GEOMETRY AND KINEMATICS OF THE LATE CENOZOIC PACIFIC—EURASIA +NORTH AMERICA BOUNDARY

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Summary

Quaternary faults of eastern Asia, most of them currently active, which are parallel to the Pacific margin run both along the margin and as far away of it as the other side of the marginal seas and back-arc basins. Most of the faults of the belt reveal dextral component of motion that likely diminishes landward down to very low fault movement rates. They are extended in the north Pacific with the dextral faults of Alaska and west North America. Together with the island arc systems of east and northeast Asia these faults constitute a single mobile belt between the Pacific plate, from one side, and the North American and Eurasian plates, from the other.

The island arc systems of the north and northwest Pacific are similarly asymmetric, their apexes and back-arc basins shifted towards their west or southwest corners relative to the arc midpoints. If interpreted as having resulted from the arc's yielding to the pressure from the subducting Pacific plate, which is oblique, these features may also be suggestive of the same dextral shear within the Asian segment of the belt.

The inner limit of this late Cenozoic Asian-North American (circum-Pacific) belt follows a great circle on the Earth globe, and is the seaward limit of the more rigid insides of the EU and NA. The amount of tangent dextral component of oblique Pacific subduction in its Asian segment roughly equals that of dextral transform shear along the belt in its North American segment. The EU+NA–PA boundary thus shows up as a single wide and "soft" plate boundary rather then a line-like systems of trenches along which the entire relative motions between the plates could resolve.

Introduction

That the outlines of the western margin of North America and the eastern margin of Asia go altogether close to a great circle line was noticed long ago. Thus, Carey S.W. (Carey1976) advocated the existence of two "near-great-circle" zones of megashear, one of them encircling the Pacific. Later Dickinson W.R. (Dickinson 1978) emphasized the same fact though without any special conclusions on the matter.

It is known that projection-dependent distortions, hardly noticeable for areas of the order of hundreds km in dimension, may grow immensely for larger regions — to the degree when they mask true proportions of geological and tectonic features. This is certainly the case of the NA+EU-Pacific margin which extends for about a third of the Earth's equatorial length. Any non-polar projection gives a view of Pacific margin as sort of a circular feature, and of faults in east Asia as striking at nearly right angle in respect to those in west North America. Polar projections may provide a more realistic impression of the two continents alignment, but cannot be entirely satisfying: any great circle that is not a meridian shows up in a map as a curved line.

To circumvent this kind of problems we utilized cylindrical Mercator projection known for performing near-equatorial areas within a band between about 20°S and 20°N of the Earth's surface with minimum distortion, no matter how long these areas are in the direction of the equator. First, mainly relying on how this boundary appears on a globe, and with intention to present it as straight as possible, we chose six most seaward points of the NA and EU Pacific margin all of them lying in the foot of a slope to either oceanic abyssal plain or a deep trench, always close to the Asian continental crust edge. Then, rotating the equatorial plane both in respect to NS-, and EW-axes, each going through the Earth's center, we found a new position for the equatorial plane with which the sum of standard deviations of distances (measured in great circle degrees) between each of six chosen points and the line of a "new" equator comes to minimum. New 0°-latitude, shown in Fig., was finally found as passing through the point with true 56°N and 143.8°E and making an angle of about 64.4° with the Earth equatorial plane. Performing the procedure as described we did not account for not a pure sphericity of the Earth globe. Apparently, the uncertainty the tentative selection of six points involves is much greater then that is delivered by the deviation of the Earth's surface from being purely spherical. Having acquired a great circle plane oriented as indicated above we recalculated longitudes and latitudes of some of the geographical and tectonic features, previously digitized, assuming our great circle as a new "equator".

The great circle of the Pacific margin, shown in Fig., lies so that it leaves all the island arcs, marginal seas, back-arc basins, and major Quaternary faults of both east Asia and North America to its Pacific side. All the features listed form altogether a belt between mainland of continents and the Pacific ocean. With a distinction made among the islands arcs that developed on the continental crust of the Asia edge, and those that primarily formed on the Pacific oceanic crust (the Izo-Bonin-Mariana system, the northern part of the Philippine arc) this transitional belt comes out as having about the same width all along its length.

Faults

Two fault directions are distinguishable within the belt. First, it is the strike of the San Andreas, Queen Charlotte and Fairweather faults in North America, of the Tanlu fault in east Asia, and of a number of less known faults in northeast Asia all of them stretching mostly along the continental side of the zone behind island arc systems. The San Andreas (for up-to-date citation on the fault see, for example, (Dickinson 1996)), Queen Charlotte and Fairweather faults, as well as the Tanlu (Tancheng-Lujiang) fault zone (Wu *et al.* 1981; Chen Nabelek 1988) are dextral by the sense of motion. The same dextral, at least in one of components, sense of motion may be deduced from focal mechanisms available for some of the extreme NE Asia faults. The Lankovaya-Omolon fault zone (1 in Fig.) is believed to be dextral too (Smirnov 1989), though no data on Quaternary displacements have been so far reported. This fault zone, still plausibly active, is remarkable as barring the transverse-to-Pacific faults of the Chersky-Momsky Range system (2 in Fig.) from penetrating to the western Aleutians. It may be argued that neither the Lankovaya-Omolon fault nor the coastal ridges it follows are disturbed by any transverse structures. NW-trending faults of the Chersky Range simply wane and die out close to the Lankovaya-Omolon fault but not touching it.

Another fault direction is represented by faults of Alaska, then of Kamchatka and Sakhalin, that is, of the island arc flanks which run obliquely to the faults of the first group as if splaying off

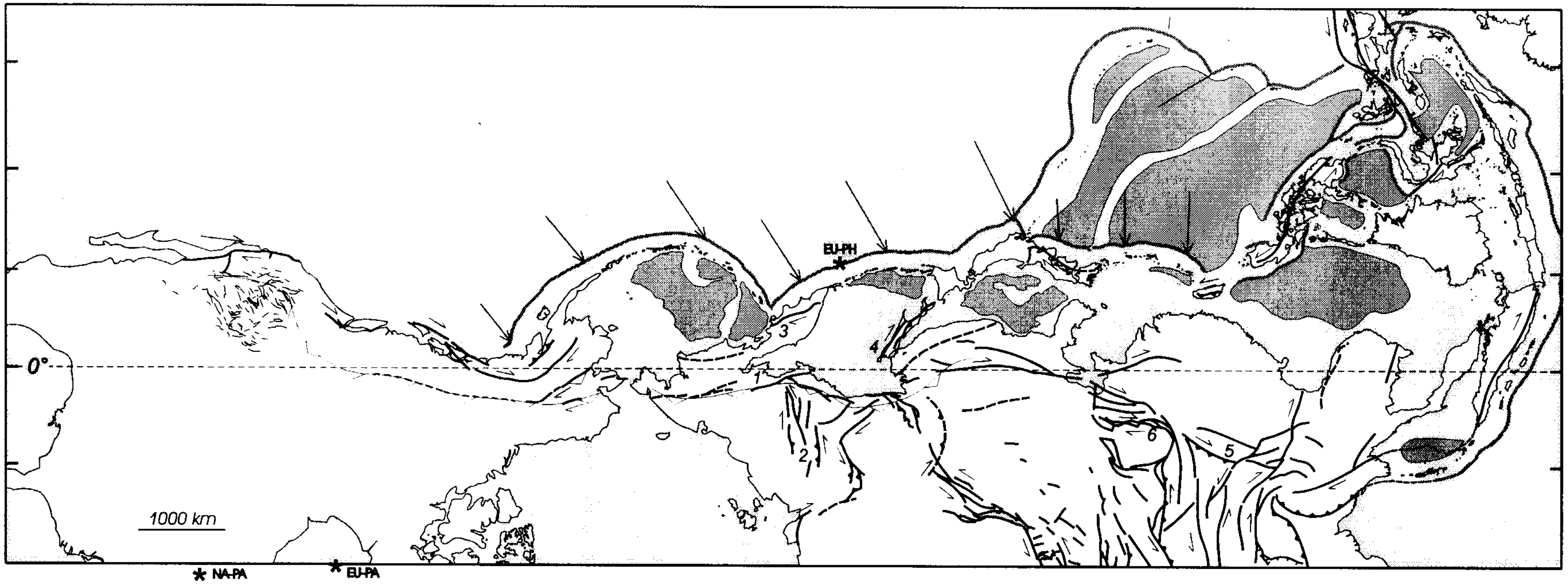

Fig.: Some Late Cenozoic tectonic features of the North American and Eurasian margins of the Pacific ocean
Thick solid and dashed lines are major Quaternary and active faults known and inferred (for numbers see text) , sense of fault motion indicated when available. Dark gray lines and shading show location of deep trench axes and back-arc basins. Arrows are vectors of the Pacific and Philippine plates movements (with the Eurasian and North American plates fixed), their lengths rate dependent, and asterisks are Euler poles (plate movement rates and poles of their rotation are from De Mets *et al.* 1990).Thin open tooth line marks an approximate continental limit of the terrane belt in North America and East Asia.
Mercator projection with 7°N and 7°S as standard parallels, latitudes are scaled with 10°-steps (see text for details). Linear scale is true only for the equator line.

them. Kinematics of Alaskan faults are relatively well known, and they are again chiefly dextral (for full citation and data collection see (Plafker *et al.* 1994). East Kamchatka fault zone (3 in Fig.) combines normal and right-lateral movements, the latter dominating and as fast as reaching about 1 cm per yr (Kozhurin 1988, 1990). In Sakhalin Island there are two main fault zones, each striking its island margin. The fault zone along the Okhotsk sea margin (4 in Fig.) has been predominantly right-lateral since at least middle Miocene, the Pliocene-Quaternary cumulated dextral offset reaching 25-30 km (Rozhdestvensky 1975). The 1995 Neftegorsk earthquake reveals its present-day activity (Shimamoto *et al.* 1996). The fault zone along the other, west, Sakhalin margin, built-up of alternating compressional and tensional (Rozhdestvensky 1976, 1982) or strike-slip (Fournier *et al.* 1994) segments, may be also dextral, but obviously have had significant reverse or thrust component of motion. The northern segment of the Tanlu fault and Sakhalin fault zones bracket the Central Sikhote Alin fault. No data exist in regard of the fault late Cenozoic activity, and it may only be inferred that lateral motions along it, if any, could have most likely been dextral as for a fault between and roughly parallel to two right-lateral neighbouring ones.

Thus, most of the faults along the Asia and North America Pacific margin are right-lateral or have a significant component of dextral motion. Probably, their set should be added with the Longmenshan fault zone, mainly reverse, but with right-lateral component (5 in Fig,), and the right-lateral graben arrays of the Pacific side of the Ordos block (6 in Fig.), both striking along the Pacific coast and transversely to strike-slip faults of Tibet and Inner Mongolia.

The spatial and kinematic integrity of the fault set as described above allows us to see in them elements of a single specific in its circum-Pacific (marginal) position fault belt contrasting with all the other fault systems of the Asian inside evolution of which has been driven by India-Eurasia interaction. Important is that neither of the transverse fault systems and belts of inner Asia appear to cut through the Pacific-parallel fault belt, as the junction between the Chersky Range faults and NE faults of NE Asia clearly exemplifies.

Island arc rises

Remarkable is the inner geometry of the chain of ensialic island arcs of the zone. All of these arcs have much of common in their shape. First, the Aleutian, then Kuril-Kamchatka and Japan island arcs with their extensions beyond junctions with a neighboring arc, and probably Ryukyu arc, if extended with the Korean Peninsula elevation, feature internally regular array (Fig.). To add, even the South China Sea configuration and dimensions do not fall out of this array. Corresponding back-arc basins, in each case shifted to one, and always away from North America, side of an arc, make this regularity even more spectacular. At second, each individual island arc bears a certain degree of asymmetry in its shape. Shape of an arc may be described through the axis line of its deep trench or the line connecting its volcanoes. For the Aleutian arc this was first performed by Streltsov (1988, 1997) who convincingly showed that the best fitting curve for the Aleutian arc shape is parabola, but not a circumference. This seems true for most of other arcs, but important is that all of them are asymmetric uniformly, always skewed towards their ends with back-arc basins.

Terranes

At its position in North America, the new equator line goes close, partially coinciding, with the inner (continental) limit of the belt of suspect terranes that experienced large-scale transcurrent displacements during the Mesozoic and Cenozoic (Coney *et al.* 1980; Bally *et al.* 1989). The other side of the Bering Strait, the same limit may be traced by the Okhotsk-Chukchi volcanic belt, between terranes and exotic blocks of the Verkhoyansk-Chukotka Mesozoides, which likely had never opened into the Pacific basin (Sokolov *et al.* 1997), and those of the Koryak-Kamchtka orogenic area with all their resemblance to North American terranes and links to oceanic plate motions in the Pacifica (Sokolov *et al.* 1997). Further to China, it follows the Asian margin of the Okhotsk Sea, the suspect terranes of which is left to the Pacific side, and west of the Sikhote-Alin further south.

Discussion

Since about 40 Ma ago Eurasia and North America have rotated in respect to each other not more then 8° around the pole in North-East Asia (Engebretson *et al.* 1985). Thus, rectilinear form of the Pacific margin seems to bear on the plate tectonics of the northern Pacific margins over the whole mid-late Cenozoic. The circum-Pacific fault belt spatially coincides with the terrane belt of the North American and Asian Pacific margins, thus location of the belt as a whole and of its individual faults may be thought to be determined by the relatively mobile terrane fringe of both Asia and North America Pacific edges.

The geometrical integrity of the NA and EU Pacific margins manifested in their tendency to follow a great circle line, obvious continuation of Asian Pacific-paralleling faults into the regions of Alaska and western North America, and their in general coincidence with the terrane-built circum-Pacific fringe of both continents imply that all the features most likely originated from interaction of Pacific plate, on one side, and Eurasian and North American plates on the other. Vectors of the Pacific-Asia interaction (see Fig.) show oblique convergence with about 5 cm per yr of right-lateral tangential component, if calculated in respect to the general strike of its margin (new equator line). Thus, the Pacific plate passes by both North American and Asian segments of the belt at about the same rate, and, as in America, its motion may be the cause of dextral fault movements in peripheral Asia.

Gephart (1994) showed that subduction normal to the edge of an overriding plate, and with its vector following Euler equator, is likely to create perfectly symmetrical, in respect to the Euler equator, arched orogenic systems. The explicit asymmetry of east Asia island arc systems may be thus attributed first of all to always oblique to the Asian margin subduction of the Pacific plate.

Conclusions

EU-Pa and NA-Pa plate boundaries make altogether a great circle, and given the negligibly small relative motion between EU and Na, form thus a single plate super boundary. Motion of the Pacific plate relative to this boundary gradually changes along its strike, but always remains significantly tangential. The value of tangential component of Pa - NA+EU convergence seems large enough to explain phenomena of dextral motions along most of the faults of the Asian and American Pacific margin, the width of the belt and of individual faults position, the latter determined in general by relatively mobile terrane-built fringe of both continents. In this respect, the NA+EU-Pacific boundary comes out as rather a wide internally deformable («soft») plate boundary.

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