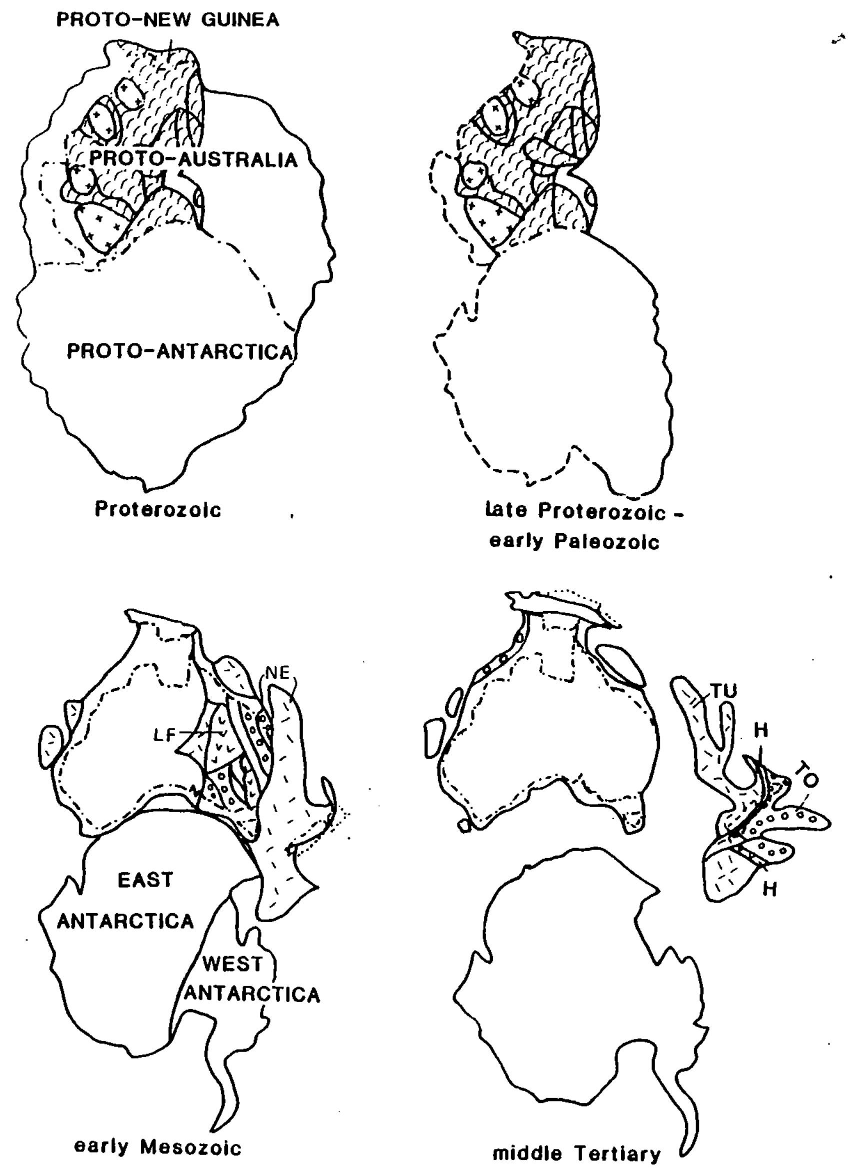

Figure 3 Schematic representation of accretion and dispersion events in Antarctica, Australia, and New Zealand. NE = New England fold belt; LF = Lachlan fold belt; TU = Tuhua terrane; TO = Torlesse terrane; H = Hokonui terrane. Open circles indicate terrane composed of continental margin strata; other symbols as in Figure 1.

seamounts within ocean basins. In the context of plate tectonics we view stratigraphic sequences in a three-part classification: (*a*) passive or trailing margin sequences, (*b*) consuming or leading margin sequences, and (*c*) transform margin sequences.

Passive margin facies are preserved in allochthonous continental fragments of the size of the Australia, Yangtze, or Sino-Korea terranes; smaller fragments of the Cordilleran collage of western North America, such as the Nixon Fork and Dillinger terranes, may also exhibit a passive-margin history (Figure 1). Nonetheless, within this cordillera, many terranes show characteristics of rifting and subsidence. For example, the Triassic portion of the Chulitna terrane of Alaska is composed of basalt and

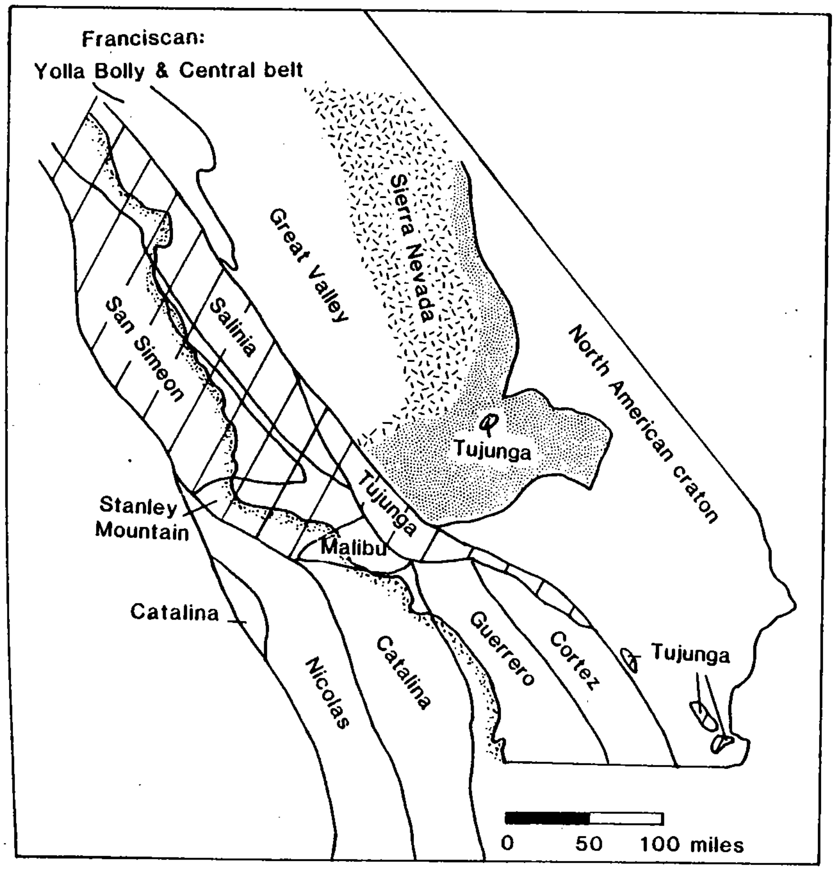

Figure 4 Terranes of southern California. Diagonal lines indicate extent of the Santa Lucia-Orocopia allochthon; dashes indicate Mesozoic batholithic rocks of the Sierra Nevada that obscure older terrane boundaries; stipple indicates Paleozoic "eugeosynclinal" sequences and Mesozoic plutonic rocks, undifferentiated.

redbeds reflecting a possible rifting event; these beds are overlain by deep-water and sandstone and shale. The Nikolai Greenstone of Wrangellia may be rift related, and the overlying carbonate and clastic rocks suggest later subsidence (Jones et al 1980).

Consuming margins are commonly characterized by volcaniclastic basinal facies of either forearc or backarc settings. These strata lie on igneous basement near the axis of the volcanic arc, but they also lie on oceanic crust in more distal forearc or backarc directions. Disrupted strata of inferred trench and trench-slope environments may lie structurally alongside and/or below the forearc beds. This tripartite division of volcanic arc, coherent forearc, and disrupted trench strata (accretionary or mélange wedge) reflects the popular plate-tectonics model of a subduction setting. Seismic reflection profiling across modern subduction zones has indicated that this model is in many instances too facile. For example, portions of the Middle America Trench have no mélange wedge (von Huene et al 1980), and accretionary prism rocks of the Aleutian margin compose only a small volume, hardly representative of the 60 m.y. of subduction beneath this arc (Scholl & Vallier 1983).

Terranes that are composed all or in part by consuming margin facies include the Hokonui terrane of New Zealand (Figure 3), the Stanley Mountain terrane of California (Figure 4), and the basal portion of Wrangellia; in these instances it is not possible to unequivocally link the submarine fan facies of the forearc to any graywacke sequences of a subduction complex, and all or part of the arc source terrane is also missing. Terranes such as those that compose the Franciscan assemblage of California or the Manley terrane (Figure 1) and other flysch sequences of Alaska [such as the Gravina-Nutzotin assemblage (Berg et al 1972)] are considered by some workers to be arc-related (either forearc or trench deposits). Alternatively, we believe that some of these thick sequences of structurally complicated graywacke represent a variety of deep-marine depositional environments; nonetheless, their postdepositional tectonic histories may be similar in that they all represent the effects of basin closure and terrane amalgamation and accretion. The Molucca Sea is a modern example of this type of setting (Silver & Smith 1983).

Transform margins are typified by wrench tectonics (transpressional and transtensional stresses) that generally result in borderland settings. Lithofacies reflecting nonmarine to deep-marine environments grade rapidly one into the other, both vertically and horizontally. The Upper Cretaceous clastic facies of the Salinia and Tujunga terranes of California reflect a sliding margin history. The "porpoising" (alternate uplift and subsidence in time and space; Crowell & Sylvester 1979) of crustal blocks within wrench-tectonics settings leaves a special sedimentologic imprint

(Howell et al 1980): basins fill rapidly, often with restricted water circulation that promotes accumulation of organic-rich sediments. If the transtensional phase passes into a transpressional one (Harland 1971), strata of the basins are "squeezed" out, and in the process large petroleum traps can be created such as those that developed in Neogene strata along the San Andreas fault system. The transcurrent-faulting effects of wrench tectonics also are evident in the slicing and slivering of terranes into smaller tectonostratigraphic units (dispersion). The collage aspect of much of the western North American Cordillera is in part a result of the northwestward transcurrent dispersion throughout the Cordilleran margin.

Terrane Processes

CONTINENTAL CONSTRUCTION: AMALGAMATION AND ACCRETION Several different processes may affect a terrane during transport from its origin to its place of accretion and consolidation onto a continent (Figure 2). Amalgamation occurs when two terranes collide prior to their accretion onto a continental margin. For example, the Santa Lucia-Orocopia allochthon is composed of the Stanley Mountain, San Simeon, Salinia, and Tujunga terranes (Figure 4); the details of the timing of the amalgamation and accretion of these terranes are discussed below.

Accretion most profoundly affects the tectonic history of a terrane, and in some cases it may severely obscure the evidence of the original geologic history. Thrust faulting appears to play an important role in the accretion process, and many terranes occur as thick stacked thrust packages, but in many cases thrust faults are later reactivated and cut by high-angle faults. Commonly, mélange formation and blueschist metamorphism accompany accretion of blocks in subduction zone settings. For example, in northern California, the metamorphism of the Yolla Bolly terrane of the Franciscan assemblage was possibly associated with a 90 m.y.-old accretion event, and the older blueschist metamorphism of the Franciscan Pickett Peak terrane seemingly reflects an earlier but discrete accretionary episode. Later accretion of seamounts within the Franciscan assemblage resulted in formation of some of the Central belt melange (Blake et al 1982b).

In some cases high-temperature metamorphism and plutonism as well as local anatexis have been documented (Hudson et al 1978, Hudson & Plafker 1982, Monger et al 1982). For example, in the Coast Plutonic Complex of British Columbia, magmatism and metamorphism are thought to have occurred in response to accretion of the Peninsular-Wrangellia-Alexander composite terrane (Monger et al 1982). Ophiolite obduction may occur with the accretion of some terranes. The sedimentary record itself may indicate accretion, including phenomena such as deposition of molasse in the foreland, development of unconformities due to uplift and erosion,

changes in sedimentary polarity (the direction in which sediment is shed from a source area), and development of provenancial links (see below) between terranes or between terranes and a continent.

The timing of amalgamation and accretion episodes can be established through the analysis of one or more of the following: (*a*) plutons or batholiths may stitch together two or more terranes, thereby indicating a minimum age of amalgamation [e.g. 60 m.y.-old plutons stitch terranes between the Denali fault and the Border Ranges fault in Alaska (Reed & Lanphere 1969, Hudson 1979), and the 125–90 m.y.-old Peninsular Ranges batholith of southern California stitches the Cortez, Guerrero, and Malibu terranes (Figure 4; Silver et al 1979)]; (*b*) sedimentary basins may overlap two terranes; and (*c*) debris from one terrane may be deposited on another (provenancial linkage). An example of an overlap assemblage is the late Cretaceous Gravina-Nutzotin belt of southern Alaska, which links the Wrangellia and Alexander terranes; an example of provenancial linkage is provided by the Middle to Upper Jurassic strata of the Bowser Basin of British Columbia, which are deposited on the Stikine terrane and contain debris from the Cache Creek terrane (Eisbacher 1974, Monger et al 1982). Unless ties to the continent or continental margin can be demonstrated, the linkages may only indicate intermediate amalgamation episodes rather than accretion.

Postaccretionary consolidation processes also play an important role in the evolution of the terrane collage. This tightening of a loose package of terranes in the North American Cordillera has been interpreted as a major cause of the Laramide orogeny and probably has resulted in deformation in the Cordilleran foreland (Coney 1981).

CONTINENTAL DESTRUCTION AND MODIFICATION: RIFTING AND DISPERSION Whereas accretion adds to a continental margin, rifting and dispersion attenuate terrane boundaries and erode the margin. Pieces of continental crust may be rifted away from a craton and sent toward a consuming margin. Numerous fragments of this type are found around the margins of Australia, e.g. the Queensland Plateau, the Lord Howe Rise, and the Exmouth Plateau (Figure 1). Dispersion is the process by which previously accreted or amalgamated terranes are faulted into smaller pieces and scattered along the margin. Dispersion may occur by rifting or strike-slip faulting and may operate at the same time as accretionary processes (e.g. during oblique subduction). In western North America, dispersion is presently occurring along right-slip faults such as the San Andreas, Fairweather, Denali, Fraser River, and Tintina fault systems. In Japan, left-slip faults such as the Median tectonic line and, in New Zealand, the right-slip Alpine fault are also slivering and dispersing terranes. Dispersion creates disjunct terranes consisting of stratigraphically correlative but spatially distinct fragments. Wrangellia is a good example of a disjunct terrane; it occurs as several correlative fault-bounded bodies from Oregon through British Columbia to Alaska over a latitudinal spread of nearly 24°. However, based on paleomagnetic data, these bodies originated within less than 7° of each other (Hillhouse & Gromme 1983). Dispersive processes may destroy original accretionary structures and produce wrench-fault basins that cover terrane basement rocks [e.g. the Methow Trough of British Columbia (Figure 1) and numerous basins in the southern California borderland.

Terrane Displacements

Displacement for some terranes has been estimated at several thousand kilometers; for others, the movement is clearly much less. Although much attention has been directed toward "exotic" terranes, terrane *recognition* is not dependent on establishing a minimum amount of relative displacement. The important criterion is that movement be sufficient to completely disrupt original facies relations and thus to render uncertain original genetic relations.

Terrane displacements can be measured in several ways. Traditional geologic methods of measuring fault displacement (e.g. measuring offset of shorelines, dike swarms, fold hinges and other linear elements, or matching offset distinctive rock types or stratigraphic sequences) can determine offsets of generally less than 500 km with relatively good precision. Matching offset biogeographic provinces or climatically controlled lithologies such as redbeds and sabkhas offers less precision but can determine offsets greater than 500 km, and paleomagnetic studies can document latitudinal offsets of greater than 300 km.

Recent plate motion studies have attempted to determine travel paths for terranes whose geologic history and timing of accretion are relatively well known (e.g. Engebretson & Cox 1982, Engebretson 1982). By assuming that a certain terrane rides on one or more plates, such as the Pacific, Farallon, or Kula, during its travel history, it is possible to use one or a combination of plate trajectories to track the terrane from its origin to its accretion at a part of the continent. Reconstructions of oceanic plate motions older than ca. 150 m.y. are uncertain, and are not possible for those older than ca. 180 m.y. owing to the subduction of all pre-early Jurassic oceanic crust. While plate motion trajectories can give a better idea of large amounts of offset, rarely are the geologic history, the timing and location of accretion, or the plate motions sufficiently well known to make such travel histories unequivocal. With more work, plate motion studies may become a feasible way of determining displacement histories for terranes accreted since the

Jurassic, although the complete subduction of some plates makes such reconstructions highly subjective. The plate kinematics must be constrained by the geologic data, e.g. the provenance of strata, within a terrane. For example, Wrangellia preserves an entirely oceanic history in the early Mesozoic, allowing for a trans-Pacific migration. In contrast, upper Mesozoic and Cenozoic sedimentary rocks of Salinia indicate proximity to a continental margin throughout its migratory path.

Terrane analysis involves a combination of as many of the above displacement measurements as possible. If two or more methods are in agreement as to the origin and displacement of a terrane, much more confidence can be placed in paleogeographic reconstructions. An outstanding example of the concordance of geologic, paleontologic, and geophysical data is afforded by Wrangellia. Here, paleomagnetic data indicate equatorial paleolatitudes during the Triassic (Hillhouse 1977), and Triassic carbonate rocks are characteristic of tropical supratidal conditions (Armstrong & MacKevett 1983) and contain high-diversity, endemic Molluscan faunas of low-latitude aspect (Stanley 1982, Tozer 1982, Newton 1983, Silberling & Jones 1983).

Oceanic Plateaus and Terrane Analysis

Oceanic plateaus are anomalously high parts of the sea floor that at present are not parts of continents, active volcanic arcs, or spreading ridges. Plateaus comprise fragments of continents, oceanic islands and seamounts, hotspot tracks, remnant arcs, and other anomalously thick volcanic piles (Figure 1; Ben-Avraham et al 1981, Nur & Ben-Avraham 1982). Examples of continental fragments include the Campbell Plateau and the Lord Howe Rise. Oceanic islands and seamounts, such as the Mid-Pacific Mountains, the Caroline Ridge, and the Galapagos Rise, are abundant throughout the Pacific. Some of these are hotspot tracks, such as the Hawaiian and Emperor seamount chains and the Line Islands Ridge, or remnant arcs, such as the Bowers and Palau-Kyushu ridges. Large plateaus, such as Ontong-Java, Hess Rise, and Shatsky Rise, seem to be characterized by oceanic basalt and sedimentary rocks in their upper portions, but seismic refraction data indicate that they have a continental-like structure at depth (Vallier et al 1981, Nur & Ben-Avraham 1982).

These anomalously thick and low-density bodies are more likely to be obducted than subducted when they encounter a convergent margin. Oceanic plateaus that have collided with fossil and modern subduction zones include the Sea of Okhotsk Plateau, Shirshov Ridge, Nazca Ridge, and Carnegie Ridge (Figure 1). The effects of these collisions include the creation of a volcanic gap and anomalous seismic activity along the subducting margin. In addition, some pieces may be obducted onto the island arc or the continent, as has been proposed for the Ontong-Java Plateau (Coleman & Kroenke 1981) and the Nazca Ridge (Nur & Ben-Avraham 1981).

The presence of similar lithotectonic elements in oceanic plateaus and as onshore accreted terranes suggests that many terranes originate as oceanic plateaus. Nur & Ben-Avraham (1977) have proposed a lost continent of Pacifica as the origin for several terranes of circum-Pacific orogenes, but there is little evidence to support the idea that any of these diverse fragments had a common origin. More likely they began as numerous arcs, seamounts, and continental fragments similar to those present in the southwest Pacific and Indonesian regions today.

AMALGAMATION, ACCRETION, AND DISPERSION OF CIRCUM-PACIFIC TERRANES

The Growth and Shaping of Continents

From the perspective of tectonostratigraphic terrane analysis, the shape of continents results from both terrane accretion and dispersion. Just as the accretion of terranes results in continental growth or outbuilding, the dispersion of terranes, by either rifting or sliding, results in the diminution of continents. The continents of the circum-Pacific can be viewed in this context.

Only a few terranes in the North American Cordillera have well-documented displacement histories, although geologic evidence suggests exotic origins for many. Because the history of terranes in Alaska and British Columbia (Wrangellia, Alexander, Peninsular, Stikine, and Cache Creek) has been extensively discussed and reviewed (e.g. Jones et al 1977, 1981, 1983, Jones & Silberling 1979, Monger et al 1982, Saleeby 1983), this need not be repeated here. Instead, we present below an example of the amalgamation, accretion, and dispersion history of terranes in southern California. We also give some examples from the rest of the circum-Pacific, including Asia, Australia and New Zealand, and South America, although the characteristics of these terranes and their displacement histories are very poorly known; in fact, studies are only now in progress to identify and characterize these terranes (Jones et al 1982, Howell et al 1983, Howell et al, in preparation).

Proterozoic and Phanerozoic of North America

In North America, the Archean massifs that are surrounded by a variety of Proterozoic fold belts (Figure 1) suggest successive terrane accretions between 2 and 1 b.y. B.P. (Condie 1982, Hoffman et al 1982). The combined occurrences of upper Proterozoic tillites along the margin of the present

craton and upper Proterozoic rifting sequences outboard of these glacial deposits suggest that North America was the interior part of a much larger continental agglomeration ca. 800 m.y. ago. For most of the Paleozoic, the western Cordilleran and Ouachitan regions remained a passive or trailing margin while the Franklinian and Appalachian margins experienced episodic growth caused by terrane accretion (Williams & Hatcher 1982). By the late Paleozoic, the east and southeast margins of North America were again interior regions of a supercontinent; in the Mesozoic, rifting reshaped these areas. The northern margin was modified in the Paleozoic and in the late Mesozoic by major rifting events. In the Cordilleran region, beginning in the late Paleozoic and still active today, a protracted series of collision events combined with dispersive phenomena to distribute terrane slivers along the western margin of North America.

Southern California

In southern California, allochthonous terranes that were accreted during the Cenozoic are juxtaposed against autochthonous upper Proterozoic and Paleozoic platform strata. A host of pre-Cenozoic dispersive events have been inferred, including left-slip of 600 km along the Mojave-Sonora megashear during the Middle Jurassic (Silver & Anderson 1974). In this region, Proterozoic and Phanerozoic terranes currently outboard of the truncated margin of North America represent a wide variety of different geologic environments.

The Santa Lucia-Orocopia allochthon comprises the San Simeon, Stanley Mountain, Salinia, and Tujunga terranes that amalgamated by the late Cretaceous, prior to their accretion approximately 55 m.y. ago (Figure 4; Vedder et al 1983). Some of the terranes composing Santa Lucia-Orocopia are themselves composite; for example, the Tujunga terrane is composed of at least three Precambrian terranes that represent different crustal levels of basement rocks and a variety of sedimentary environments (Powell 1982). While these rocks could represent different crustal levels of the same block, discrepancies in age and lithofacies relations are sufficient to render the original paleogeographic relations uncertain; hence, they are called separate suspect terranes until genetic linkage can be proven. The Salinia terrane is a middle Cretaceous continental volcanic arc; Ross (1977) has distinguished several subterranes of differing lithologies in the prearc basement. The Stanley Mountain terrane consists of Middle Jurassic ophiolite overlain by pelagic and forearc submarine fan sequences, while the San Simeon terrane is a disrupted terrane composed of Cretaceous chert, graywacke, and greenstone—the well-known Franciscan assemblage.

These terranes were once thought to conform to the typical arc-forearc-subduction complex model (e.g. Dickinson 1970) because they appear to fit into three such belts that stretch along the California continental margin. Much new data argue against this model. Although ophiolite complexes similar in age to the Stanley Mountain terrane occur at the base of the Great Valley sequence (Hopson et al 1981), some of these complexes are sufficiently different in terms of their environments of formation that they are best treated as separate terranes (e.g. Blake et al 1982a). The Franciscan Complex is also composed of numerous discrete terranes that differ in age, metamorphic grade, and tectonic history. Some parts of the Franciscan appear to have originated in the Southern Hemisphere (Alvarez et al 1980), whereas others may be from equatorial or northerly latitudes. The arc-forearc-trench belt is repeated in central and southern California; the eastern belt comprises the Sierra Nevada batholith, the Great Valley sequence, and the Franciscan assemblage, while the western belt is made up of the Salinia, Stanley Mountain, and San Simeon terranes (Figure 4).

There are numerous arguments for and against the role of the San Andreas fault in producing this doubling up of the belts (see Champion et al 1983, Dickinson 1983). For example, strata overlying ophiolite in the Stanley Mountain terrane are extremely similar to coeval strata of the Great Valley sequence (Dickinson 1983). However, paleomagnetic data show that the western belt of terranes originated at far more southerly latitudes than can be attributed to right-slip motion on the San Andreas fault (Champion et al 1980, 1983, McWilliams & Howell 1982). McWilliams & Howell (1982) have documented the displacement and amalgamation history of Stanley Mountain and Salinia; their data suggest that Stanley Mountain was in low northerly or southerly latitudes (14°) in the late Jurassic, then moved to 6° north or south by the early Cretaceous. Salinia and Tujunga were linked by middle to late Cretaceous time, as indicated by pluton stitching and overlap sequences. Stanley Mountain and Salinia were amalgamated by the late Cretaceous; provenancial linkage and overlap assemblages of this age are supported by the paleomagnetic data, which indicate both terranes were at ca. 21°N at this time and then moved together to 25°N through the Paleocene. Displacement for Salinia since Cretaceous time is estimated to be at least 2500 km (Champion et al 1980, 1983). Eocene strata are the oldest to overlap all the terranes of the Santa Lucia-Orocopia allochthon as well as the continental margin, indicating accretion had occurred by that time.

Several terranes of the southern California borderland also show significant northward displacement, but their movement and accretion history is much younger than that of Santa Lucia-Orocopia. Continental strata of the Cortez terrane, Upper Jurassic to Cretaceous island-arc rocks of the Guerrero terrane, and Jurassic metamorphosed arc rocks of the Malibu terrane are stitched together by 125–90 m.y.-old plutons of the

Peninsular Ranges batholith (Figure 4). By at least 90 m.y. ago, Jurassic ophiolite and Cretaceous turbidites of the Nicolas terrane were accreted to the Cortez-Guerrero-Malibu composite and overlapped by forearc basin and submarine fan strata. We are not aware of any stratigraphic sequences reflecting either provenancial linkage involving blueschist metamorphosed rocks of the Catalina terrane or overlap assemblages on this terrane that are older than Miocene. Thus, amalgamation of Catalina to the other terranes could not have occurred prior to this time. The first strata that overlap all the terranes of the borderland and the California margin are upper Miocene. The inference that these terranes were not accreted until late Miocene time is supported by paleomagnetic data, which indicate that Eocene rocks of the Nicolas terrane have been translated 19° northward, and that lower and middle Miocene rocks of the Nicolas and Malibu terranes may have been translated 10–15° northward and rotated as much as 110°, while Miocene rocks of the Stanley Mountain and Tujunga terranes show rotations but no translations (Kamerling & Luyendyk 1979, Champion et al 1981, Hornafius et al 1981).

Asia

Asia is composed of several large cratonal blocks separated by fold belts of various ages (e.g. Figures 1 and 5; Terman 1974, Chinese Academy of Geological Sciences 1975, 1976, 1979, Bally et al 1980). These fold belts formed during major orogenic events, and each is composed of many terranes of oceanic, volcanic arc, and continental affinities. Paleomagnetic data from rocks on several of the cratons indicate that they were widely separated during the Permian. While the Siberian craton was at ca. 57°N, the Omolon terrane (formerly considered part of a Kolyma microplate) lay at 33°N, Sikhote Alin at 34°N, Sino-Korea at 10°N, Yangtze at 2°N, Japan at 5°S (McElhinny et al 1981), and the Malay Peninsula at 15°N (McElhinny et al 1974). Because several of these microcontinents are probably composed of numerous terranes, the Permian Panthalassa Ocean was apparently filled with many isolated fragments, much like the modern southwest Pacific.

Many of the fold belts in Siberia and China are marked by ophiolite belts and blueschist, which provide good evidence for the occurrence and age of fossil subduction zones and ocean closures. Preliminary plate-tectonics reconstructions of China have been proposed by Li et al (1980) and Huang (1978), but much more detailed work is needed to date the ophiolites and blueschist and to discriminate between terranes within the fold belts, so that the characteristics and timing of accretion can be better documented.

On a broad scale, this region has undergone sequentially southward-stepping accretionary events that constructed a collage of terranes against the 1.4 m.y.-old Baikalian rifted margin of southern Siberia. This period of growth began with late Proterozoic accretion of oceanic and arc material in the Baikalides fold belt (Figure 5). Throughout the Paleozoic, accretion occurred in Mongolia and northern China as the Dzungaria-Kasakhstania block approached the Siberian margin. Accretion of this block may have

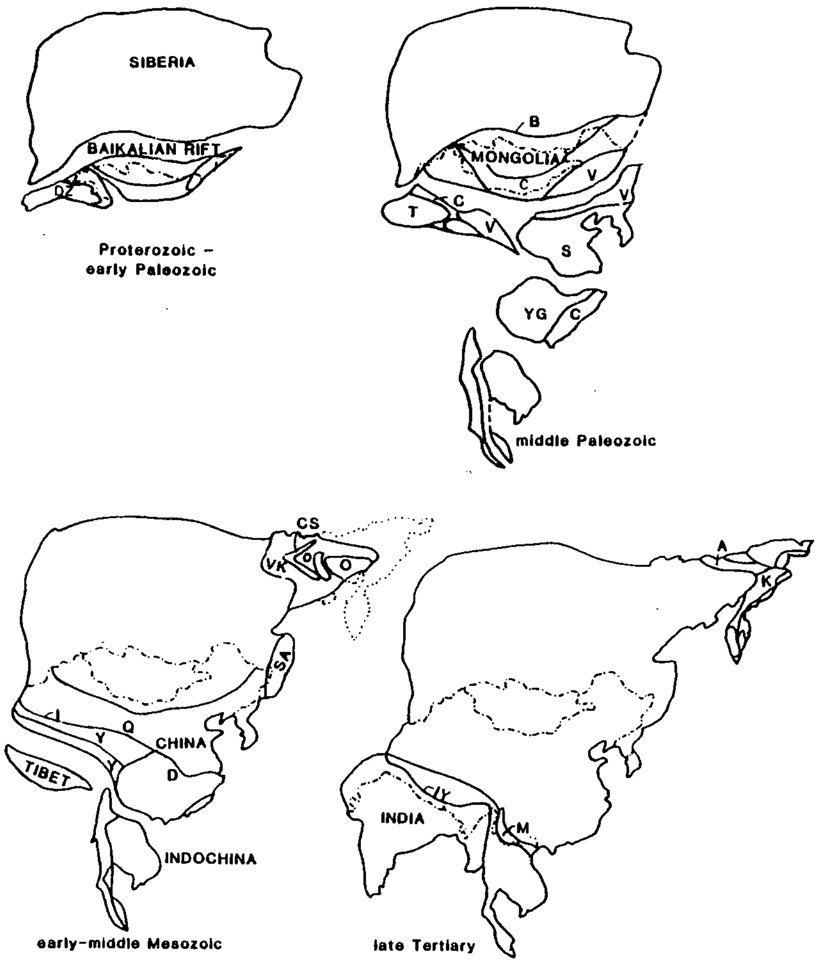

Figure 5 Schematic representation of accretionary evolution of Siberia and Asia. DZ = Dzungaria; C = Caledonian fold belts; B = Baikalian suture; V = Variscan fold belts; T = Tarim; S = Sino-Korea; YG = Yangtze; CS = Cherskiy terrane; VK = Verkhoyansk fold belt; O = Omolon terrane; SA = Sikhote Alin; I = Indosinides sutures; Q-D = Qilian-Dabie Shan suture; Y = Yenshanides fold belts; A = South Anyui; K = Koryak Highlands; M = Mekong fold belt; IY = Indus-Yaluzangbu suture.

produced the Caledonian (early Paleozoic) fold belts of this region. Collision of the Tarim block and the Sino-Korean block in latest Paleozoic was accompanied by accretion of several island arcs, oceanic terranes, and small continental fragments to both the northern and southern margin of these blocks, forming the Variscan fold belts (Figure 5).

During the Triassic, the paleogeography of China was vastly different from that of today. The southern margin of China appears to have been along what is now a major suture marked by several ophiolite belts and blueschist that passes through the Qilian Mountains (North Qilian-Dabie Shan belt, Figure 5). North of the ophiolite belts, Triassic deposits are continental facies; south of the suture are a variety of disparate marine environments (Wang et al 1981) whose boundaries appear to correlate with terrane boundaries. The Triassic to Jurassic Indosinian orogeny appears to have been marked by the collision of the Yangtze block with the continental collage to the north; this may have been coincident with or followed by the collision of Southeast Asia along a major suture marked by ophiolitic and island-arc terranes of the Mekong fold belt. The Mekong fold belt and some of the Indosinian fold belts also record Jurassic to Cretaceous (Yenshanian) accretionary events, which may indicate that collisions of Yangtze with Sino-Korea and of Indochina with the Yangtze block were not complete until Cretaceous time. The Indosinian and Yenshanian fold belts have been considered to fit into a typical backarc-arc-subduction complex model (e.g. Li et al 1980, E. Zhang, written communication, 1982). However, there appears to be more than one island-arc sequence; one or more continental fragments are apparently embedded in the "subduction complex"; and the ages and chemistry of oceanic crustal fragments differ, so that they may or may not represent genetically related backarc basin, arc, or trench basement materials. Thus we suspect that this region is a complex collage of accreted terranes whose paleogeographic relations need to be elucidated. The collision of India with Tibet in the Eocene was the culmination of numerous Jurassic through Cretaceous accretions of arc, ophiolitic, and continental fragments (including Tibet). Continued northward movement of India under Tibet is presently causing strike-slip dispersion of terranes in northern and eastern China.

Northeast Siberia has experienced mostly middle to late Mesozoic accretion of continental fragments, such as the Omolon terrane, and predominantly oceanic material along the eastern and northeastern margins. This region, including the Koryak Highlands and the South Anyui fold belt (Figure 5), contains a complex series of arcs and ophiolitic terranes that amalgamated and accreted during the late Jurassic and Cretaceous (Fujita 1978, Churkin & Trexler 1981, Fujita & Newberry 1982).

Australia and New Zealand

Australia is similar to other continents in having several Archean cratons surrounded by Proterozoic fold belts. Major reshaping of the continent occurred in the late Proterozoic to Cambrian with the development of a rifted margin in what is presently central Australia (Figure 3). Deposits of aulacogen environments (intracratonic basins within the failed arm of a triple junction) resulting from this breakup are still preserved in central and southern Australia. From the early Paleozoic through the early Mesozoic this margin was a consuming margin of Gondwana, and numerous accretionary events occurred. A composite of oceanic, island-arc, and continental fragments accreted during the Paleozoic make up the Lachlan fold belt; late Paleozoic to early Mesozoic island-arc and ophiolite terranes accreted generally during the Triassic compose the New England fold belt (Figure 3). The Paleozoic strata in the Tuhua composite terrane of New Zealand must also have been accreted during the early Mesozoic (Figure 3; E. Scheibner, written communication, 1983). Jurassic and Cretaceous accretionary events are reflected by the additions of the Hokonui, Caples, and Torlesse terranes of New Zealand (Howell 1980).

Australia is different from other circum-Pacific continents in that much of its Mesozoic-Cenozoic history has been dominated by rifting rather than accretionary events. The western margin was rifted in the early Mesozoic during the breakup of Gondwana. In the middle Cretaceous, New Zealand and the Lord Howe Rise rifted away from the eastern margin with the opening of the Tasman Sea, and the southern margin formed as it rifted away from Antarctica. The northwest Australian margin grew during the middle Tertiary as a result of accretion related to the collision of the Banda arc (Figure 3). These rifting events have scattered continental fragments around the margins of Australia and have caused dispersion and deformation of previously accreted arc, oceanic, and marginal basin terranes of New Zealand.

South America

The distribution and nature of tectonostratigraphic terranes in South America is very poorly known. The core of South America comprises the Guyana and Brazilian shields; however, the Brazilian shield appears to be composed of two Archean cratons that are separated by a latest Proterozoic orogenic belt that may contain ophiolitic rocks (Figure 1; Borello 1972, Burke et al 1977, de Almeida 1978). The thick volcanic and plutonic rocks of the Andean arc cover and obscure most of the pre-Jurassic basement of western South America; however, several continental fragments that may have been accreted during the Paleozoic or early Mesozoic

have been distinguished (Figure 1). The principal Paleozoic suture appears to be marked in part by the Sierra de la Ventana and in the Precordillera of Argentina (Burke et al 1977). It is currently debated as to whether Precambrian rocks found along the western coast of South America (e.g. the Arequipa massif; Figure 1) are uplifted outliers of the shields or exotic fragments of sialic crust. Paleomagnetic studies are in progress on Devonian strata of the Arequipa massif of Peru to determine whether there has been any relative movement with respect to cratonal South America (M. O. McWilliams, oral communication, 1982).

Because the western margin of South America has been a convergent margin since the Jurassic, we expect to find terranes accreted during the Mesozoic along the Andean margin. In contrast to the central Andes, where only terranes with continental affinity have been identified, well-developed oceanic (including ophiolite and blueschist) sequences are present in the northern and southern sections. These appear to represent a series of accretions of island-arc and oceanic rocks that occurred in the middle Cretaceous and possibly earlier in the southernmost Andes (Dalziel et al 1974) and from the middle Cretaceous to Tertiary in the northern Andes and Caribbean Mountains. These terranes comprise island-arc, oceanic, and continental fragments (Maresch 1974, Case et al 1971, 1983); paleomagnetic studies indicate significant amounts of translation and rotation for several of them (MacDonald & Opdyke 1972, Hargraves & Skerlec 1980, Skerlec & Hargraves 1980, Case et al 1983).

CONCLUSIONS

From studies of the geology and geophysics of the circum-Pacific region, it is apparent that this vast region is a collage of disparate crustal fragments. Throughout Proterozoic and Phanerozoic time, accretion of terranes has resulted in continental growth and rifting, and dispersive processes have operated to modify and attenuate continental margins. These tectonically eroded margins, in addition to oceanic plateaus, may serve as the source areas for crustal blocks that eventually become accreted terranes. Because the present Pacific Ocean is no older than Middle Jurassic, the geologic history of the proto-Pacific Ocean (Panthalassa) and surrounding cratonal regions will only be elucidated through further work to characterize the origins and kinematic histories of allochthonous terranes. Terrane analysis can be used to provide an objective, interdisciplinary approach to interpretation of geological and geophysical data in which genetic relations in time and space must be proven before they are used as the basis for plate-tectonic reconstructions. Within the framework of plate tectonics, this approach enables the refinement of more actualistic models to depict the fragmented nature, structural complexities, and great mobility of active margins.

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