# Lack of Evidence for Subduction Renders Plate Tectonics Unlikely Part I—Trench Sediments and Accretionary Prisms

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## Abstract

Scientists accepted plate tectonics too quickly. Despite many anomalies, all observations are automatically fit into the plate tectonics paradigm. Geological and geophysical data at subduction zones are critically examined. Trench sediments and accretionary prisms are not in character with early conceptions of subduction zones, resulting in many ad hoc hypotheses.

## Introduction

The paradigm of plate tectonics is widely believed by scientists and laymen alike. Plate tectonics is indeed an impressive theory. It has supposedly solved a number of tough problems in geology, such as the origin of magmatism, the cause of orogeny, and sedimentation within "geosynclines" (Hamilton, 1979, p. 14).

Plate tectonics was little accepted by scientists until the magnetic anomalies in the ocean crust were discovered in the 1960s (Glen, 1994, p. 75). Then, there was a wholesale and rapid conversion—a bandwagon effect—to widespread belief in plate tectonics. Edward Bullard quipped in 1967 that as a result of plate tectonics his field, geophysics, has been "...transformed from a backwater into a bandwagon" (LeGrand, 1988, p. 256). This is a classic example of paradigm change by scientific revolution, as described by Thomas Kuhn (1970). But was the rapid belief in the plate tectonics paradigm premature? How well did the scientific community understand the paradigm before wholesale acceptance? Have new scientific data treated the paradigm well?

In a poll of 128 Fellows of the Geological Society of America and 87 active members of the American Association of Petroleum Geologists on the acceptance of the plate tectonic paradigm, Nitecki et al. (1977) discovered that a majority of these scientists believed in plate tectonics *despite a lack of familiarity* with the relevant research. The researchers state elsewhere:

> We were led to the hypothesis that at some time in the mid- or late 1960s, there may have been a sort of 'chain reaction' or general shift in opinion, which more or less uniformly altered the attitude of the majority of the profession as a group, and which was not, at least in most cases, the result of individual judgments of the accumulating evidence and arguments for and against the theory (Lemke, Nitecki, and Pullman, 1980, p. 617).

In other words, most geologists accepted the plate tectonics paradigm by faith. Lemke, Nitecki, and Pullman (1980) add that rapid acceptance stifled critical debate and analysis. This basic critical approach was needed to understand and sort through the many difficulties that would confront the paradigm as more information became available.

The plate tectonics paradigm motivated the geological profession to interpret new results and to *reinterpret* old research *exclusively* within this paradigm (Ollier and Pain, 1988, p. 1; Ollier, 1991). The bandwagon effect blinded the eyes of scientists because they became less critical of the new paradigm as additional data came forth, many of which were not favorable to plate tectonics. It is interesting that Lemke, Nitecki, and Pullman (1980, p. 615) believed that if scientists would have possessed the results of deep-sea drilling prior to the paradigm shift, they probably would *not* have accepted the plate tectonics paradigm. But since the paradigm was firmly entrenched, contradictory data were simply forced to fit the paradigm. Wolfgang Krebs (1975, p. 1639) states:

> At first sight the undoubtedly fascinating hypothesis of new global tectonics seems to have worldwide acceptance; but in many regional, tectonic, petrologic, and geophysical details there are contradictions and peculiarities which are explained by the aid of auxiliary assumptions such as obduction, reversal of arc polarity, flipping subduction zones, mid-plate tectonics, and others.

Obduction is the supposed plastering of igneous rocks, such as seamounts, onto the landward side of the trench. A reversal of arc polarity is the complicated situation in

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Received 28 Sept. 1999; Revised 28 Dec. 1999

which a subduction zone changes dip, for instance from a southwest dip to a northeast dip. This supposedly occurred between the Australian and Pacific plates in the vicinity of the New Hebrides island arc. Flipping subduction occurs when a subduction zone shifts many tens to hundreds of kilometers, as in the case of the eastward jump postulated for the Mariana Trench. Since plate margins are deemed responsible for vertical tectonics, mid-plate tectonics actually does not fit this paradigm. Examples of intraplate tectonics include the high Transantarctic Mountains within the Antarctic plate and the South African superswell within the African plate. The many auxiliary assumptions and explanations are likely the main reason why researchers, who once envisioned the plate tectonics process as simple, now view it as *much more complicated* than originally envisioned (Lemke, Nitecki, and Pullman, 1980, p. 616).

In analyzing plate tectonics, one must go beyond the plethora of secondary hypotheses that plate tectonics proponents have proposed to explain anomalous new data. One must examine the raw data itself. In view of the premature acceptance of plate tectonics, the faith of many in the paradigm, and the willingness to interpret data only within the paradigm, the new data need to be examined to see how well they fit into the plate tectonics paradigm. I will limit this paper to certain geological aspects of subduction zones.

## The Classic Subduction Zone

According to plate tectonics, the earth is divided into about a dozen major plates and a number of minor plates. These plates diverge at mid-ocean ridges, converge at deep ocean trenches, and slide past one another along transform faults. As new ocean crust is formed at mid-ocean ridges, the old crust spreads away from the ridges in a process called seafloor spreading. Since there must be a balance between crustal origin and destruction, the old ocean crust must converge with another plate and descend back down into the mantle. These zones of convergence are called subduction zones. The existence of these subduction zones was at first an inference:

> The concept of subduction in the framework of plate tectonics was introduced more or less as a logical consequence of sea-floor spreading to keep the surface area of the earth constant (Uyeda, 1982, pp. 133,134).

Figure 1 shows schematically what scientists had envisioned in the 1970s as a classic subduction zone—a trench-accretionary prism-island arc-backarc system. There are also subduction zones where an ocean plate is converging with a continent, and these convergent zones are somewhat different from an ocean-ocean plate collision. The difference depends upon such variables as tectonic environment, sediment supply, duration of subduction, and convergence rate (Mrozowski and Hayes, 1980, p. 223; Cloos and Shreve, 1988a). In Figure 1, an ocean plate subducts under an island arc, starting at an ocean trench. A trench is a deep ocean trough that may stretch thousands of kilometers along the ocean floor. The Mariana Trench is the deepest trench in the world at 11,003 m, deep enough to drown Mount Everest beneath 2,155 m of water. Although there are individual differences, trenches have similar topographic profiles (Fisher, 1974). Figure 2 shows three profiles along the lower Japan Trench that are generally similar but show significant lateral variations. Trenches notably outline the Pacific Ocean (Figure 3), while only two comparatively short trenches occur in the Atlantic Ocean.

Uniformitarian geologists assert that sediment which had been accumulating on the ocean plate for millions of years is scraped from the upper plate margin, forming a thick, deformed wedge. This is called either an accretionary wedge or accretionary prism. The offscraped sediments form a series of imbricate underthrust sheets, and

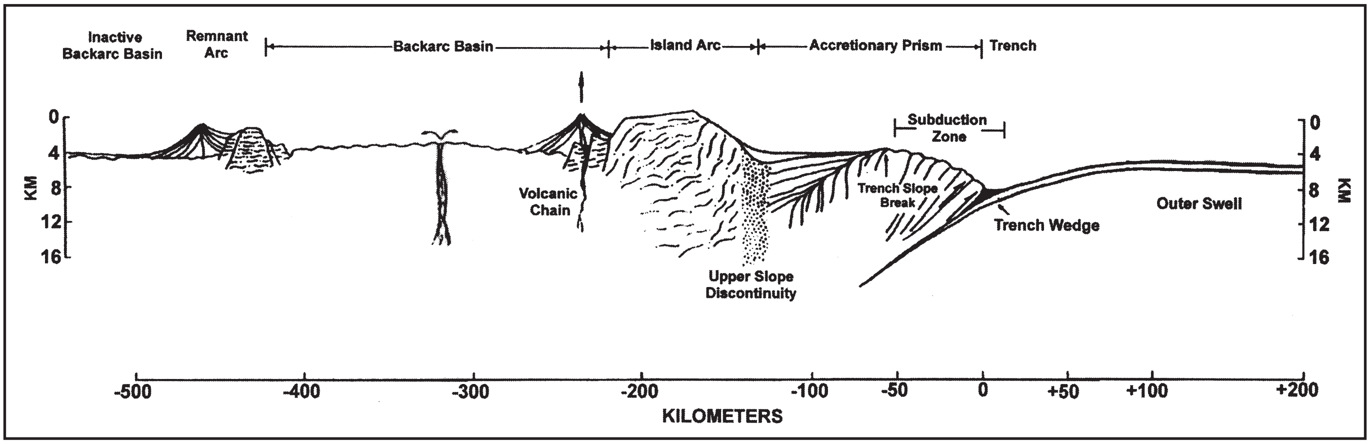

**Figure 1. A classic subduction zone-island arc system as envisioned in the 1970s (from Karig and Sharman, 1975; redrawn by Nathan Oard). Vertical exaggeration is 5:1.**

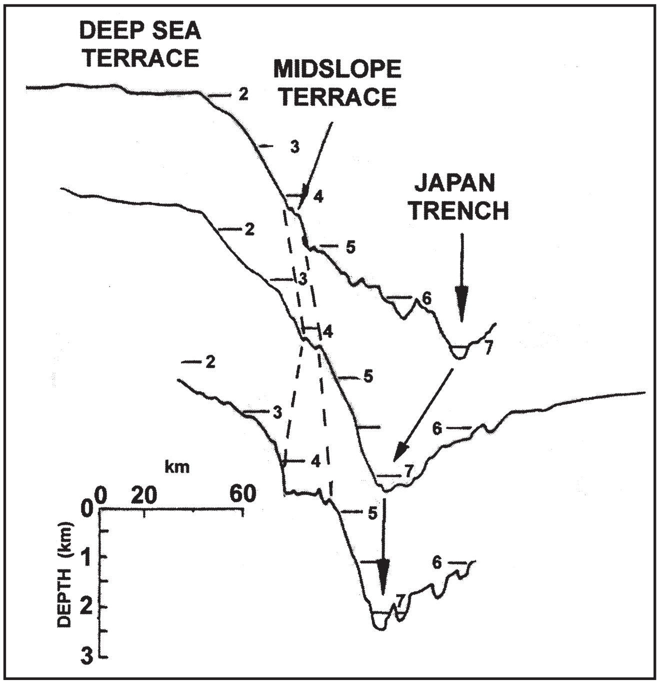

**Figure 2. Three profiles along the lower Japan Trench (from Nasu et al., 1980; redrawn by Nathan Oard). Vertical exaggeration is 20:1.**

the accretion wedge grows and uplifts with time. The island arc is a mass of volcanic debris or reworked volcanic debris that is believed to be caused by subduction. In plan view the island arc is usually a curved line of volcanoes parallel to the trench. The trench-island arc system is also called a convergent margin. Farther from the trench, there may be an active backarc basin, also called a marginal sea. Sometimes a remnant or fossil island arc, which lies beyond the backarc basin, is postulated (see Figure 1). Fossil island arcs are supposedly formed by a flipping subduction zone. All of these features can be lumped together and generally referred to as a *subduction zone*.

## Trench Sediments

A trench is a zone where two plates supposedly have been converging for millions of years. According to the theory of plate tectonics, thousands of kilometers of lithosphere (ocean sediment, ocean crust, and upper mantle) have been converging. The soft oceanic sediment is supposed to have been plastered against the upper plate while the lithified ocean crust and upper mantle lithosphere descend into either the upper mantle or into the lower mantle. For instance, the Kermadec Trench, north of New Zealand, would have been required to swallow 13,000 km of oceanic lithosphere, or one-third the circumference of the earth, during the past 150 million years of geological time (Carey, 1988, p. 178). Based on the classic early vision of a subduction zone, one would expect that over many millions of years of such convergence, the deep ocean trenches and the upper plate would be loaded with huge piles of contorted pelagic and hemipelagic sediments. Except for areas of clay, ocean sediments are usually pelagic, which are sediments composed predominantly of the shells of marine organisms, or hemipelagic, which are pelagic sediments that contain a significant proportion of terrigenous or volcanic sediments and usually accumulate near continental margins. Do we see thousands of kilometers worth of pelagic and hemipelagic sediments in the trench and plastered against the landward side of the trench?

### Many trenches contain little or no sediment

The character of trench fills has been known for some time. As is the case, some trenches have virtually *no* sediment in them at all! For example, the Chile Trench between 16°S and 28°S has almost no sediment (Thornburg and Kulm, 1987). Some locations within the Middle America Trench are also barren of sediments (Moore, Shipley, and Lonsdale, 1986, p. 517). There is little or no sediment in the Tonga Trench; the sediment that is observed appears to have been deposited by mass movement from the arcward slope (Lonsdale, 1986, p. 295). Most of the floor of the Kermadec Trench is bare rock (Carey, 1988, p. 178). Some locations in the Japan Trench contain no sediment; those areas that do have minor sediment are normally at the mouths of submarine canyons (Ludwig et al., 1966; von Huene, Arthur, and Carson, 1981, p. 394). Empty trenches or trenches with a thin trench fill are indeed anomalous, since the ocean crust seaward of these starved trenches generally possess 200 to 600 meters of soft pelagic and hemipelagic sediments (von Huene and Scholl, 1991, pp. 291,292). These observations seem most anomalous.

### Thick trench sediment horizontal and generally undeformed

Most other trenches have a moderate to thick trench fill, up to 2 km thick or more in several Pacific trenches (von Huene and Scholl, 1991, p. 289). The interesting fact about these trench fills is that the sediments are *horizontal or nearly horizontally layered*, showing little or no evidence of compression within the trench (Shor, 1974). For instance, the Chili Trench has undeformed sediment south of 28°S, with the trench completely filled south of 37°S (Scholl et al., 1970; Thornburg and Kulm, 1987). The central and eastern Aleutian Trench is floored by horizontal beds (von Huene, 1972; McCarthy and Scholl, 1985). When von Huene and Scholl were more open minded about plate tectonics, they considered the undeformed trench fill of the eastern Aleutian Trench as evidence *against* subduction: "The undeformed fill provides no evi-

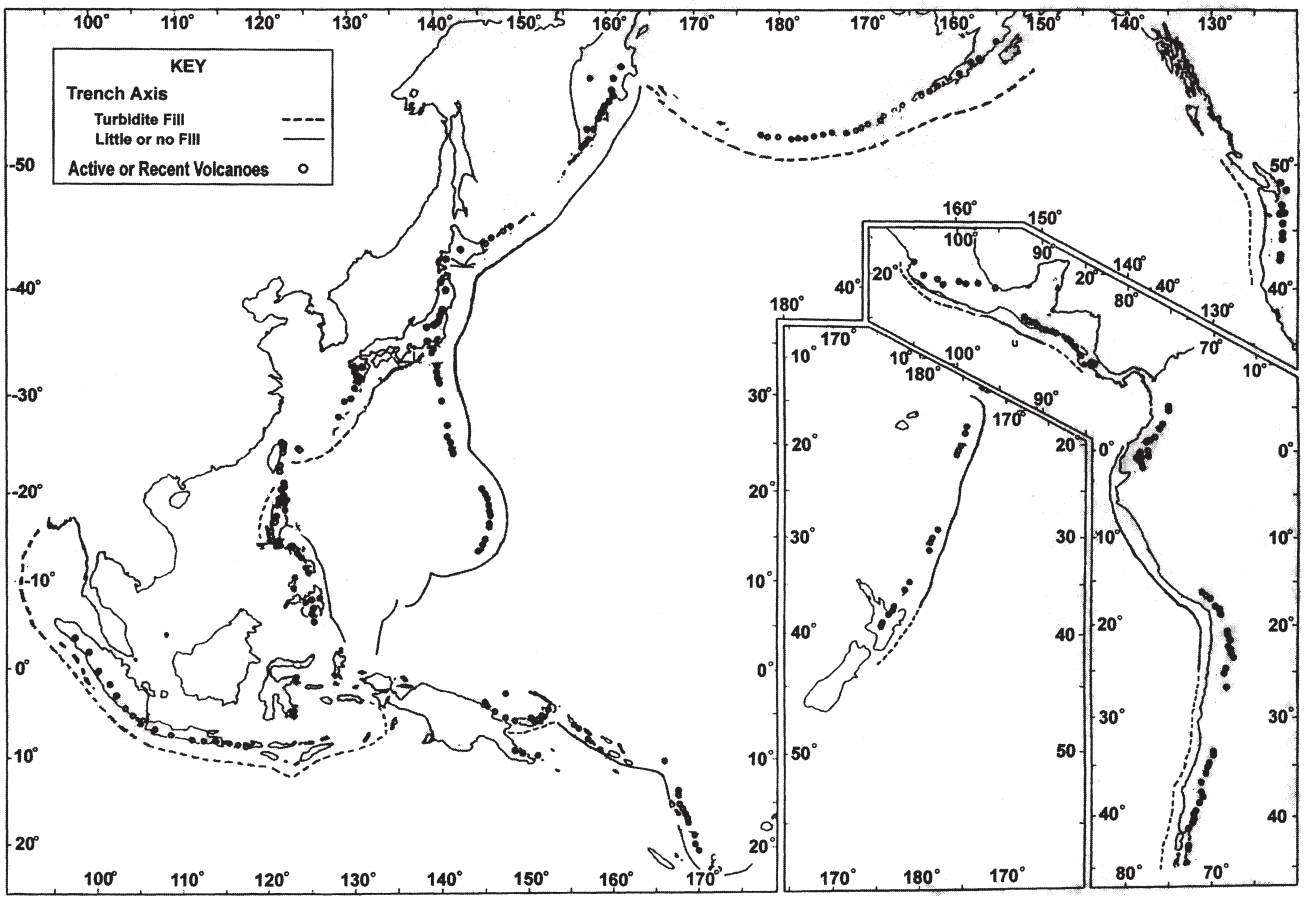

Figure 3. Active trenches in the Pacific Ocean. Trenches with little or no sediment shown by a solid line, while those with relatively thick, undeformed sediment indicated by a dashed line (from Karig and Sharman, 1975, and von Huene and Scholl, 1991; redrawn by Nathan Oard).

dence for a large thrust fault zone at the base of the continental slope" (von Huene and Shor, 1969).

Hatherton (1974, p. 95) considered the flat, undeformed trench sediments remarkable and anomalous for a subduction zone:

> The sediments in the bottoms of most trenches appear to be remarkably undeformed, and provide no evidence for a large thrust fault at the base of the continental slope...

The state of the trench sediment is indeed an anomalous feature for a location that is supposed to have been converging for many millions of years:

> ...sediments in the Chile Trench were found undisturbed...this evidence has been considered anomalous and incompatible with an active spreading of the ocean floor (Katz, 1971, p. 1753).

Francis (1971, p. 98) exclaims:

> One baffling problem is the almost complete lack of deformation in the sediments found in oceanic trenches...there is no evidence for the accumulations of contorted sediments that were originally expected.

Figure 3 shows the trenches that contain little or no sediment and those with relatively thick, but undeformed sediments.

### Trench sediments predominantly turbidites

Since converging oceanic plates have soft bottom sediments above the ocean crust (Cloos and Shreve, 1988a), one would expect that the trench fills would contain a large proportion of pelagic and hemipelagic sediments within the trench. Most of the trench fill sediments, however, are *unconsolidated turbidites* that have collected in the trenches from the continents or island arcs. S. Warren Carey (1988, p. 177), once a believer in plate tectonics, summarizes the evidence:

> Dr. David W. Scholl and Dr. Tracy L. Vallier of the United States Geological Survey pioneered the work that established the absence of accumulations of oceanic sediments anywhere around the allegedly subducting Pacific rim.

### Plate tectonics explanations

The trench turbidites are believed to be quite young, mostly Pleistocene within the geological time scale (Scholl, 1974; von Huene and Scholl, 1991, p. 287). Hence, the sediments are assumed to have collected rapidly and have not had time to deform. This explanation is bolstered by the uniformitarian ice age idea that sea level was as low as –120 m with much erosion during multiple glaciations. Neither sea level this low nor multiple ice ages enjoys much support (Oard, 1990). It is likely that the young age of trench turbidites is simply assumed because the turbidites generally are undeformed, which would be an example of circular reasoning. This excuse seems hollow when one considers that *all* thick trench sediments are generally undeformed. Besides, there still would have been 100 km of plate convergence at the trench in the presumed two million years of the Pleistocene period at a modest convergence rate of 5 cm/yr. It seems that even a fraction of this movement should have deformed thick trench sediments, but extensional features are more common in the trench fill (as will be shown in Part II).

Because plate tectonics is considered a fact—Hatherton (1971, p. 294) even calls it a *dogma*—there have been several hypotheses to explain these enigmatic observations in trenches. One idea to account for the relatively thick, flat turbidites in trenches is that earthquakes shook and liquefied the sediments that subsequently settled as horizontal layers, a process call thixotropy (Francis, 1971). The same hypothesis is used to explain similarly undeformed, horizontally stratified sediments in fracture zones that cut perpendicular to the mid-ocean ridges (Francis, 1971, p. 100). However, this idea apparently never took hold, probably because of the large scale of the liquefaction that would be required.

Another ad hoc hypothesis to account for the lack of sediments in some trenches or trench segments is that the ocean plate and trench sediments were simply subducted. This hypothesis is widely believed but seems virtually incredible, since trench sediments are quite soft. Porosities of trench fills are quite high, 70% as a rule in the upper portion and probably about 50% one km deep (Francis, 1971, p. 99).

An ancillary hypothesis to account for the subduction of soft sediments is that the sediments pooled in grabens, which are common on the oceanward trench wall. As the grabens are subducted, so are the soft sediments (Hilde, 1983). This process can be envisioned as the teeth of a gear in which the sediment caught in the trough is subducted while the friction is born at the gear ridges. One problem with this explanation is that in many trenches the sediment is usually too deep, deeper than the horsts and grabens, but is still horizontally layered.

A popular explanation for the horizontally layered sediment is that the trench sediments deform only against the edge of the continent or island arc at a "backstop." Trenchward of the backstop, the trench fill has not yet converged and hence remains undeformed. It is questionable whether such a backstop, envisioned as a snowplow deforming the sediments close to the blade but not out away from it, would result in undeformed trench sediments. I have observed that pushing a snow shovel through powder snow on the sidewalk causes underthrusting and deformation well out ahead of the snow shovel. A similar process should occur well out into the trench from the toe of the continental or arcward slope, especially since sediment is more cohesive than snow.

## Accretion Wedges

As an ocean plate converges, the soft pelagic and hemipelagic sediments are believed to become plastered onto the inner trench wall. Terrigenous sediment from the island arc or continent deposited into the trench would also be plastered against the slope. Several examples of large accretionary wedges have been claimed, such as in the Lesser Antilles, Cascadia, and Makran forearcs (Cloos and Shreve, 1988a, p. 473). These accretionary wedges are mostly under the ocean surface in forearcs adjacent to "active" subduction zones.

Geologists also point to what they believe are ancient accretionary wedges on land, which supposedly act as a guide to their understanding of the accretionary process. The Franciscan Formation in central and northern California has been the most intensively studied of these supposedly ancient accretionary prisms.

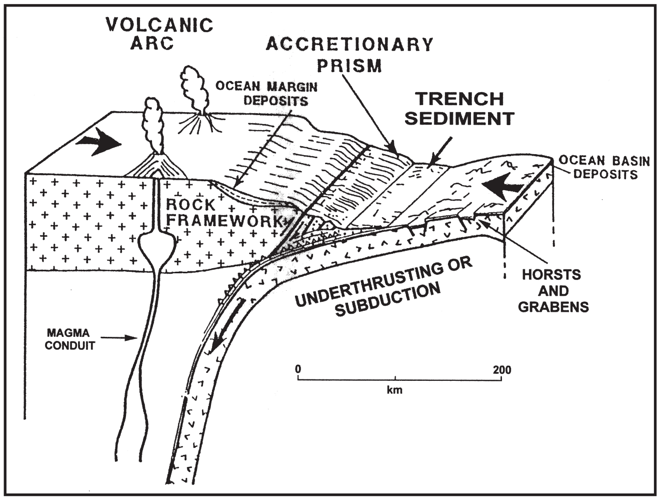

**Figure 4. Schematic of a typical accretionary prism in subduction zone (from von Huene and Scholl, 1991; redrawn by Nathan Oard).**

Figure 4 is a drawing of a typical accretion wedge as envisioned today. A comparison with Figure 1 will demonstrate that the accretion wedge is now viewed as small and mainly found on the lower trench slope. It is presumed that convergence has caused underthrusting of trench sediments against an increasing accumulation of accreted sediment. Seismic reflection profiles sometimes show landward dipping reflectors below the boundary or toe of the accretionary wedge that are assumed to be the top of the downgoing ocean plate. However, there are quite a number of significant problems with the hypothesis that accretionary wedges are evidence of plate tectonics, if indeed they really are wedges of sediment caused by a converging plate boundary.

### No accretion prism along many subduction zones

In the beginning, plate tectonic advocates fully expected to find all ocean and trench sediment plastered against the landward side of the trench:

> Not long ago, it was generally believed that oceanic and trench deposits are accreted to the leading edge of the overriding plate as an oceanic plate enters the subduction zone at a deep-sea trench... (Hilde, 1983, pp. 381,382)

It has come as a shock that many subduction zones do not have an accretionary wedge at all!

In 1973, the Middle America Trench off Guatemala was considered a *type site* for an accretionary margin based on landward-dipping seismic reflections (Aubouin and von Huene, 1985; Moore, Shipley, and Lonsdale, 1986, p. 513). However, further information from drilling and seismic profiles demonstrated that there is no classic accretionary prism in the Middle America Trench off Guatemala (see Figure 5) (Shipley and Moore, 1986). Little or no accretion has taken place in the southeastern Middle America Trench (de Lépinay et al., 1997), and much previous interpretation was simply wrong (Aubouin and von Huene, 1985). Moore et al. (1979) lament that an extensive accretionary prism and fore-arc basin should have developed landward of the Middle America Trench in view of 100 million years of convergence with an average of 170 m of soft sediment seaward of the trench, but the accretionary wedge is largely missing. There is a small accretionary prism in the northwest section of the trench off Mexico, at least locally (Karig et al., 1978; de Lépinay et al., 1997).

Karig and Sharman (1975) had predicted a classic accretionary prism along the arcward wall of the Mariana Trench (Hussong and Fryer, 1981, p. 33). However, there is little if any accretionary prism along the Mariana Trench (Hussong, Uyeda et al., 1981). Bloomer (1983) stated that although 600–800 m of sediments on the ocean plate between 17°N and 19°N are being carried into the Mariana Trench, there is no accretionary prism on the arcward slope, which is composed largely of igneous rocks.

Karig (1974) once claimed that the Tonga Trench possessed a large accretionary prism. However, the Tonga Trench is now known to lack such a prism (Clift et al., 1998). Bloomer and Fisher (1987) stated that the ocean sediment is thin on the oceanward side of the Tonga Trench, but this should not matter in view of the belief that over 10,000 km of ocean crust and thin sediment have supposedly converged at this trench. The geophysical data that led to the original interpretation of a large accretionary wedge were misinterpreted (Bloomer and Fisher, 1987, p. 469). Misinterpretation at subduction zones has been common without borehole data (Karig et al., 1980; von Huene, Arthur, and Carson, 1981; Cloos and Shreve, 1988a, p. 462; von Huene and Scholl, 1991, pp. 283, 284).

To further develop the point, little if any accretion has occurred at the Japan and Philippine Trenches (Ludwig et al, 1966, p. 2124; Cardwell, Isacks, and Karig, 1980, p. 18; Hilde, 1983, p. 388; von Huene, Arthur, and Carson, 1981, p. 399; Bloomer and Fisher, 1987). This is in spite of 1 km of soft ocean plate sediment, along at least one transect, converging with the Japan Trench (von Huene, 1986, p. 9). There is no accretionary prism at the "inactive" Yap Trench (Hawkins and Batiza, 1977), nor at the Kuril Trench (Cadet et el., 1987, p. 323)

### All accretionary prisms too small

Even in trenches that do possess an accretionary wedge, the amount of sediment estimated in the wedge is far short of the amount that should have accumulated over many millions of years of plate convergence. For instance, Karig et al. (1978, p. 265) lament:

> Plate convergence between the Mexican section of the North American plate and either the Cocos or other lithospheric plates within the Pacific Ocean has been occurring at least intermittently for more than 100 m.y. and probably for several times that long...It is quite anomalous, then, that much of the Mexican continental margin so poorly reflects the maturity normally associated with persistently convergent plate boundaries.

Maturity in this case is associated with a thick accretionary prism.

Von Huene (1972, p. 3624) stated that there is not enough sediment in the eastern Aleutian accretion zone for the subduction of 7,000 km of soft ocean sediment. Ryan and Scholl (1989, p. 499) reinforced this conclusion for the central Aleutian forearc when they claimed that accretion had occurred only since the Pliocene while subduction has supposedly been continuous since the Eocene. Von Huene and Scholl (1991, p. 287) have stated that in small-to-medium-sized accretionary prisms, only

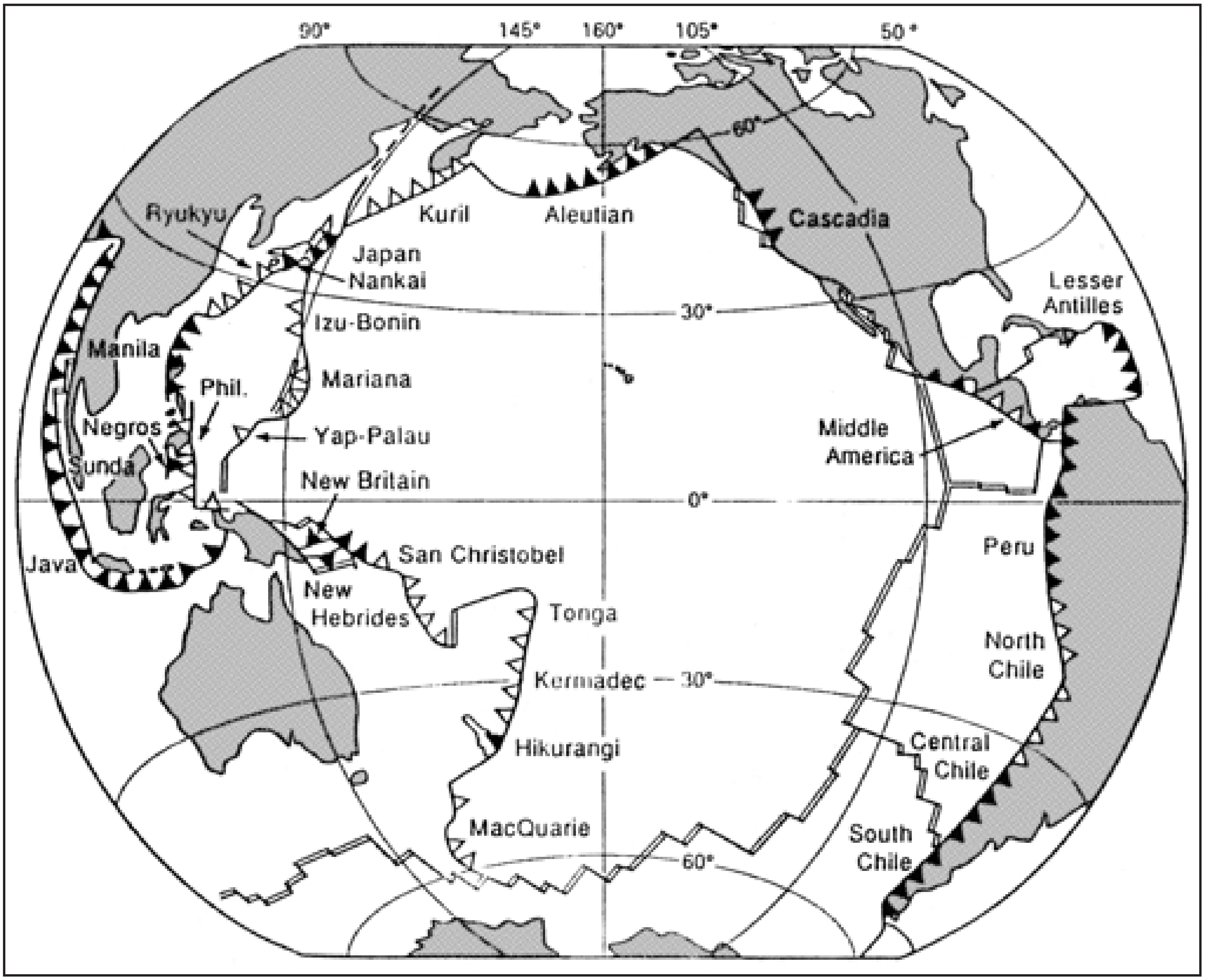

**Figure 5. Trenches with accretion wedges (solid triangles) and those without accretion wedges (open triangle) (from von Huene and Scholl, 1991; redrawn by Nathan Oard).**

about 20% of the sediment deposited during the Cenozoic is found in the accretionary prism.

Some marine geologists claim that western Pacific trenches mostly lack accretionary masses because of a dearth of terrigenous sediments reaching the trench (von Huene and Scholl, 1991, p. 288). However, these island arcs are areas of extensive volcanism. One would expect that copious volcanic debris would have been deposited on the forearc and into the trenches over many millions of years, similar to terrigenous sediments along continental margins bordering trenches. However, the problem is not necessarily the lack of continental or island arc sediments reaching the trenches, but a *lack of oceanic* sediments. Oceanic sediments should not only have entered the trench, but also thickly piled against the landward trench wall.

Figure 5 shows the locations of both the accreting and non-accreting subduction zones within and around the Pacific Ocean. The total length of all of these trenches is about 43,500 km. Of this amount, 19,000 km, or 44%, have no accretion wedge (von Huene and Scholl, 1991)! Of the remaining 24,500 km, about 16,300 km, or 37% of the total trench length, have small to medium wedges, and about 8,200 km, or 19% of the total, have thick wedges. Where did all the sediment that should have been accreted to the landward or arcward trench wall during millions of years go?

### Sediment within "accretionary prisms" predominantly terrigenous

Another major problem with the hypothesis that accretionary wedges are evidence for plate tectonics is that practically all presumed accretionary wedges consist of terrigenous sediment and *not* offscraped oceanic sediment. When scientists have been able to drill into what was believed to be an accretionary wedge, they have commonly found that the sediments were derived from the land and not from the ocean (Cloos and Shreve, 1988b, p. 510). For instance, marine geologists drilling landward of the Japan Trench discovered mostly terrigenous sedimentary rocks, even close to the trench (von Huene, Arthur, and Carson, 1981). Moreover, the "imbricate accretionary model," based mainly on the interpretation of seismic reflection profiles, did not apply:

> The study of some recently obtained drillcore samples at convergent margins casts doubt on the validity of interpreting seismic records only in terms of the 'imbricate accretionary model.' (von Huene, Arthur, and Carson, 1981, p. 393).

This is another example of misinterpretation based on blindly following the plate tectonics paradigm.

Von Huene and Scholl (1991, p. 279) admitted that a large majority of accreted sediments are terrigenous: "The bulk of the subducted material is derived directly or indirectly from continental denudation." For instance, the fairly thick accretionary prism in the eastern Aleutian Trench is constructed of mud and sand turbidites (von Huene et al., 1998, p. 468). The thick accretionary wedge of the Lesser Antilles Arc in the Caribbean is mostly terrigenous, derived from northern South America (Speed and Larue, 1982).

For many years, most of the information for accretionary wedges came from presumed ancient accretionary wedges on land, such as the Franciscan Complex of coastal California (Dickinson and Seely, 1979, p. 18; von Huene and Scholl, 1991, p. 281). However, practically all the Franciscan Formation, as well as other presumed accretionary wedges on land, are *turbidites* with a minimal amount of ocean sediment (Scholl, 1974; Scholl and Marlow, 1974; Kimura et al., 1996, p. 76). After many years of study, these supposedly ancient accretionary wedges on land have offered only limited information on the subduction process:

But the study of these accretionary complexes provided little insight into inferred and suspected processes that might effect the bypassing of ocean sediment (subcrustal sediment subduction) and wastage of upper plate material (subduction erosion)...(von Huene and Scholl, 1991, p. 281)

### Subsiding accretionary complexes

Accretionary prisms are supposed to *grow and uplift* with time. There are several classic examples of this presumed development. For instance, in the forearc of the Sunda Trench, the growing accretionary prism has supposedly uplifted and formed several islands, such as Nias Island (Moore et al., 1980). However, it has come as a mild shock to discover that some forearcs are believed to have *subsided* several kilometers. For instance, in the eastern Aleutian accretionary prism, von Huene et al. (1998) suggested that the prism had subsided. This conclusion is based on the imaging of a regional erosion surface, presumably formed at sea level. The scientists drilling DSDP legs 56 and 57 concluded that the Japan trench inner slope subsided, which was puzzling and not envisioned by most popular models of convergent margins (Arthur and Adelseck, 1980, p. 5). von Huene (1986, p. 9) suggested that the Japan forearc has subsided 5 km.

Based on shallow water benthonic foraminifera and a broad erosion surface, the shipboard scientific party of ODP leg 112 concluded that the continental margin off Peru has subsided several kilometers (Suess, von Huene et al., 1988). The Middle America forearc probably has subsided at least 3 km, based on the submersible discovery of a 10 m thick layer of well-rounded conglomerate covering an erosion surface on plutonic rocks (de Lépinay et al., 1997).

### Tectonic or subduction erosion

Researchers have also discovered that many convergent margins, instead of being areas where sediment is plastered onto a backstop, are probably areas where *rock has been removed* by a process called *tectonic or subduction erosion*. Based on the short distance between the Middle America Trench off Mexico and Cretaceous plutons in the forearc, Karig et al. (1978) conclude that the former continental margin has somehow been removed. This conclusion was bolstered by the recovery of "old" Cretaceous and Eocene sedimentary rock at the toe of the inner trench slope (Aubouin, Bourgois, and Azéma, 1984). Tectonic erosion along the Japan Trench is also suggested by the discovery of Mesozoic and Paleozoic consolidated or metamorphosed rocks along the inner trench slope (von Huene and Lallemand, 1990). Supposedly, the lack of younger sediments requires tectonic erosion of the missing rocks. Tectonic erosion has been virtually forced onto researchers because of these "old" sedimentary rocks:

> The recovery of Mesozoic and Paleogene sediment at the front of the Japan, Mariana, and Middle America convergent margins *required* not only subduction of sediment but in some cases, massive tectonic erosion [emphasis mine] (von Huene, 1986, p. 2).

The suggestion of tectonic erosion of forearcs is rather unusual for a margin that supposedly should have been converging and collecting sediments for millions of years. Tectonic erosion is mostly based on "old" dates of some of the continental or arcward plutons or sediments. The process of tectonic erosion is supposedly bolstered by the horst and graben topography on the ocean plate entering the trench. Researchers suggest that this bathymetry acts like a chain saw cutting away at the upper plate. Such a process is nearly impossible in those trenches with thick sediment or when the horst and graben structure is buried by ocean sediments. Von Huene (1986, p. 12) stated that, "Such a process is difficult to envision when the cutting surface is blanketed by sediment such as along the Japan Trench." Regardless, tectonic erosion is another one of those many auxiliary hypotheses necessitated by the conflict between data and theory.

### The explanation of sediment subduction

As with the trenches that contain little or no sediment, researchers claim sediment that should have been accreted was instead *subducted*. Furthermore, the subduction process was even able to erode the continental or arcward edge of the trench and subduct the rock down into the mantle. Plate tectonic advocates have drifted afar from their original theoretical vision of a subduction zone. In subduction zones with no accretionary wedge, 100% of the soft ocean and trench fill sediment must be subducted. Sediment subduction is also how they explain the paucity of pelagic sediments in presumed accretionary wedges (Cloos and Shreve, 1988b), although this does not seem reasonable for thick accretionary prisms. In small to medium accretionary wedges, 80% of the ocean sediment is believed subducted, while in trenches with thick wedges, 70% is thought subducted (von Huene and Scholl, 1991).

The subduction of soft oceanic and trench sediment brings up an interesting mechanical problem. How are these unlithified to semi-lithified ocean sediments supposed to be passively transported down into the mantle on top of subducting hard ocean crust shearing under the mostly consolidated inner trench slope? von Huene (1972, p. 2624) once thought subducting soft sediment a difficult mechanical problem:

> The first alternative [subduction] results in injecting large amounts of soft sediment down a thrust fault, a difficult mechanical concept.

However, since he is a staunch believer in plate tectonics, he now has no choice but to believe such a notion anyway:

> In our view the widespread occurrence of both nonaccreting margins and accreting margins that retain in frontal accretionary bodies only a fraction of the oceanic sediment provided documents the workings of efficient sediment subduction processes... (von Huene and Scholl, 1991, p. 290)

In other words, the missing sediment *justifies* the difficult mechanical concept of sediment subduction, as well as tectonic erosion.

Instead of a difficult mechanical problem subducting soft sediment into the mantle, some have come to believe the soft sediment acts as a *grease* to aid the sliding (Thornburg and Kulm, 1987, p. 50). What pressure keeps the "grease" from squirting back out, the way real grease does in machinery? "Elevated pore pressure" in the sediment is supposed to aid the shearing of one plate past another (Aubouin, Bourgois and Azéma, 1984, p. 216). Of course, reduced friction due to soft sediment will not work for the many sediment starved trenches, which are believed to be high stress environments (von Huene, 1986, p. 1). Now that sediment subduction has been accepted, further support supposedly comes from trace elements and isotope ratios, as well as young ages, for volcanic arc magmas assumed to have been produced by melting in the subduction zone (Cloos and Shreve, 1988b, p. 536; von Huene and Scholl, 1991, pp. 306,307).

## Acknowledgments

I thank John Reed, Carl Froede, John Woodmorappe, and Peter Klevberg for reviewing an earlier manuscript and offering valuable suggestions.

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