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TECTONIC MAPS FOR THE CIRCUM-PACIFIC MAP PROJECT

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TECTONIC MAP STYLES

The tectonic map emphasizes structural elements and rock units that portray the major features of the current architecture and past evolution of the earth's crust. Earth scientists might agree that all parts of the earth's continental crust can be said to represent some stage in a hypothetical diastrophic or tectonic cycle, but do not all agree on the description of such a hypothetical tectonic cycle. Two tectonic interpretations, or styles, are discussed below.

A. The Geosynclinorial Tectonic Postulations

Prior to 1967, the majority of earth scientists favored a model suggesting the following successive stages:

1. Geosynclinal subsidence--an initial prolonged downwarping accompanied by sedimentation and possibly volcanism.

2. Orogenic deformation--episodic and spasmodic diastrophism, mainly folding and faulting, accompanied by magmatism and metamorphism.

3. Postorogenic uplift--regional upwarping and planation accompanied by sporadic renewed subsidence and deposition in intermontane basins or marginal foredeeps.

4. Platformal consolidation--tectonic stabilization accompanied by minor movement, sedimentation, or magmatism; isolated sporadic formation of fault-block basins and some neotectonic warping.

The structure of any part of the earth's crust is determined by the extent, nature, and history of diastrophism. Two principal types of diastrophic processes were recognized: epeirogeny, or relatively gentle movements of uplift and subsidence, and orogeny, or intense deformation of geosynclinal sediments in elongate mobile belts within relatively short periods of time. Variants of the basic processes were also recognized; block faulting and monoclinal warping, characterized by vertical movement; and strike-slip faulting, characterized by horizontal movement.

A geosynclinorial tectonic map, such as the Tectonic Map of China and Mongolia, (Terman, 1974); Tectonic Map of North America, (King, 1969); and Tectonic Map of Australia and New Guinea (Tectonic Map Comm. 1971) emphasizes the time of occurrence of the most easily dated geologic event in the cycle, the orogeny, as indicated by the time of folding of geosynclinal sequences, the time of metamorphism of pre-existing terranes, or the time of igneous activity. These events generally serve to separate, on a broad scale, intervening periods of deposition which are not worldwide nor even necessarily synchronous within principal regions. Both the tectonic events and the depositional sequences may vary in age along the strike, significant differences being commonly introduced over great distances.

Archean and most Proterozoic structural patterns and terranes evolved as the primary continental crustal elements were formed and consolidated into stable cratons. Some Proterozoic and all Phanerozoic tectonic patterns became significantly different in nature and extent as the area of continental crust expanded by accretionary cratonization. The latest Proterozoic rocks, limited in areal distribution, are easily separable by lithology and structure from earlier terranes and are closely associated with later terranes; thus, some might be appropriately considered part of the Phanerozoic sequence. The Caledonian and Hercynian orogenies, definitely separate in time and space in Europe, commonly become merged or inseparable in Asia. The Caledonian of Asia normally constituted an early time of tectonic consolidation within a belt where mobility culminated in the Hercynian; thus, in many areas, the Caledonian could be considered to be only the initial stage of a single Paleozoic deformation which is classed as Hercynian. This concept is supported by the appearance of foredeeps which only follow Hercynian orogeny. Also, in some places in Asia, the Paleozoic Hercynian has been extended to include continuing processes that culminated in the Triassic. Mesozoic and Cenozoic events can be readily identified, and they commonly are mapped separately, although this differentiation tends to mask possible continuity in the evolution of the southern and eastern edge of the Asiatic continent.

B. Plate-Tectonic Postulations

Major new advances since 1967, particularly in oceanographic and geophysical work, have inexorably led earth scientists to new understandings of dynamic crustal processes. The principal assumption of the new theoretical synthesis of global tectonics (Heirtzler and others, 1968; Morgan, 1968; Le Pichon, 1968; Isacks and others, 1968) is that the earth's crust is composed of relatively thin (generally less than 150 km thick) but rigid lithospheric plates overlying a low-velocity layer in the soft weak asthenosphere; crustal tectonic phenomena are associated with the interrelated movements (at long-term rates of 2 to 20 cm/yr) of these plates. Active current plate boundaries are defined by the global pattern of seismicity; generally continental margins are not coincident with plate boundaries, and it becomes apparent that the continents are passive passengers on the plates. Inactive or former plate boundaries must be deduced from geologic or geophysical data. The following types of plate boundaries can be recognized (see Dennis and Atwater, 1974, for derivations and discussion):

1. Accreting or divergent boundary--Two plates move apart as basic magma is injected at an oceanic rise (rifting or spreading center); and new crust is created as plates separate; reversal of geomagnetic field as new crust forms produces parallel linear magnetic anomalies in a symmetrical pattern flanking the rise and indicating time and rate of sea-floor spreading.

2. Consuming or convergent boundary--Two plates move toward each other as one oceanic plate is subducted into the asthenosphere at an oceanic trench (subduction zone) and is destroyed as plates overlap; dynamic stresses initiated by bending and descent of plates produce a seismic pattern (Benioff zone) indicating nature, direction, and rate of subduction.

3. Conserving or shear boundary--Two plates slip past one another laterally with no formation or destruction of plates; active transform faults connect segments of oceanic rifts, oceanic trenches, or rift and trench, uniquely indicating pole and relative vector of rotational motion; major inactive strike-slip shears probably are similar evidence for past plate motion.

4. Collision or continental suture--Former plate movement, including possible strike-slip displacement, brought two areas of continental crust together, subduction ceased, and plate motion was globally redistributed; continental suture remains as fossil evidence of former active plate boundaries.

5. Subduction or oceanic suture--Former movement between two plates, at least one of which had oceanic crust, ceased as spreading center was subducted, or jumped to new location as plate motion was globally redistributed; oceanic suture remains as fossil evidence of former active plate boundary.

A plate tectonic map, such as the Preliminary tectonic map of the Indonesian region (Hamilton, 1972) and Tectonic Map of New South Wales (Scheibner, 1974), emphasizes the active and former plate boundaries by distribution of seismicity and selected rock associations.

By accepting the movement of lithospheric plates as a premise, a significant number of convergent boundary conditions can be predicted, and a corresponding variety of tectonic chronologies can be envisioned. Thus, the fundamental conceptual model of geosynclinorial tectonic cycles becomes outmoded if not obsolete (Coney, 1970), as no single developmental or plate-tectonic cycle can be conceived; rather, multiple origins for orogeny can be expected (Dewey and Bird, 1970). However, the two principal orogenic mechanisms postulated, thermal and mechanical, and accompanying tectonic events, tend to be concentrated within specific time intervals of the geologic past which may reflect a cyclic or, more likely, an episodic developmental character of the basic processes responsible for plate movement. The end result of the unreversible orogenic or cratonization process is the continued accretion of new sialic crust around the older continental nuclei.

TECTONIC ELEMENTS

Accretionary cratonization of continents, a postulate of both geosysynclinorial and plate-tectonic models, suggsts that the most fundamental classification of the earth's crust would be:

1. Oceanic crust--Thin layered simatic crust, post-Paleozoic in age, and characterized by volcanic islands, seamounts, and rises.

2. Transitional crust--Sialic crust of variable thickness, mostly post-Paleozoic in age and marginal to continents, and characterized by mobility, deformed sedimentary sequences, seismicity and/or volcanism.

3. Continental crust--Thick sialic crust, mostly pre-Mesozoic in age and characterized by stability in areas of both exposed crystalline basement and relatively undeformed sedimentary cover.

The major tectonic elements of the continental crust are defined principally by their current state of mobility and their relation to the postulated tectonic cycle.

A. In the geosynclinorial model, the stable segments of the continental crust are characterized chiefly by epeirogenic diastrophism and were consolidated or cratonized primarily in pre-Phanerozoic time.

These platforms (cratons, kratogens) are extensive irregular crustal segments normally composed of large, variously shaped shield or elongate uplift regions of outcropping pre-Phanerozoic basement rocks and platform or basin regions in which locally thick, generally flat lying or gently dipping sedimentary deposits cover the basement (old platform, young platform). Stable blocks (massifs, nuclear basins) are smaller platform regions, generally having a thin cover; most of them are confined between more mobile regions.

The mobile segments of the continental crust have undergone an entire tectonic cycle within Phanerozoic time and are characterized by intense orogenic diastrophism. These fold systems are elongate crustal segments, composed of a series of interfingering parallel foldbelts (orogenic belt, orogene, geosyncline), each representing a separate locus of subsidence, sedimentation, and subsequent deformation. Large regions, particularly those consolidated early in the Phanerozoic, have been greatly affected by metamorphism and intrusion, and some could be termed crystalline belts. Some major regions appear to be characterized by volcanic rocks and could be termed volcanic areas.

B. In the plate-tectonic model, the grouping of tectonic elements does not depend on the primary differentiation of stable and mobile segments of the continental crust as much as on suture delineation. Such plate identifications then lead to differentiation of significant components of each plate and finally to the chronologic synthesis of the interaction of plates as evidenced by the tectonic character of those components.

The tectonic map thus could be divided into principal regions on the basis of major differences in the state of tectonic mobility and/or into plates along postulated sutures. These principal regions or plates can be named and outlined on an index map. The principal regions or plates can be subdivided into regions on the basis of gross differences in physiography and structure. These regions can be named on the tectonic map where their configurations are recognizable by the distribution of map units; they also can be named and outlined on an index map. The names of subregions can be introduced in some places for convenience in subsequent description.

The units and tectonic features are shown in outcrop position, as indicated in the geologic source material available in 1977. Tectonic terminology generally should follow the guidelines of the International Geological Congress, Commission for the Geological Map of the World (Dennis, 1967, and Dennis and Atwater, 1974).

TECTONIC MAP COMPILATION

This section is concerned with the application of the two tectonic styles to the compilation of a tectonic map, and it describes, briefly, the rock units and structural and tectonic features of the map.

ROCK UNITS

The rock units are differentiated, by commonly used petrologic names, only into those major categories considered to be tectonically significant. The boundaries between units represent geologic hiatal discordances, such as stratigraphic unconformities, fault contacts, or intrusive contacts, and thus the units in effect are tectonic stages. The age (color) of each unit is the general age of the last geologic evolutionary event, such as intrusion, metamorphism, and deformation of a sedimentary sequence or initiation of sedimentation of an undeformed sequence. The map thus becomes an interpretation of the geologic map, emphasizing the distinction between basement and covering rocks.

A. Basement rocks of the sialic continental crust consist of metamorphic rocks and intrusive igneous rocks, which are defined as felsic, mafic, or ultramafic by their mineral or chemical nature; basement rocks of simatic oceanic crust consist predominantly of submarine volcanic rock.

1. The metamorphic terranes are differentiated by general facies, simply to indicate relative relationships, rather than to present any absolute mineralogic or chemical classifications. Most of these terranes are very poorly known, and the delineation of isograds or specific metamorphic facies is commonly difficult. Trends of foliation formed by orogenic deformation are generally extrapolated from limited published field evidence or inferred from regional interpretation. In a geosynclinorial model, the degree of metamorphism parallels intensity of deformation and cratonization. In the plate tectonic model, the common amphibolite facies containing andalusite or sillimanite indicates high T/P environment of arc-related metamorphic rocks, and the widespread phyllitic or greenschist facies containing kyanite indicates low to medium P and T environment developed regionally by plate collisions or between arcs and trenches; local occurrence of blueschist facies containing glaucophane and jadeite indicates high P/T environment at a subduction site.

2. The felsic intrusive rocks are principally the widespread granite and grandodiorite types. In the geosynclinorial model, these have evolved both by recrystallization and rheomorphism in the chemically and mechanically mobilized environment characteristic of foldbelts. Granitization and orogeny appear to be related crustal phenomena, that may, however, occur quite independently in either time or space. Most granites are considered to be evolutionary products within the axial parts of major geosynclinal fold systems, forming synchronously with the principal orogenies; both the granites and the orogenic foldbelts are identified by age. In the plate-tectonic models, these silicic or granitic intrusive rocks and consanguinous calc-alkaline or andesitic to rhyolitic eruptive rocks form a plutonic-volcanic-volcaniclastic sequence in a magmatic belt or arc superjacent to and resulting from the long-continued partial melting of the descending oceanic lithospheric plate at a convergent boundary; polarity of subduction is indicated by increase of potash as distance from trench increases.

3. The mafic and ultramafic intrusive rocks emphasize the distribution principally of gabbros and serpentinized periodotites, commonly occurring as linear or small plutons. In the geosynclinorial model, these were believed to be intruded along major crustal fractures, possibly originating in the mantle, during the first major tectonic activity within major foldbelts. In the plate tectonic model, the idealized ophiolite sequence consists of ultramafic rocks, gabbro, basaltic or spilitic pillow lavas, cherty pelagites, and abyssal red clays, and represents a vertical section of oceanic crust, generally preserved in the continental geologic record by being scraped off a descending plate at a convergent boundary. No attempt has been made to map these rocks by age or to include all occurrences of other varieties of the ophiolite suite, such as submarine volcanics, diabase, and gabbro.

4. The submarine volcanic rocks, principally tholeiitic basalts, commonly comprise the uppermost basement rocks of the oceanic crust. In the plate-tectonic model, these basalts are created at an oceanic rise and thereby acquire magnetic signatures unique to the time of origin. These rocks can be characterized by the numbered magnetic lineations normally developed symmetrically in relation to the spreading center.

B. Cover rocks include suites of sedimentary and volcanic rocks that are separated from the basement by an unconformable or intrusive contact and a geophysical discontinuity. The sedimentary rocks are identified primarily by tectonic environment or origin and secondarily by a combination of depositional domain (continental, paralic, or marine) and major lithologic group (clastic, carbonate, evaporite, and organic). The tectonic environments are assumed to govern the formation of the following associations or facies.

1. Deformed sedimentary rocks are characterized by thick deeper water marine clastic rocks, notably graywackes, volcaniclastics, and cherts in association with submarine basaltic or spilitic volcanic rocks in peripheral belts (eugeosynclines or arc-related basins on active margins), and by shallower water marine clastic rocks, notably orthoquartzites, and carbonates on adjacent continents (in miogeosynclines or foreland basins). Both sequences are commmonly deformed, possibly much later than their deposition, creating major foldbelts. In the plate-tectonic model, an additional unit of trench-related sedimentary rocks is now recognized as a chaotic melange of exotic blocks of diverse origin within fine-grained turbidite matrix which is interpreted to indicate intense tectonism accompanying the scraping off of sediments from the descending plate at a convergent boundary.

2. Basin deposits are characterized by paralic and terrestial clastic rocks including red beds, wedge arkoses, and coal cyclothems; associated with volcanic rocks in some faulted basins; usually related to post-orogenic uplift or extension in formerly active continental margins.

3. Platform strata covering shields and foldbelts are characterized by shallow-water marine carbonate and clastic rocks, notably reef deposits and orthoquarzites, and some locally extensive evaporites. Inactive or passive continental ocean boundaries (within plate interiors) are characterized by miogeoclinal deposits (Deitz and Holden, 1966) which include lateral gradations from fine-grained clastic and carbonate rocks of continental-shelf facies, and turbidites, clastic wedges, and thin pelagites of continental-rise facies.

   Where marine sedimentation was followed by continental deposition, widespread coal deposits have formed. Isopach lines on the platform deposits will show thickness of strata above the "economic basement," that is the metamorphic or igneous rocks or sedimentary rocks which are too intensely deformed to be potential hydrocarbon reservoirs.

4. Terrestrial volcanic rocks, which are divided on the basis of their mineralogy into, mostly, mafic alkalic basalt, intermediate basalt and andesite, or felsic rhyolite, form extensive cover above basement, deformed sedimentary rocks and, to a lesser extent, the basin and platform strata. The most widespread mafic extrusions apparently are associated with major extensional crustal fractures forming some time after orogenic consolidation. The rather rare felsic rhyolitic extrusions generally are limited in distribution, possibly in association with subjacent arc-related or postorogenic granites.

STRUCTURAL AND TECTONIC FEATURES

Structural features on continents are identified by the simplest symbols and nomenclature compatible with a scale of 1:10,000,000. Fold axes are differentiated into broad anticlines (arches) and selected broad synclines, all typical of platform areas, and tight to overturned anticlines characteristic of foldbelts. Because of the complexity of structures and the lack of detailed data concerning some foldbelts, the symbols in places indicate only the principal interpreted composite fold structures (anticlinoria), rather than single features. Fault traces are classified wherever possible as normal faults, thrust faults, or lateral faults. These imprecise terms are used in a general slip sense-- normal movements down a fault surface which generally dips at a high angle, thrust (reverse) movements up a fault surface which generally dips at a low angle (locally high), and lateral (strike-slip, wrench, tear, transcurrent) movements along the strike of a fault surface. Many unclassified faults indicate general fracture patterns even though detailed knowledge of slip displacement is lacking. Other features shown by symbols denote diapirs, commonly salt-related, volcanoes, emphasizing historic activity, seismic epicenters, magnetic anomaly trends, geochronologic age, paleomagnetic data, and depth to basement rockes. The overall objective in the presentation of structural and tectonic features has been to emphasize major trends and relationships, possibly at the expense of individual smaller structures or features.

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