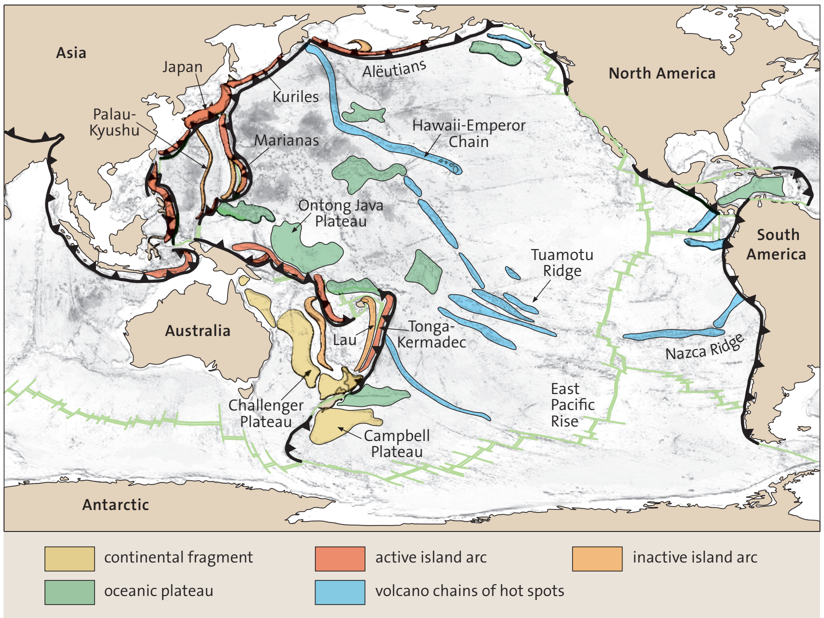
Terranes

During the 1980's geological and geophysical investigation showed that large parts of the North American Cordillera are characterized by the welding of "allochthonous tectonostratigraphic terranes" onto the North American continent. In the following years, a large number of terranes have been identified in other regions around the Pacific Ocean and elsewhere on Earth. It is now known that most mountain ranges including the Appalachians, Alps, and Himalayas are largely constructed of allochthonous terranes.

Tectonostratigraphic terranes, generally simply called "terranes" (the spelling is intentional in order to differentiate from the commonly used term terrain), consists of a block of geology, usually bounded by fault zones, that shows a geological evolution that contrasts with the geology of neighboring crustal blocks (Jones et al., 1982; Schermer et al., 1984). Therefore, it forms a tectonic and stratigraphic entitiy of its own. A characteristic of a terrane is its *allochthonous* nature (*Greek* other terrain). Allochthonous means that its place of formation was remote relative to the neighboring blocks. By inference, terranes have undergone plate drift as they wandered across ocean basins, until they collided or docked, and became welded to a larger continental block or another terrane.

Terranes are known to have several origins. A clue to one type of origin can be deduced by studying the components of modern, large ocean basins with long, complex histories, commonly several hundreds of millions of years in duration. The present Pacific Ocean contains numerous crustal pieces, commonly called oceanic plateaus, that differ from the surrounding normal ocean floor (**Fig. 9.1**). These pieces generally possess greater crustal thickness and lower density than the normal ocean floor and are not easily subducted as they enter a subduction zone. Rather, they collide with the upper plate, perhaps become partially subducted, and become welded onto the upper plate (**Fig. 9.2**). The process of collision and welding is called accretion or docking. In principle, it is the same process that is responsible for a large orogeny when two continents collide (Ch. 11). Also, the accretion of sediments in the accretionary wedge of a subduction zone is a similar phenomenon (Ch. 7).



▲ **Fig. 9.1** Various crustal fragments in the Pacific Ocean that could collide with, and be accreted to, one of the circum-Pacific continents as terranes (Howell, 1985).

The distance between place of origin and the later accretion of a terrane can exceed several thousand kilometers. Crustal pieces that formed in the Pacific Ocean and later collided with one of the circum-Pacific continents are known to have traveled such distances. However, terranes are not defined by their travel distance, but rather by their own distinct geologic evolution. The size of terranes varies greatly; they range from small blocks, less than 100 km^2, to fragments of a small continent ("microcontinent") that may be 1000's of km^2. Terranes commonly break into several pieces that drift apart prior to or during accretion; such events makes terrane reconstruction difficult (see "dispersed terranes"; **Fig. 9.2**).

Terrane boundaries are generally faults or wide, complex fault zones. Commonly they are thrust faults along which the accreting terrane was pushed beneath or upon the margin of the continent. Many terrane boundaries are further complicated by overprinted strike-slip motion of considerable lateral displacement; after the terrane accretes, they can slide along the margin of the continent for several hundreds or thousands of kilometers. Like suture zones in major continental-collision orogens, terrane boundaries are commonly imbedded with

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ophiolites, splinters of the otherwise consumed oceanic lithosphere that was intermediate between the terrane and continent.

The crustal pieces that generate terranes can be constituted in various ways. Segments of thickened oceanic crust, oceanic islands, seamounts and volcanic chains above hot spots, active or inactive island arcs, oceanic plateaus, and continental fragments all exist presently in the modern oceans and each has been documented as the source of ancient terranes. Segments of oceanic crust that formed as either parts of mid-ocean ridges or backarc basins are especially common. Such hot and relatively light ocean floor complexes are accreted to the upper plate or obducted (thrust over its margin), rather than subducted. Examples of large obducted ocean floor segments are the Semail nappe in Oman (see **Fig. 5.16**) and the Troodos ophiolite complex in Cyprus.

Volcanic islands, seamounts, and volcanic chains above hot spots form obstructions during subduction and can be sheared off from the subducting oceanic basement and accreted to the upper plate. The northern end of the Emperor Seamount chain in the northwestern Pacific Ocean is presently colliding with the Asian continent in the Kamchatka subduction zone (**Fig. 9.1**). Parts of this volcanic chain have become accreted as terranes. Accretion of a single volcanic edifice may create a microterrane with a size of only a few square kilometers. The western Pacific Ocean contains a number of active and inactive island arc systems, also candidates for becoming accreting terranes. Oceanic plateaus with their thickened oceanic crust (Ch. 6) may also resist subduction and therefore become accreted.

Continental blocks may split off from larger continents and drift separately as so-called microcontinents. Commonly such fragments possess reduced crustal thickness because the splitting process occurred under extension and crustal thinning. Microcontinents with thinned crust may lie completely below sea level like the Challenger Plateau east of Australia (**Fig. 9.1**).

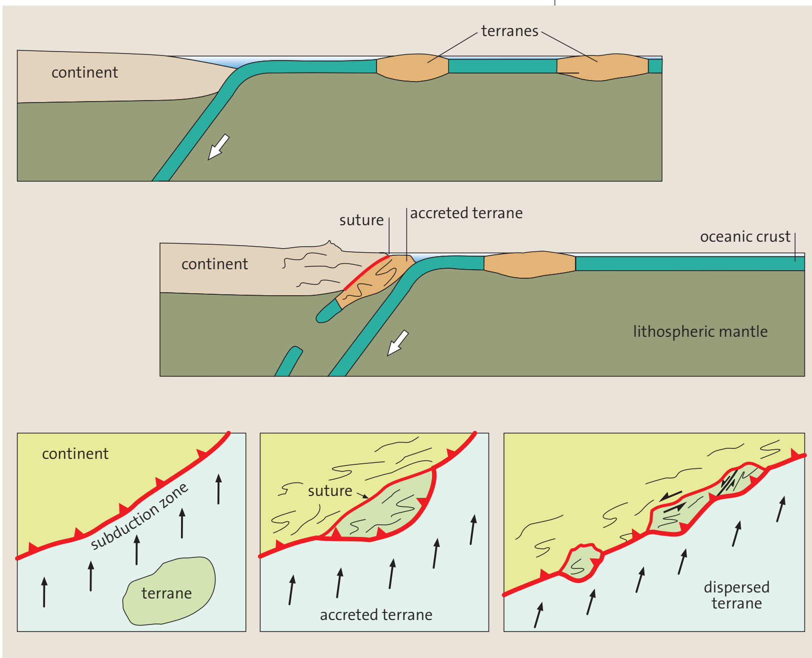
Terranes may collide among themselves, usually in subduction zones or along transform faults. Presently such collisions are occurring in complex areas like the triangle between the Philippines, Java, and New Guinea, where several subduction zones, some with opposing subduction polarity, act simultaneously (see **Fig. 13.1**). The collision of terranes is called amalgamation; the outcome is a "composite terrane". Large composite terranes are called superterranes. Composite terranes usually consist of different types of crust and become accreted to a continent during a later event. The Insular Superterrane is several hundred kilometers wide and stretches over 2500 km from Vancouver Island, British Columbia to central Alaska. It is a composite of the Wrangell and Alexander terranes (**Fig. 9.3**) and several smaller terranes. Geologic evidence shows that the two terranes were already amalgamated when they collided with western North America.

Documenting terranes

Documenting a terrane's history, especially its travel distance and ultimate origin, can be a difficult and controversial process. Paleomagnetic research provides information concerning the drift history of a given terrane through geologic time. The magnetic orientation of iron-bearing minerals yields two pieces of information, declination (deviation from north) and inclination (deviation from the horizontal). This information is locked in the minerals during a past time when the mineral cooled through a certain temperature referred to as its Curie point. The inclination of the magnetic vector is a function of geographical latitude; orientation is horizontal at the equator and vertical at the poles. If the original horizontality of a rock can be determined, for example, sedimentary rocks that display bedding, then the inclination angle can be measured and the paleo-latitude can be reconstructed. A paleomagnetic survey can demonstrate the drift of a crustal block over several degrees of latitude and compare those measurements with measurements from adjacent tectonic blocks. The drift along a parallel cannot be measured by paleomagnetic means.

Paleontological data also yields clues that can document past geographic positions of given terranes. Flora and fauna in rocks express past climate and environmental conditions. Sharp contrasts in flora and fauna of the same age between adjacent tectonic blocks suggest that those blocks were widely separated during the time interval indicated by the fossils. Differences in paleo-latitude are generally easier to detect than distant places at similar latitude. However, some fossils are more provincial (of local extent) than others; in general, bottom-dwelling organisms that lack well-travelled larva forms are more provincial than swimming or floating organisms that are more readily widely distributed. This knowledge has been used to document the presence of exotic terranes in western North America. Certain tectonic units in the North American Cordillera contain Late Paleozoic strata that yield remnants of the East-Asian Cathaysia (Chinese) flora, whereas the remainder of North America shows a completely different, North American–European flora association during that period. The tectonic units containing the Cathaysia

▶ Fig. 9.2 Map and cross-section views illustrating terrane accretion. A terrane approaches a continent by subduction of the intervening ocean floor. The eventual collision leads to underthrusting and accretion of the terrane. The subduction zone then jumps outboard of the terrane to the adjacent oceanic realm. During and after accretion, the terrane may be broken and dispersed along the continental margin.



flora mainly drifted latitudinally over the area of the present Pacific Ocean. In this case, the distinct flora associations do not reflect strongly different climatic conditions but rather are explained by the large paleodistances that prevented mixing of floral elements.

Sedimentary facies, an expression of the sum of all features of a sedimentary rock, can provide strong evidence for past environmental conditions including climate, depositional environment, and the presence and composition of nearby mountains. Such information can then be used to speculate on the ancient geographic setting of terranes. Clay minerals form by weathering of magmatic and metamorphic rocks. They serve as paleogeographic indicators not only as to the source area of the clays, for example, igneous versus metamorphic, but also to the climatic conditions under which the clays formed. Carbonate rocks preferentially form in warm oceans and different limestone types are characteristic of various coastal, shallow water, or deep-water environments of formation. The composition and texture of sandstones and graywackes, sandstone with clay matrix as well as feldspar and lithic fragments, reflect whether their mineral components were derived from a large continental hinterland with metamorphic and granitic rocks or a nearby juvenile volcanic island arc complex with a steep relief. The study of heavy mineral spectra may also be of great value. Heavy minerals are extremely useful in terrane analysis. Heavy minerals occur in sandstones, have a specific gravity of 3 g/cm^3 or more, and are resistant to weathering; therefore, they are able to be transported and preserved over long distances. Their nature provides key information concerning age and composition of source areas of clastic sediment. One of the newest and most widely used techniques in terrane analysis involves the study of detrital zircons ($ZrSiO_4$; specific gravity 4.7). Zircons contain small amounts of U and that makes them easy to date using the latest U-Pb radiometric techniques. They form in acidic igneous rocks and are introduced into sediments either by direct ash fall that preserves delicate original crystal morphology or by weathering and erosion of igneous outcrops that produce rounded and abraded zircon crystals. The former are useful in directly dating the sediments in which they occur because they were directly deposited by the source volcano, and the latter are useful in dating the age of the source rocks of the sediment. An example is the Alexander Terrane of western Canada and southern Alaska. This terrane contains detrital zircons that yield an age that is incompatible with any rocks of western North America; this makes the Alexander Terrane “suspect” and suggests an exotic origin away from western North America. In fact, the age of the zircons along with carbonate facies information, fossil data, and age of included deformed rocks suggests that during the Precambrian, Alexander lay adjacent to Baltica or Siberia, both far removed from western North America at the time.

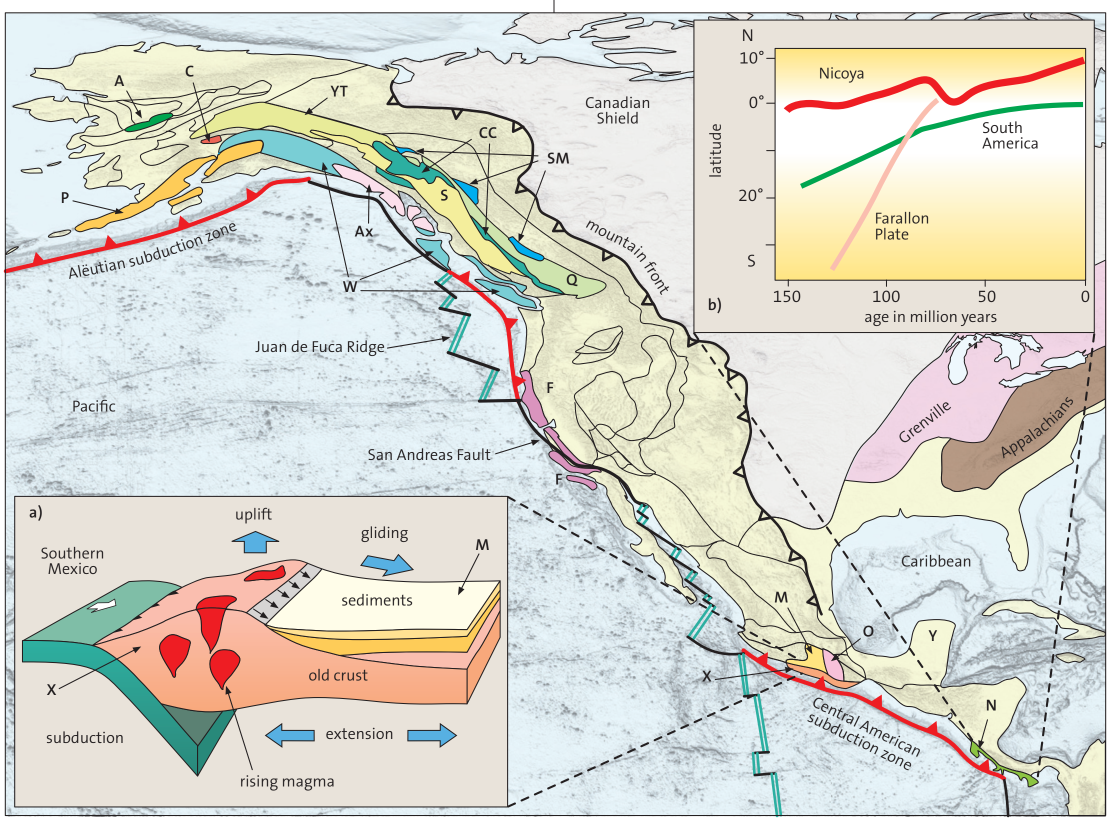
Each of the above helps to reconstruct the paleogeographic position of a terrane and to evaluate whether differences between the possible bordering terrane and adjacent continent can be explained by normal facies transistions over relatively short distances or rather require distant places of formation in their geologic past. To verify the existence of a terrane, all appicable methods should be used. Not all of the numerous terranes defined in the 1980's in the circum-Pacific region withstood subsequent examinations with more exact methods. Although some such as Alexander and Wrangellia have withstood later scrutiny and are believed to be truly exotic, others are now believed to be transported laterally along a given coast, to have formed as offshore island arcs, or to have formed as rifted terranes, later redocked to their continent of origin. Such terranes are generally referred to as peri-allochthonous or peri-autocthonous, depending on the speculated amount of displacement through geologic time.

Terranes in the North American Cordillera

In the Cordilleran Region of the United States and Canada, a large number of terranes have accreted since the Late Paleozoic. Over the past 300 Ma, the continental margin has accreted and shifted westward more than 800 km. Some of the terranes have travelled for more than 5000 km. During much of the Paleozoic era, western North America was a classic passive margin on which thousands of meters of sedimentary rock were deposited. This all changed in the Carboniferous and Permian as exotic island arcs and oceanic plateaus were accreted; from this time to the present, western North America has been characterized as active continental margin. Oceanic crust of the Pacific region was subducted beneath the North American continent and along with it came numerous terranes too buoyant to be subducted. Most of these terranes were subsequently accreted to the continental margin. To put in perspective the amount of potential terrane accretion and subduction that has occurred along the Cordilleran Region, consider that during the early Mesozoic, the Farallon Plate was the largest plate on Earth; all but a few small pieces of this once mighty plate have either been subducted or accreted to the west coast of the Americas!

One of the earliest and still most convincing arguments for terrane accretion is the presence of far-travelled fusulinids, large foraminifera (protozoans) of Late Paleozoic age, now present in the Cordillera. Many exotic crustal blocks contain these fusulinids that are known from the Tethys region, that oceanic realm from which later emerged the Alpine-Mediterranean mountain belt in southern Europe and Asia (**Fig. 4.8**). Indigenous North American fusulinid faunas fundamentally differ from the Tethyan ones. They belong to another faunal province that had no direct connection to the Tethyan fauna.

The North American continent east of the Rocky Mountains consists of crust that was cratonized and stabilized during numerous Precambrian orogenies by crustal thickening and metamorphism; the Canadian Shield is an example (**Fig. 9.3**). On this stable platform terrestrial and shallow-marine sediments were deposited during the Paleozoic and Mesozoic. This region is in sharp contrast to that of the mobile terranes of the Cordillera. Figure 9.3 is a greatly simplified map showing terranes accreted to North America (Jones et al., 1982; Howell, 1985).



▶ **Fig. 9.3** Selected terranes along the west coast of North America and suspect terranes in Middle America (Howell, 1985). Terranes: A: Angayucham, Ax: Alexander, C: Chulitna, CC: Cache Creek, F: Franciscan, M: Mixteca, N: Nicoya, O: Oaxaca, P: Peninsular, Q: Quesnel, S: Stikinia, SM: Slide Mountain, W. Wrangell, X: Xolapa, Y: Yucatan, YT: Yukon-Tanana. YT, S, CC, SM, and Q comprise the Intermontane Superterrane. P, Ax, and W comprise the Insular Superterrane. **a)** Sketch showing the setting of the Xolapa complex in southern Mexico in Cretaceous time (Ratschbacher et al., 1991a). **b)** The slow northward drift of the Nicoya complex in Costa Rica corresponds with the wander path of South America and precludes the drift as a part of the Farallon Plate from the Pacific region (pink wander path) (Frisch et al., 1992).

The discussion below illustrates the diversity of some of the various terranes.

The *Angayucham Terrane (A)* in the Brooks Range of Alaska consists of late Paleozoic and Mesozoic oceanic basalts and siliceous and calcareous deep-water sediments. Accretion to Arctic Alaska occurred in the late Mesozoic. It represents obducted oceanic crust that carried individual volcanoes. The oceanic basalts and the mainly basaltic volcanoes, mostly formed by hot spot activity, can be discerned by their chemical characteristics, even though they have been disrupted and strongly deformed.

The *Chulitna Terrane (C)* is one a dozen small terranes in the Alaska Range. Each is composed of strongly contrasting geologic blocks surrounded by thick flysch successions. These microterranes represent pieces scraped off of larger units. The Chulitna Terrane consists of a sequence that is unknown elsewhere in all of North America. The sequence comprises a Paleozoic ophiolite complex with siliceous deep-water sediments overlain by Late Paleozoic to Triassic shallow-water sediments that were deposited on top of island-arc volcanics. This rock association probably represents a subduction-related volcanic chain in an intraoceanic environment because it does not show any sedimentary influence from a continent. An Early Triassic ammonite fauna reveals that the strata were deposited in low latitudes. In contrast, the neighboring region of the Canadian Shield was positioned at about 40° northern latitude at that time. In the Late Triassic, the tectonic setting of the Chulitna Terrane changed dramatically. Influx of large volumes of quartz sand indicates the presence of a large, nearby continent with exposed metamorphic or granitic rocks. This is interpreted to reflect the accretion of the terrane onto the North American continent. In the neighboring Wrangell Terrane (see below) the Early Triassic sedimentary sequence shows a completely different setting as compared to the Chulitna Terrane.

One of the finest examples of terrane analysis comes from the study of the Intermontane Superterrane (**Figs. 9.3, 9.4**); the term Intermontane comes from the fact that the terrane lies between the folded and thrust Canadian Rockies to the east and the Coast Ranges to the west. The superterrane consists of four major components discussed below and many smaller fragments. The easternmost component consists of (1) the *Slide Mountain Terrane (SM),* mostly Triassic and Lower Jurassic ocean-floor basalt, deep ocean sediment and sediment derived from nearby continental uplands (**Fig. 9.4b,c**). Next, (2) the *Yukon-Tanana Terrane (YT)* and its southern extension, *Quesnel (Q)* consist of a continental nucleus composed of metamorphic rocks, volcanic rocks, and granites. Detrital zircon studies suggest this large, composite terrane was part of Precambrian North America (Laurentia) and was subsequently rifted some distance away during the late Paleozoic; how great this distance was is still a major controversy (**Fig. 9.4a,b**). Farther west is (3) the controversial *Cache Creek Terrane (CC)* that consists of upper Paleozoic through Lower Jurassic oceanic basalt, ophiolites, trench and mélange deposits, and meta-flysch deposits (**Fig. 9.4d**); much of this terrane is metamorphosed blueschist facies rocks. The westernmost terrane is (4) the *Stikine Terrane (S)*, a complex of oceanic rocks, arc rocks, and deep marine sedimentary rocks, but like Yukon-Tanana and Quesnel, contains a nucleus of continental crust. Consensus among geologists concludes that the Intermontane Superterrane was amalgamated in the Middle Jurassic and accreted to North America by the end of the Jurassic (Ch. 13); however, the details concerning the evolving paleogeography of the superterrane, especially its distance from North America, continue to be debated.

The Yukon-Tanana, Quesnel, and possibly Stikine terranes began as thinned and extended continental crust following the Late Precambrian rifting of western North America. After accretion of one or more island arc complexes in the Carboniferous (**Fig. 9.4a**), an active margin developed and an arc complex was built on the terranes; this was followed by Late Carboniferous to Permian backarc extension that separated the terranes, with their recently accreted arc material, from North America. The Slide Mountain backarc basin formed during this event. Meanwhile, subducted under the west flank of the terranes was the Cache Creek Ocean, part of the huge, late Paleozoic–early Mesozoic Panthalassa Ocean. The Cache Creek Terrane formed at the margin of the subducted plate as trench, obducted ophiolite, and accretionary prism deposits. Within the accretionary prism were accreted Tethyan fusulinid-bearing limestones as described above (**Fig. 9.4d**). The tectonic setting during most of the Triassic was, from east to west, the western margin of North America, the Slide Mountain backarc basin, the Stikine(?)-Yukon-Tanana-Quesnel island arc, and the Cache Creek subduction zone (**Fig. 9.4d**). By the end of the Triassic, the Slide Mountain backarc basin was closed; detrital remnants of Yukon-Tanana were deposited on western North America signifying arc collapse against the continent and subsequent mountain building. Following the closure of the Slide Mountain Basin, the tectonic history becomes controversial. Stikine accreted to

Yukon-Tanana-Quesnel from the west closing the Cache Creek Ocean and forming the Cache Creek Terrane between them. There are several tectonic possibilities that can explain this: (1) Stikine was exotic to North America and collided from the west, (2) Stikine was marginal to North America and along strike of Yukon-Tanana-Quesnel; it was subsequently transposed along transform faults and then collapsed against the continent to close the Cache Creek Ocean, or (3) Stikine formed an oroclinal fold, a fold that bends back on itself by 180°, that closed the Cache Creek Ocean (**Fig. 9.4d**). Regardless of tectonic detail, the event that closed the Cache Creek Ocean was completed by the Middle Jurassic. The amalgamated superterrane then became the leading edge of North America and a large Late Jurassic and Cretaceous arc was built on it (Ch. 13). Deformed and metamorphosed flysch occurs on both margins of Yukon-Tanana-Quesnel. Flysch is mainly formed along steep and tectonically active slopes along active continental margins. It is commonly deposited in deep-sea trenches and therefore is a strong indicator of converging plate margins. Because subduction precedes continental collision, flysch sequences are commonly precursors of collision. The flysch on the margins of the Yukon-Tanana Terrane marks terrane collision and backarc closure.

Although currently located from northern Washington to SE Alaska, the events of the Intermontane Superterrane just described occurred as much as 800 km farther south, relative to North America, than their current location. During much of the Cretaceous, transform faults moved the superterrane northward (Ch. 13). Also during the Cretaceous, the Insular Superterrane, described below, was accreted onto the Intermontane Superterrane. Late Cretaceous sedimentary rocks were deposited on the folded flysch deposits and overlap terrane boudaries indicating that the Yukon-Tanana Terrane arrived in its present position relative to the North American continent at the beginning of the Tertiary. Paleomagnetic studies confirm this.

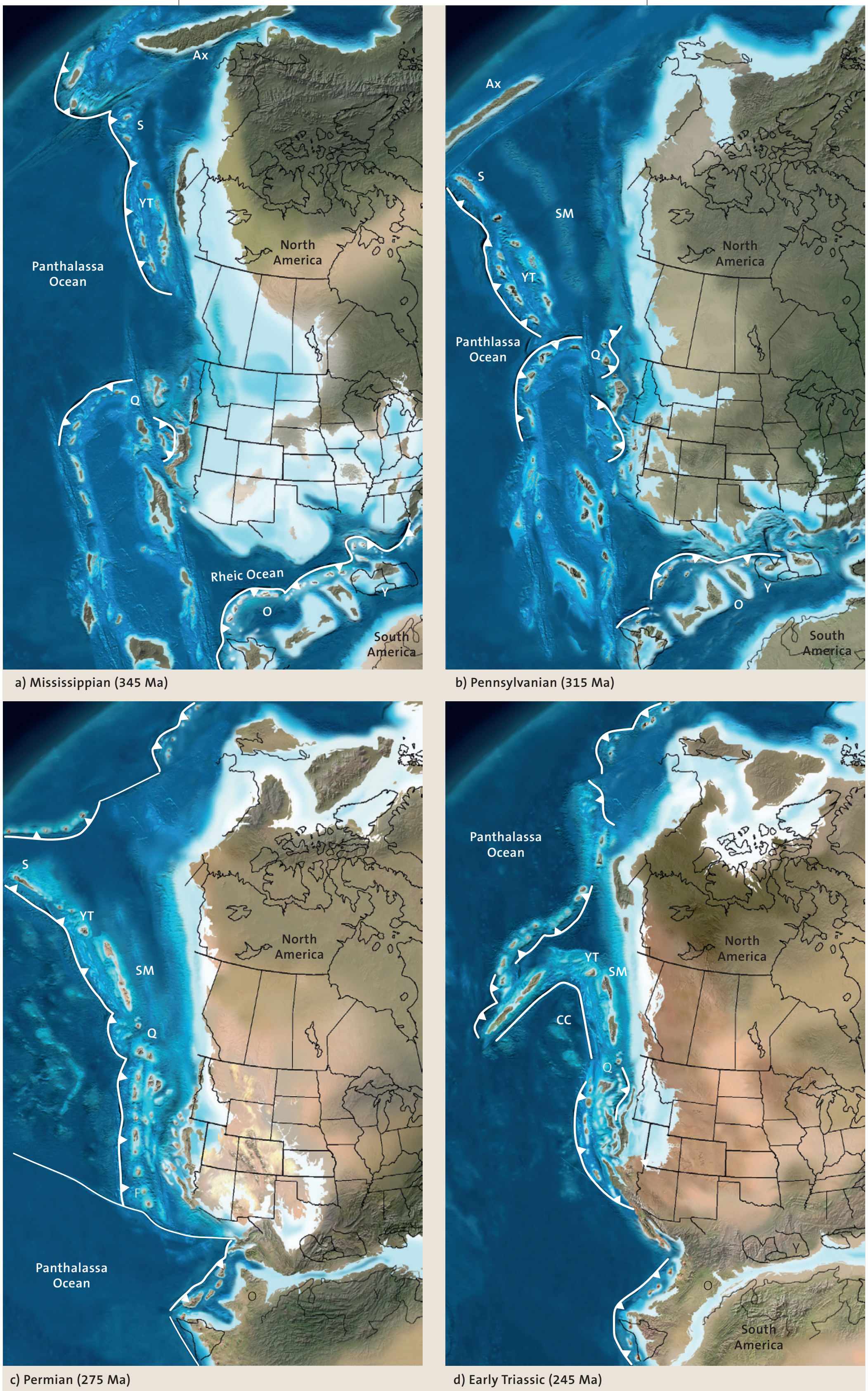
The Insular Superterrane consists of three major components (**Fig. 9.3**). (1) the *Wrangell Terrane (W)* consists of a Late Paleozoic volcanic island arc topped by thick Permian and Triassic sedimentary and volcanic rocks deposited in a regime of crustal extension. Permian limestones contain fusulinids that are clearly different from the Tethyan forms in the neighboring Intermontane Superterrane. The Wrangell Terrane probably originated from a distant place in the vast Panthalassa Ocean far away from the Tethys Ocean (**Fig. 4.8**). Late Jurassic and Cretaceous sedimentary sequences are common with the neighboring (2) *Peninsular Terrane (P)* and (3) *Alexander Terrane (Ax)*. The exotic history of the Alexander Terrane was briefly outlined above. Overlapping Late Jurassic sedimentary rocks and cross-cutting Jurassic plutons indicate amalgamation of these three terranes in the Middle Jurassic. Common also are Cretaceous folding, thrusting, and metamorphism. These events reflect the collision of the large composite terrane with North America. As a consequence of this collisional event, parts of the terrane became dispersed and therefore appear disconnected today.

The Wrangell Terrane is involved in a major controversy of western North American tectonic history. Paleomagnetic studies and some supporting geologic evidence indicate that after its initial accretion to western North America, the terrane captured parts of western North America and moved southward, as far as Baja California, Mexico in some hypotheses. It then rapidly moved northward during the Late Cretaceous to its current location. This rapidly moving terrane has been coined "Baja BC", BC standing for British Columbia where major portions of Wrangellia are currently located (Chapter 13). Subsequent studies have modified the extreme southern limit somewhat and suggest 800–1500 km of lateral translation rather than the 3000 km as required in earlier hypotheses (Wyld, et al., 2006; Umhoefer and Blakey, 2006). Analysis of Farallon Plate motions during the Jurassic and Cretaceous suggest alternating dextral and sinistral transform motions with respect to North America and add credence to the south and north transform motions of Baja BC.

A terrane of completely different nature is the *Franciscan Terrane (F)*, which is exposed along the Californian coast on both sides of the San Andreas Fault (**Fig. 9.3**). Rocks range in age from Upper Jurassic to Lower Tertiary and include ophiolites, representing ocean floor fragments, chaotic blocks, and sediments deposited in a deep-sea trench. Paleomagnetic and paleontologic studies demonstrate that many blocks present in the Franciscan are exotic to North America. The chaotic internal structure of the terrane is that of a tectonic mélange (Ch. 7): blocks of various types of resistant rocks, present in sizes from several meters to kilometers, "float" in a strongly sheared matrix of easily deformable, originally argillaceous rocks. Metamorphism of some Franciscan rocks to blueschist facies shows that the mélange formed during a subduction process.

The Franciscan is not without controversy. Original interpretations suggested that the Franciscan was the trench-accretionary prism portion of a classic forearc trench setting and the adjacent

▶ **Fig. 9.4** A series of paleogeographic maps of part of North America and surrounding regions showing the complexities of terrane accretion. Abbreviations are the same as in Fig. 9.3 with several additions explained below. **a)** Mississippian, Early Carboniferous and **b)** Pennsylvanian, Late Carboniferous; the elements of the Intermontane Terrane are widely scattered along the Cordilleran margin. Oaxaca, Yucatan, and adjacent unlabeled terranes accreted to southern North America with the closing of the Rheic Ocean. Some models show these terranes as part of South America rather than as a ribbon continent as shown here. Alexander may have rifted from Baltica or Siberia and subsequently translated northward into the Panthalassa Ocean. **c)** Permian; following a complex amalgamation involving one or more arcs, Stikine, Yukon-Tanana, and Quesnel separate from North America by backarc spreading and the formation of the Slide Mountain backarc basin. Pangaea, which lay mostly to the east of the map, was assembled by the Permian and Oaxaca and Yucatan were accreted to North America. Terranes with Permian Tethyan fusulinids drift into the Cordilleran region. **d)** Early Triassic; Stikine folded oroclinally towards Quesnel closing the Cache Creek Ocean between. Some models show this as a transform fault system rather than oroclinal fold. The Slide Mountain backarc basin was being closed.



a) Mississippian (345 Ma)
b) Pennsylvanian (315 Ma)
c) Permian (275 Ma)
d) Early Triassic (245 Ma)

sandstone and mudstone of the Great Valley Group formed in the forearc basin. More recent studies, still in accord with the earlier general interpretations, suggest more complex tectonic history with sedimentation in various forearc and interarc settings but with considerable lateral juxtaposition by coeval and subsequent transform processes. Noting that the Franciscan is never in stratigraphic contact with the supposedly adjacent Great Valley Group and using paleomagnetic and paleontologic data, some workers have suggested that the entire terrane is exotic to North America and that most of it was originally deposited off southern Mexico and Central America and later translated northward during the Late Cretaceous and Tertiary.

Suspect terranes in Mexico and Middle America

As mentioned above, many terranes have been defined around the Pacific Ocean without conclusive proof. As long as unequivocal proof is missing, the term "suspect terrane" should be used. Studies in Mexico and Middle America refute the terrane nature, the derivation from a distant place, for crustal blocks that were proposed to be terranes. It is possible that other suspect terranes represent blocks that did not travel afar but rather were displaced along fault zones from neighboring blocks.

The suspect *Xolapa Terrane (X)* in southern Mexico forms a block that is elongate parallel to the coast (**Fig. 9.3**). The boundaries with the suspect *Mixteca Terrane (M)* and suspect *Oaxaca Terrane (O)* are not thrusts or transcurrent faults, but rather low-angle detachment zones with normal displacement (**Fig. 9.3, a**). Normal faults indicate crustal extension and not terrane accretion and thrusting. There is no indication that the extensional structures overprint older structures formed by compressional or lateral motions. The Xolapa Terrane was an active magmatic belt above the Middle American subduction zone that experienced uplift as the magmatic melts penetrated the crust. Accompanying heating weakened the rocks until they became plastic and easily deformable. Finally, this led to gravity gliding of part of the upper crust away from the uplifting magmatic belt. This culminated in the formation of the normal detachment zone between the uplifted Xolapa complex and the units north of it.

This interpretation is backed by further data. Paleomagnetic studies show consistent directions between the magnetic vectors of several suspect terranes in southern Mexico. Moreover, some of these terranes contain a metamorphic basement that is typical of the North American continent; they contain rocks generated during the Middle Proterozoic Grenville orogeny and are common to rocks in the Canadian Shield. The Grenville orogenic belt is known to extend from eastern Canada to southern Mexico, although in places it is covered by younger sediments (**Fig. 9.3**).

There are documented exotic terranes in Mexico. The *Yucatan Terrane (Y)* contains crustal elements, so-called Cadomian basement, only found in terranes that broke off Gondwana during the early and middle Paleozoic (**Fig. 9.4b**). Today these peri-Gondwanan terranes extend from Mexico, to the Appalachians, Southern Europe, and Central Asia eastward to China. They represent one or more ribbon-shaped continents that rifted from Gondwana. But again there is controversy with these peri-Gondwanan terranes. Did they rift to form a separate ribbon continent (**Fig. 9.4a**) or did they collide with North America and other continents as the leading edge of Gondwana and were later stranded as the Gulf of Mexico, Atlantic Ocean, and Neotethys Ocean opened in the Mesozoic?

Another suspect terrane is the *Nicoya Terrane (N)* in Costa Rica and Panama. It represents a complex of oceanic crust (ophiolites) and Jurassic to Cretaceous deep-sea sediments. Following tectonic events with nappe thrusting in Late Cretaceous time, the deformed sequence was covered with shallow-water sediments. Most investigators of the region have proposed that the ophiolites are remnants of ocean floor from the Farallon Plate in the Pacific region that travelled into the present position in Late Cretaceous time. However, paleomagnetic data demonstrate that the Jurassic ocean floor and the overlying deep-sea sediments all formed near the equator (**Fig. 9.3, b**). The drift of the oceanic Farallon Plate was northeasterly through these long periods of time and with a velocity of more than 5 cm/yr. Therefore, if the sediments of the Nicoya complex were formed on Farallon crust, they would have been deposited at southern latitudes far from the equator. Such an interpretation contradicts the paleomagnetic data. Rather, these data indicate paleo-latitudes for the Nicoya complex that are very similar to those of the neighboring parts of South America and reflect only very slow northward movement. It is therefore likely that the ophiolites of Middle America formed on the Caribbean crust that was attached to South America during this interval. The Caribbean crust was displaced relative to South America only since the Late Cretaceous. It has subsequently been translated more than 1000 km to the east-northeast with a resulting northward shift of only few hundred kilometers. This raises an interesting question; if this newer interpretation is correct, should the Nicoya Terrane be considered exotic?