SEDIMENTARY BASINS

BASIN TYPES ACCORDING TO TECTONIC SETTING

by

Prof. Dr. Abbas Mansour

Types of sedimentary basins

- We can distinguish between (1) active sedimentary basins still accumulating sediments, (2) inactive, but little deformed sedimentary basins showing more or less their original shape and sedimentary fill, and (3) strongly deformed and incomplete former sedimentary basins, where the original fill has been partly lost to erosion, for example in a mountain belt.

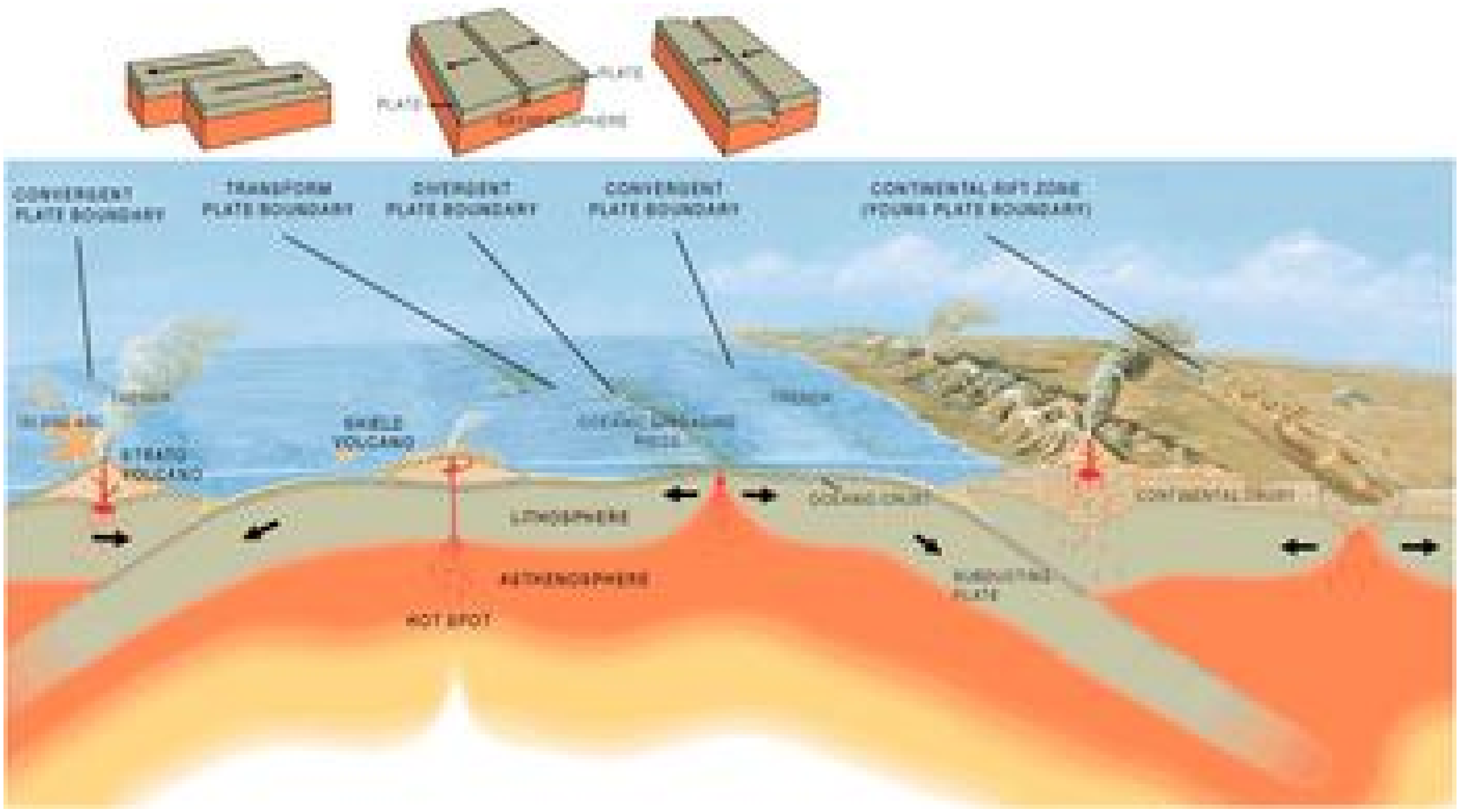
Tectonic Basin Classification

- Basin-generating tectonics is the most important prerequisite for the accumulation of sediments. Such a basin classification must be in accordance with the modern concept of global plate tectonics and hence will differ from older classifications and terminology.

Types of plate boundaries

- There are three types of plate boundaries, characterised by the way the plates move relative to each other. They are associated with different types of surface phenomena. The different types of plate boundaries are:
- **Transform boundaries** occur where plates slide, or perhaps more accurately grind, past each other along transform-faults. The relative motion of the two plates is therefore either sinistral or dextral.
- **Divergent boundaries** occur where two plates slide apart from each other.
- **Convergent boundaries (or *active margins*)** occur where two plates slide towards each other commonly forming either a subduction zone (if one plate moves underneath the other) or an orogenic belt (if the two simply collide and compress).

Types of plate boundaries



The system of Classification

- In this text we essentially use the system described by Mitchell and Reading, but add some minor modifications.
- The different types of sedimentary basins can be grouped into seven categories, which in turn may be subdivided into two to four special basin types

To identify the various basin categories

- In order to identify the various basin categories, one must know the nature of the underlying crust as well as the type of former plate movement involved during basin formation, i.e., divergence or convergence. Even in the case of transform movement, either some divergence or convergence must take place. Small angles of convergence show up as wrenching or fold belts, and small angles of divergence appear as normal faulting or sagging.

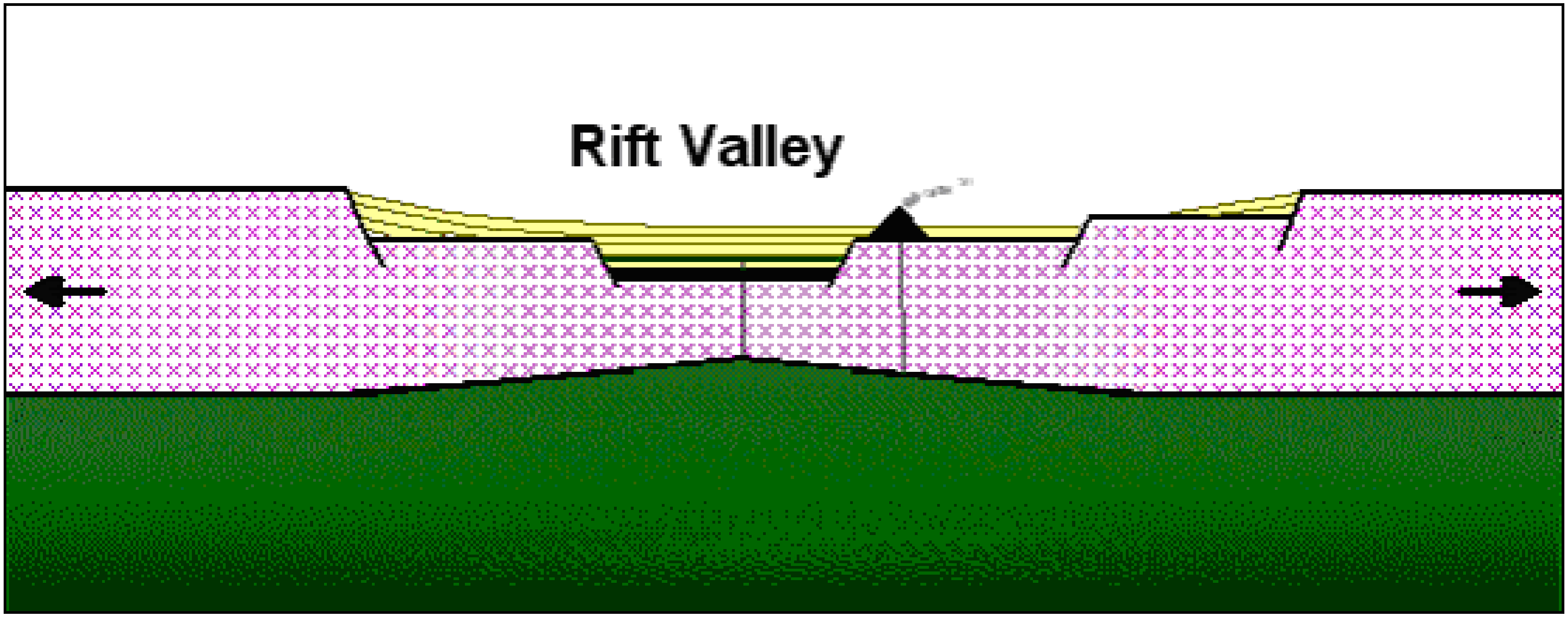
Rift-related basins

Rift basin

- **Geological Origin:** The down-dropped basin formed during rifting because of stretching and thinning of the continental crust
- **Example:** East Africa Rift

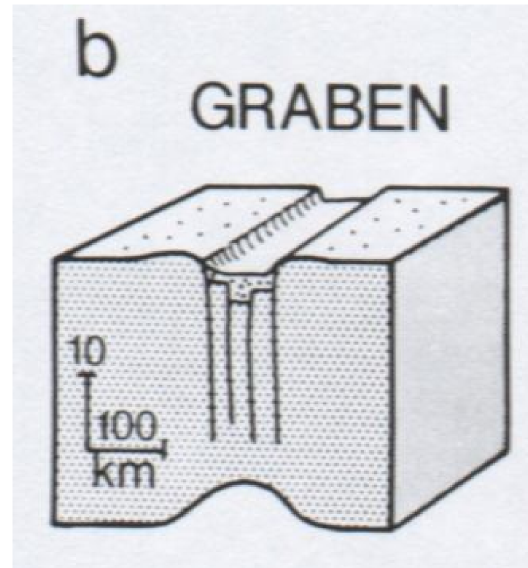
Rift-related basins

Rift basin



Continental graben strictures and rift zones

- **Continental graben strictures and rift zones** form narrow elongate basins bounded by large faults. Their cross sections may be symmetric or asymmetric (e.g., half-grabens). If the underlying mantle is relatively hot, the lithosphere may expand and show updoming prior to or during the incipient phase of rifling. Substantial thinning of the crust by attenuation, which is often accompanied by the up- streaming of basaltic magma, thus forming transitional crust, causes rapid subsidence in the rift zone. Subsequent thermal contraction due to cooling and high sedimentary loading enable continuing subsidence and therefore the deposition of thick sedimentary infillings.



A. Divergent plate margin settings

- 1. CONTINENTAL RIFT ZONES – NARROW
- Origin
  - large scale mantle convection
  - regional updoming
    - ± regional basaltic (flood) volcanism
  - extensional failure of crust
    - lystric normal fault system
    - subsided/rotated half grabens
  - widening to form central rift graben
  - may:
    - rupturing of crust
    - spreading ridge, oceanic basin

A. Divergent plate margin settings

- 1. CONTINENTAL RIFT ZONES – NARROW
- two associated basin types
  1. central rift graben basin
  2. rim basins
  – environments & facies
  1. alluvial fan, fluvial, lake
- volcanism
  1. initial (flood) basaltic (arch phase)
     - lavas
  2. intra-rift bimodal volcanism
     - basalt-rhyolite lavas & pyroclastics
     - often peralkaline
     - calderas, stratovolcano, shields
     - mantle magmas melt crust

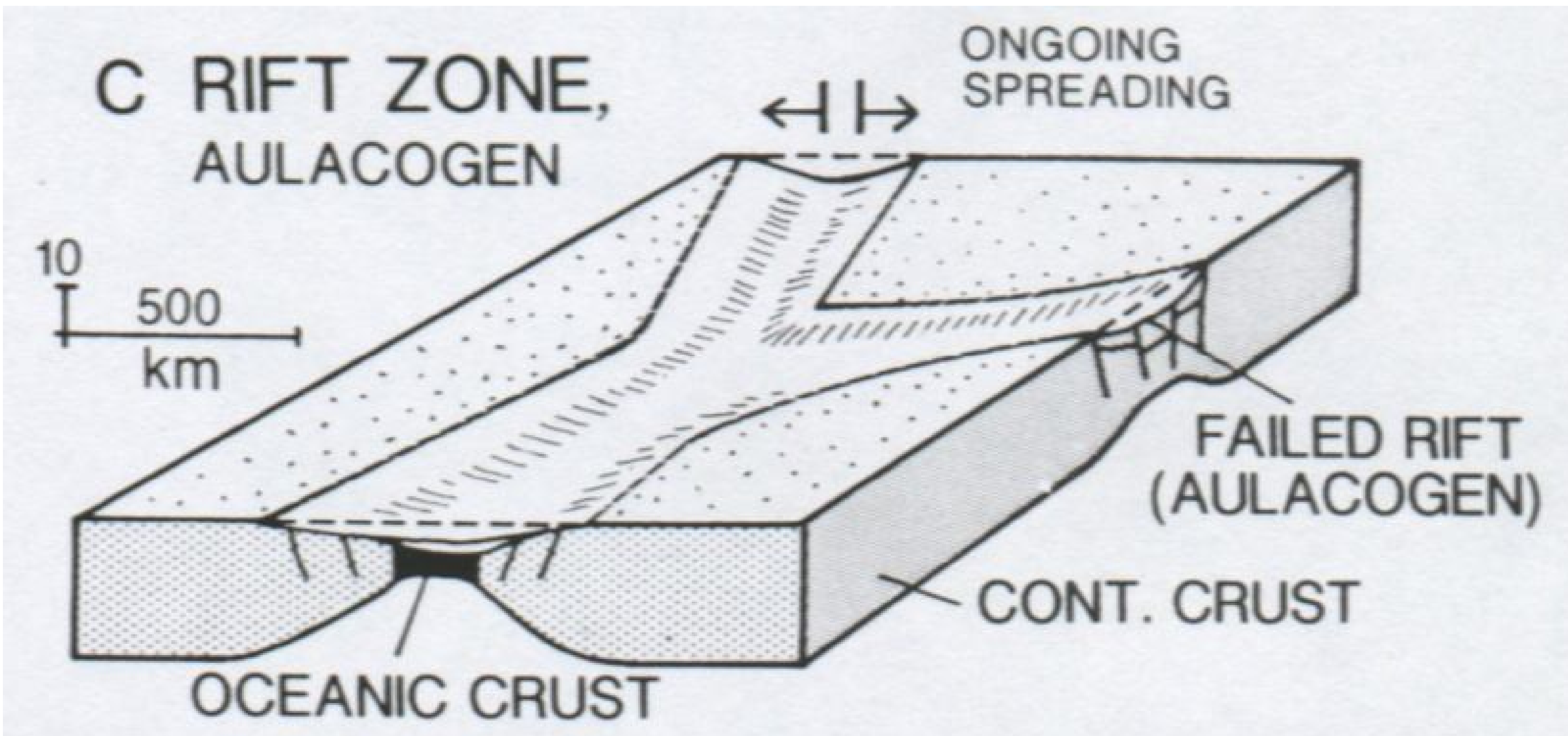
A. Divergent plate margin settings

- 1. CONTINENTAL RIFT ZONES – NARROW
- Sediment compositions
  1. mixed provenance
  2. exposed crustal rocks at rift margin
- contemporaneous volcanic sources
- Examples
  1. East Africa rift zone
  2. Rio Grande rift; Rhine graben
- May be subsequently deformed by compressional deformation
  1. e.g. Proterozoic Mt. Isa rift
  2. Devono-Carb. Mt. Howitt province, Victoria

Failed rifts and aulacogens

- If divergent plate motion comes to an end before the moving blocks are separated by accretion of new oceanic crust, the rift zone is referred to as "failed". A certain type of such failed rifts is an aulacogen. Aulacogens represent the failed arm of a triple junction of a rift zone, where two arms continue their development to form an oceanic basin. Aulacogen floors consist of oceanic or transitional crust and allow the deposition of thick sedimentary sequences over relatively long time periods. Basins similar to aulacogens may also be initiated during the closure of an ocean and during orogenies

Failed rifts and aulacogens



A. Divergent plate margin settings

- 2. AULACOGENE BASINS
- Narrow continental rifts which do not evolve into spreading ridge oceanic basins.
  - e.g North Sea basins, Europe; Gippsland Basin, Bass Basin.
- Dominated by initial alluvial fan, fluvial, lake facies; up to 4 km thick.
- May extend enough
  - crustal subsidence & extension
  - marine transgression; no oceanic crust
  - coastal plain rivers, coal swamp shoreline, shelf & slope environment (e.g. Gippsland, Bass basins
- Provenance
  - continental, mixed
  - plutonic, metasedimentary, metavolcanic, contemporaneous volcanic
  - ± marine carbonates

A. Divergent plate margin settings

- **<u>3. CONTINENTAL RIFT ZONES</u>**
- Origin
  - regionally extensive mantle convection
  - = ? driven by subduction oceanic spreading ridge under continent
    - e.g. ?Western U.S.A.
  - extensional failure of crust
  - complex lystric fault system
    - down to 15 km, Western U.S.A.
  - uprise of mantle + metamorphic core complexes - regional uplift, up to 2-3 km
  - widespread volcanism in complex multiple graben rift basins
- Environments and facies
  - alluvial fan, fluvial, lacustrine
- Volcanism
  - flood basalts, bimodal basalt-rhyolite-andesite: lavas & pyroclastics
  - tholeiitic, alkaline, calc-alkaline: lavas & pyroclastics.
- Provenance
  - mixed crustal sources
  - contemporaneous volcanic sources

A. Divergent plate margin settings

- **4. OCEANIC RIFT BASINS, Initially narrow (e.g. Red Sea)**
  - **may evolve into open oceanic basins**
- **Origin**
  - narrow continental rifts evolve
  - break-up
  - oceanic spreading ridge
  - oceanic crust inaxial basins
  - continental crust at basin margin
- **Environments & facies**
  - alluvial fans, fan deltas, shoreline narrow shelf, slope, abyssal plain
- **Volcanism**
  - MORB tholeiitic oceanic crust
  - lavas, hyaloclastite
- **Provenance**
  - mixed continental
  - contemporaneous volcanics
  - shelf carbonate, evaporites
  - oceanic carbonate, evaporites
  - oceanic pelagic, hemi-pelagic

A. Divergent plate margin settings

- **5. <u>OPEN OCEAN-PASSIVE MARGIN BASINS</u>**
- **Evolve from oceanic rift basins**
- **Become passive margin basins when MOR’s - large, wide ocean basins.**
- **Half graben system evolves into coastal plain-continental shelf & slope**
  - **oceanic abyssal plain system**
- **Volcanism**
  - **none expected after break-up**
  - **perhaps intraplate hot spot volcanism**
- **Sedimentation & provenance**
  - **as for oceanic rift basin**
  - **+ well developed shelf-slope seds (± carbonate seds.)**
- **Tectonics**
  - **post-break-up thermal & later isostatic subsidence of continental margin**
    - **transgression**

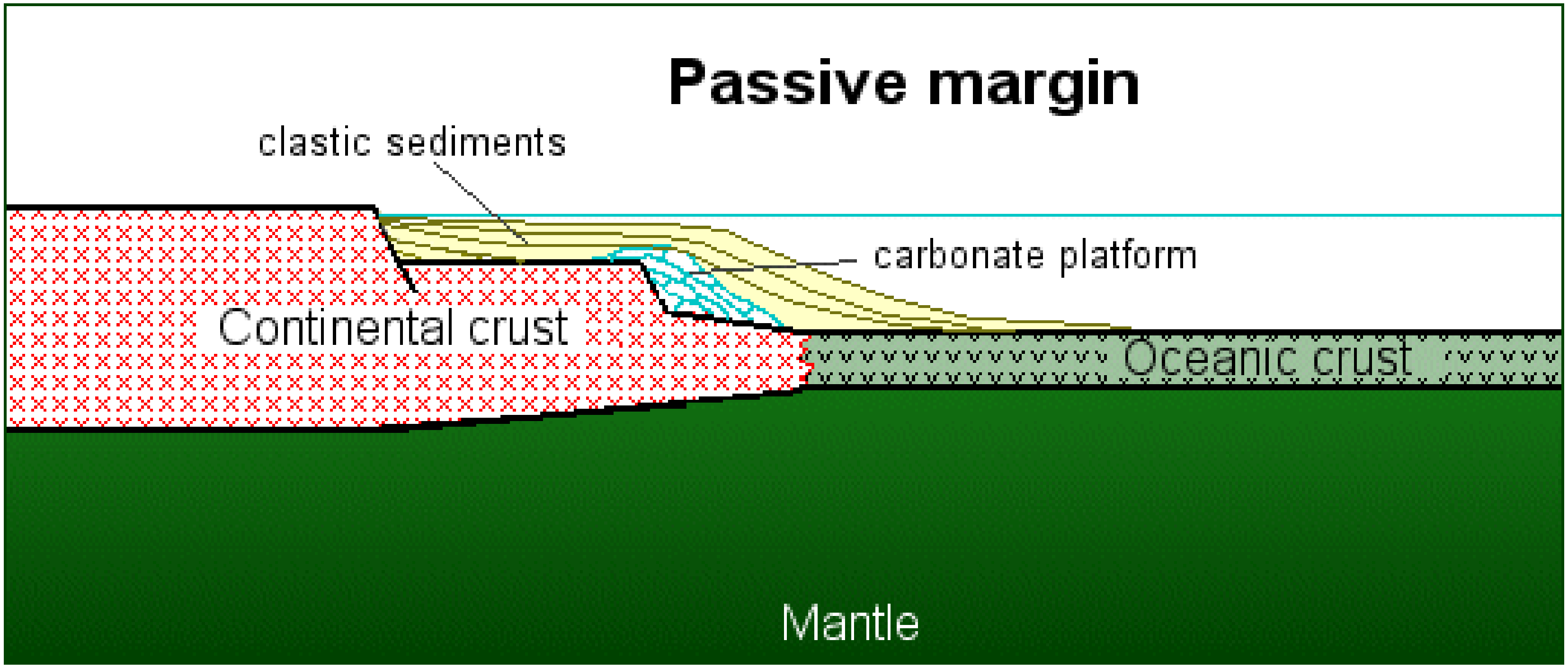
Rift-related basins

Passive margin basin

- **Geological Origin:** Subsidence along a passive margin, mostly due to long-term accumulation of sediments on the continental shelf
- **Example:** East coast of North America

Rift-related basins

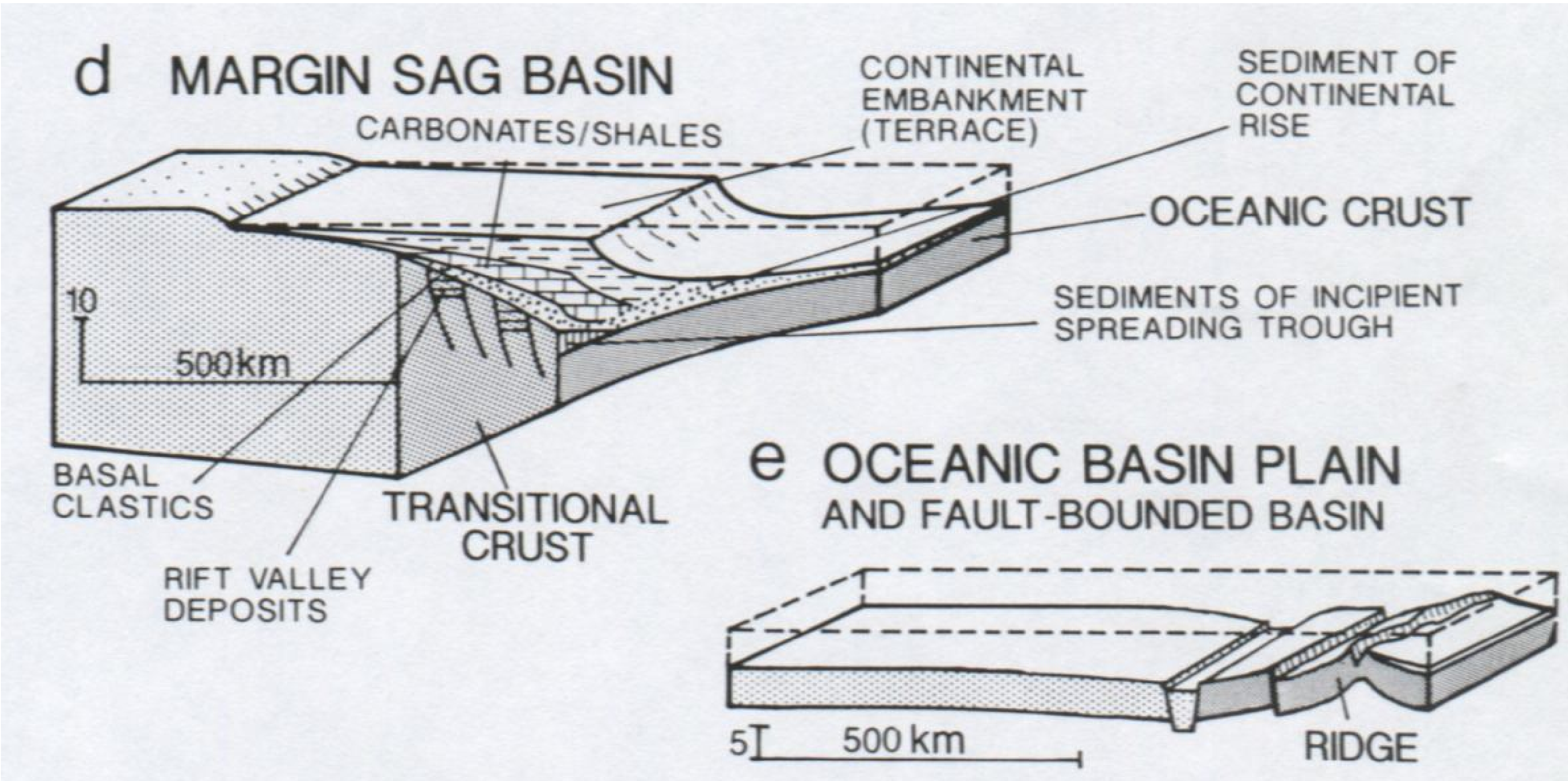
Passive margin basin



Passive margin basins

- The initial stage of a true oceanic basin setting (or *a* proto-oceanic rift system) is established when two divergent continents separate and new oceanic crust forms in the intervening space. This does not necessarily mean that such a basin type fills with oceanic sediments, but it does imply that the central basin floor lies at least 2 to 3 km below sea level. When such a basin widens due to continued divergent plate motions and accretion of oceanic crust (drifting stage), its infilling with sediments lags more and more behind ocean spreading.

Passive margin basins



Passive margin basins

- Consequently, the sediments are deposited predominantly at the two continental margins of the growing ocean basin. The marginal "basins" developing on top of thinned continental crust are commonly not bordered by morphological highs and represent asymmetric depositional areas. Their underlying crust increasingly thins seaward; hence subsidence tends to become greater and faster in this direction. Here, sediments commonly build up in the form of a prism (Fig. D).

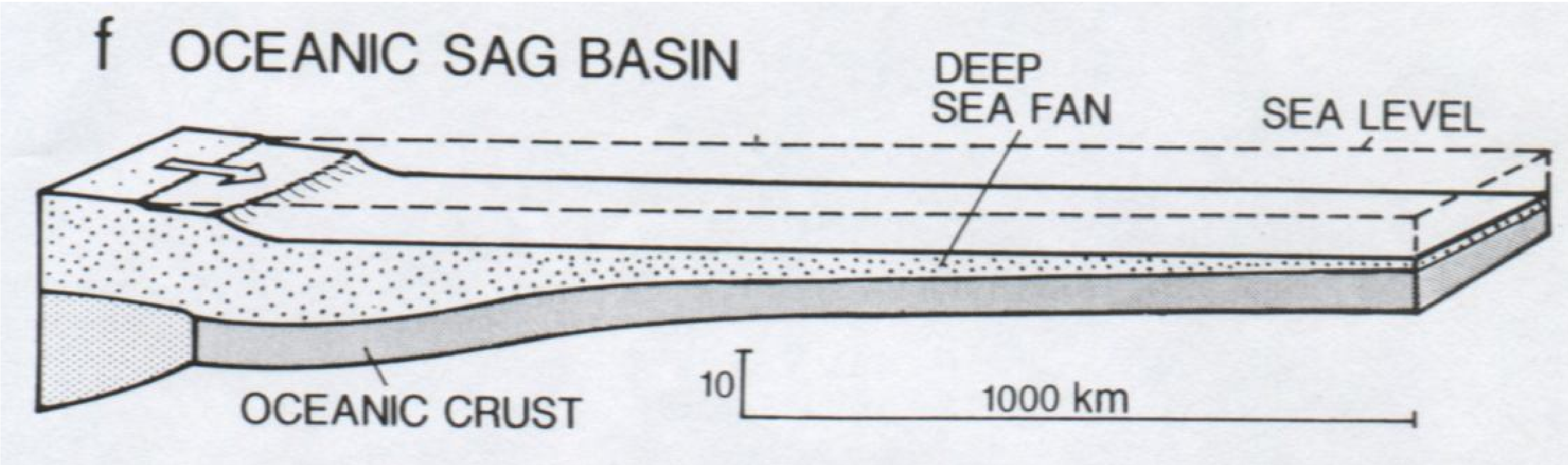
Passive margin basins

- Some of these marginal basins may be affected and bordered by transform motions (tension-sheared basins). In a sediment-starved environment, subsided transitional crust can create deep plateaus (sunk basins). In general, subsidence of these marginal basins tends to decrease with passing time, unless it is reactivated by heavy sediment loads.

Oceanic sag basins or nascent ocean basins

- **Oceanic sag basins** or nascent ocean basins occupy the area between a mid-oceanic ridge, including its rise, and the outer edge of the transitional crust along a passive continental margin (Fig. f). They commonly accumulate deep-sea fan or basin plain sediments. Due to the advanced cooling of the aging oceanic crust, subsidence is usually low, unless it is activated by thick sedimentary loading near the continental margin. Fault-bounded basins of limited extent are common in conjunction with the growth of mid-oceanic ridges

Oceanic sag basins or nascent ocean basins



B. Convergent plate margins

- Another group of basins is dominated by convergent plate motions and orogenic deformation. Basins related to the development of subduction complexes along island arcs or active continental margins include deep-sea trenches, forearc basins, backarc basins (Fig. 1.2a and b), and smaller slope basins and intra-arc basins.

B. Convergent plate margins

- **6. <u>CONTINENTAL MARGIN ARC-SUBDUCTION ASSOCIATED BASINS</u>**
- Sediment compositions
  - <u>Trench</u>
    - metasedimentary debris eroded off accretionary prism
    - v. minor volcanic debris
    - pelagic sed.
  - <u>Forearc basin</u>
    - voluminous volcanic debris
  - <u>Back-arc basin</u>
    - arc & thrust belt derived
    - mixed volc., meta-sed., metamorphic, plutonic
  - <u>Intra-arc basins</u>
    - lavas,volcanic seds, pyroclastics

B. Convergent plate margins

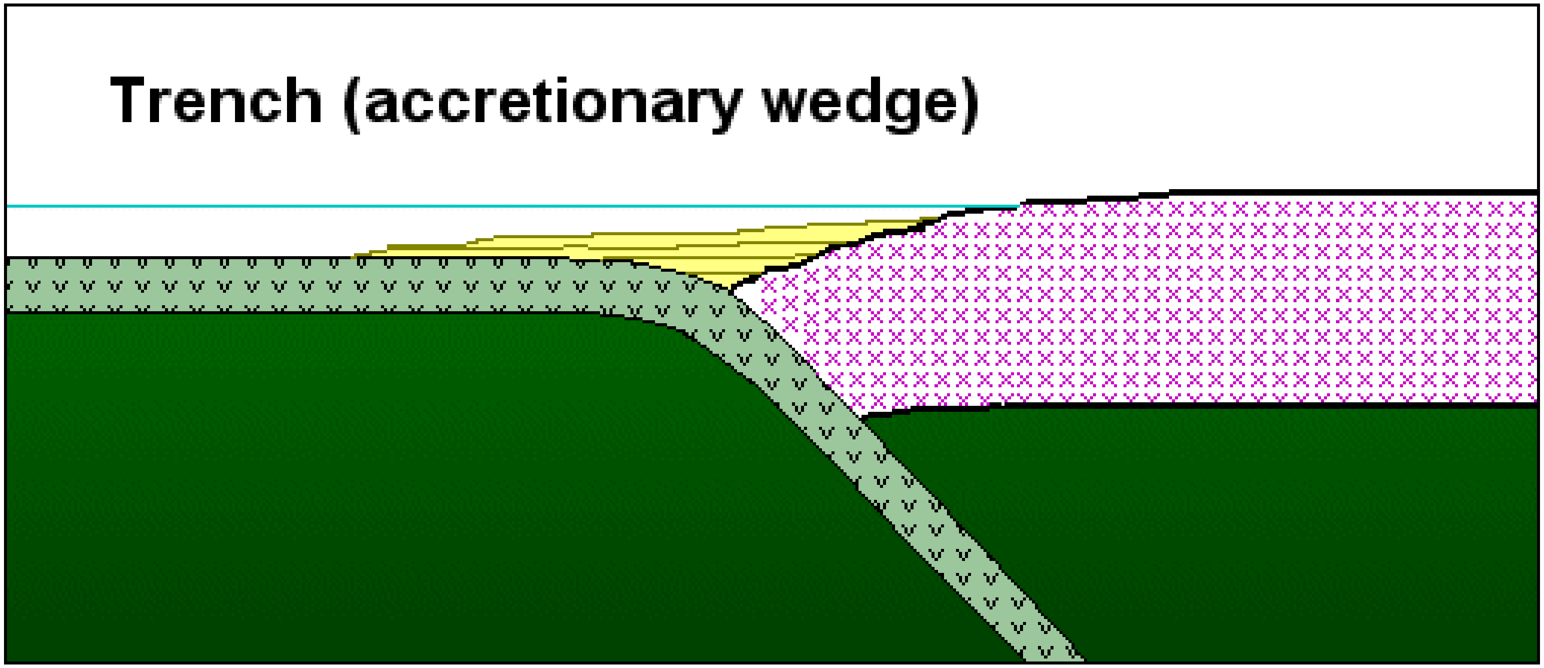
- *Deep-sea trench floors* are composed of descending oceanic crust. Therefore, some of them represent the deepest elongate basins present on the globe. In areas of very high sediment influx from the neighboring continent, however, they are for the most part filled up and morphologically resemble a continental rise. Deep-sea trenches commonly do not subside as do many other basin types. In fact, they tend to maintain their depth which is controlled mainly by the subduction mechanism, as well as by the volume and geometry of the accretionary sediment wedge on their landward side

Subduction-related basins

Trench (accretionary wedge)

- **Geological Origin:** Downward flexure of the subducting and non-subducting plates (sites of accretionary wedges)
- **Example:** Western edge of Vancouver Island

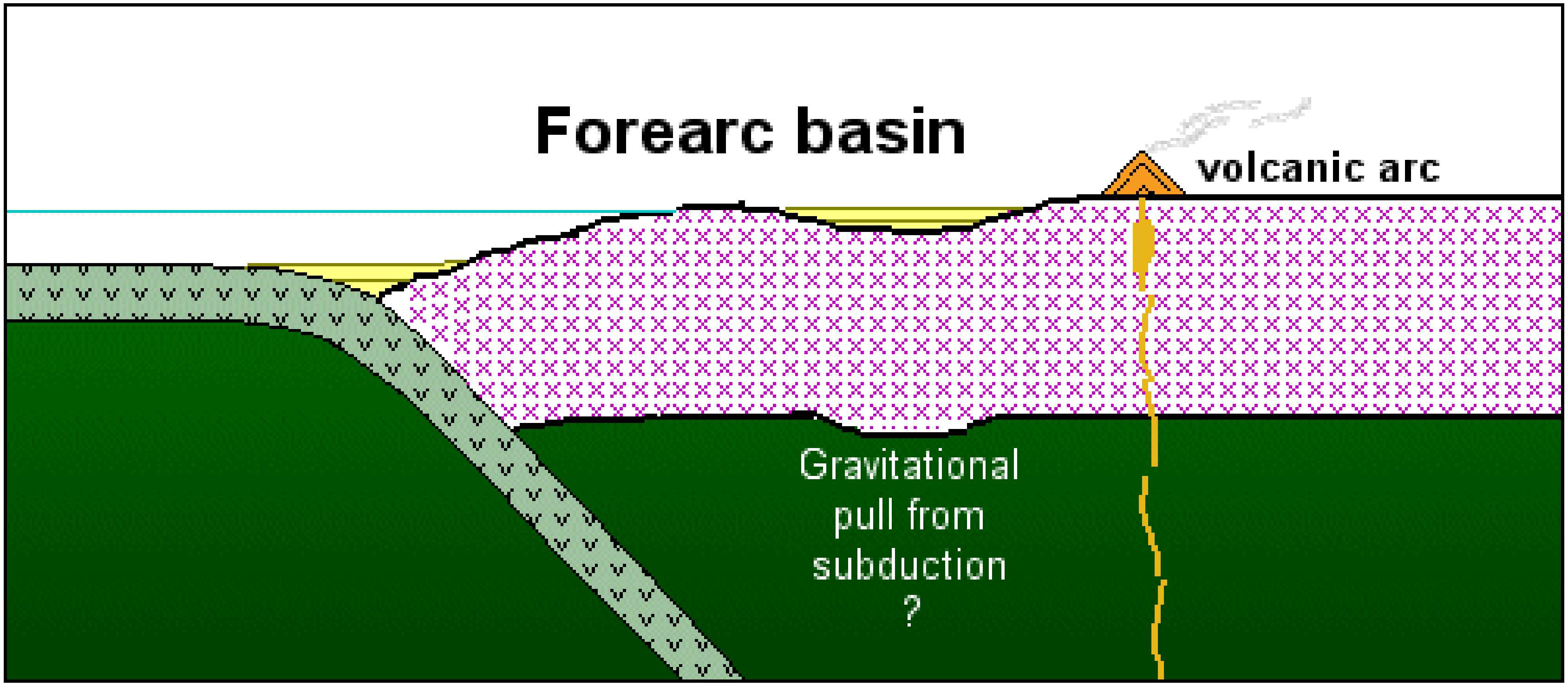
Subduction-related basins



Subduction-related basins
Forearc basin

- **Geological Origin:** The area between the accretionary wedge and the magmatic arc, largely caused by the negative buoyancy of the subducting plate pulling down on the overlying continental crust
- **Example:** Georgia Strait

Subduction-related basins



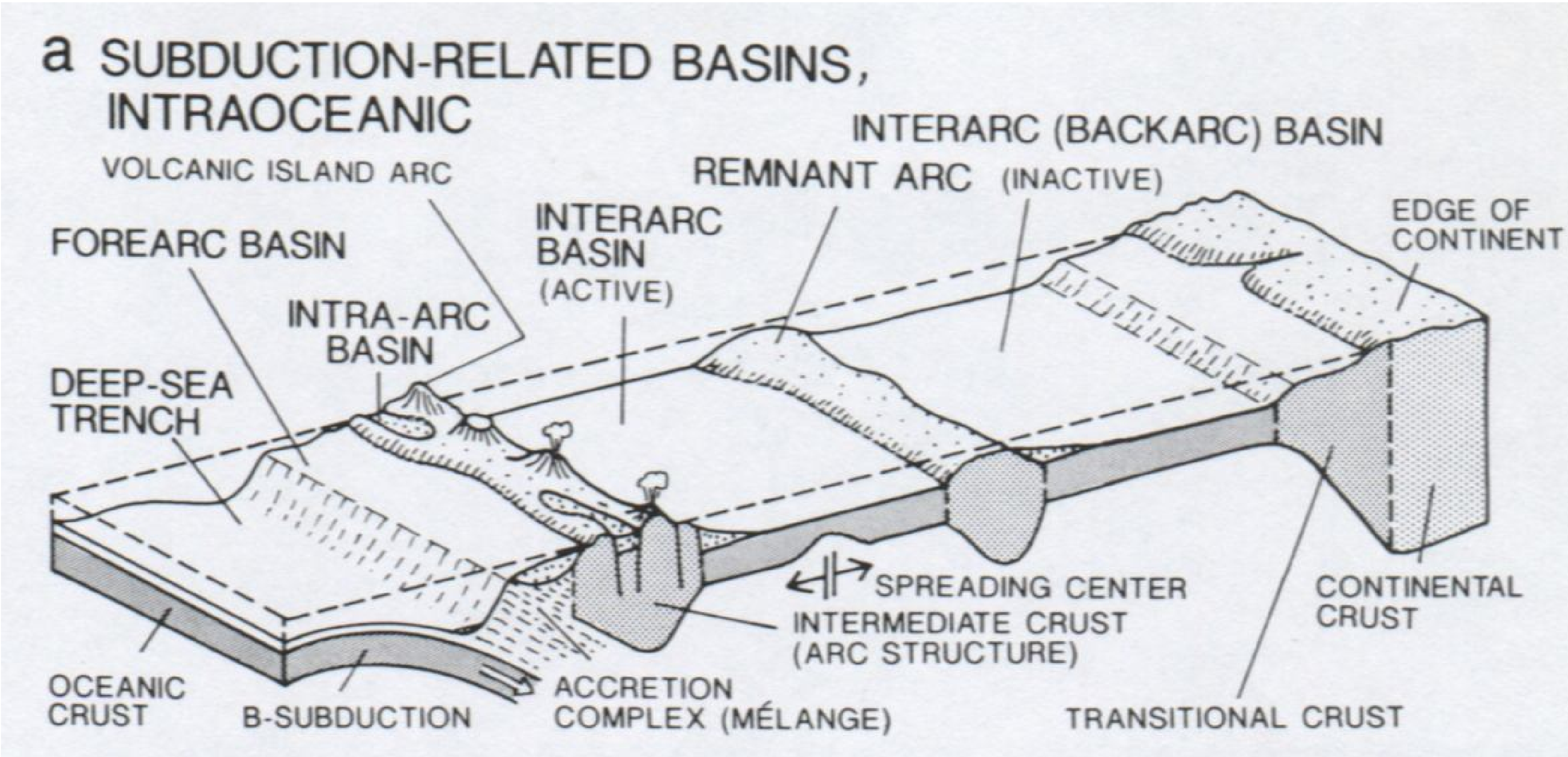
Subduction-related basins

- *Forearc basins* occur between the trench slope break of the accretionary wedge and the magmatic front of the arc. The substratum beneath the center of such basins usually consists of transitional or trapped oceanic crust older than the magmatic arc and the accretionary subduction complex. Rates of subsidence and sedimentation tend to vary, but may frequently be high. Subsequent deformation of the sedimentary fill is not as intensive as in the accretionary wedge .

Subduction-related basins

- *Backarc or interarc basins* form by rifling and ocean spreading either landward of an island arc, or between two island arcs which originate from the splitting apart of an older arc system (Fig. 1.2a). The evolution of these basins resembles that of normal ocean basins between divergent plate motions. Their sedimentary fill frequently reflects magmatic activity in the arc region.

Subduction-related basins



B. Convergent plate margins

- **7. ISLAND ARC-SUBDUCTION ASSOCIATED BASINS**
- **E.g. Marianas, Tonga-Kermadec arcs**
- **Origin**
  - oceanic plate is subducted under another oceanic plate
  - trench, accretionary prism, volcanic island arc
  - volcanic arc on oceanic lithosphere
  - back arc basin(s) originate by rifting of arc block, development of small spreading ridge
    - **widening basin; oceanic crust**
  - arc block migrates trenchward as subducting plate "rolls back".
- **Volcanism**
  - island arc tholeiitic volcanics
    - **basalts, basaltic andesites**
  - back arc basin tholeiitic crust

B. Convergent plate margins

- **7. <u>ISLAND ARC-SUBDUCTION ASSOCIATED BASINS</u>**
- **Basin types, environments, facies, provenance**
  - **<u>Trench basin</u>**
    - **turbidites, pelagic sediments**
    - **metasedimentary sed. from accretionary prism**
    - **arc derived volcanic sediment**
  - **<u>Fore-arc basin</u>**
    - **on accretionary prism**
    - **volcanic seds., carbonates**
    - **turbidites**
  - **<u>Back arc basin</u>**
    - **arc derived volcaniclastic turbidite apron**
    - **pelagic sediments, especially where basin is large**
  - **no continental derived sediment**
  - **only rare silicic volcanism**

B. Convergent plate margins

- Temne-related basins are situated between micro-continents consisting at least in part of continental crust (Nur and Ben-Avraham 1983) and larger continental blocks. The sub- stratum of these basins is usually oceanic crust. They may be bordered by a subduction zone and thus be associated with either basins related to subduction or collision.

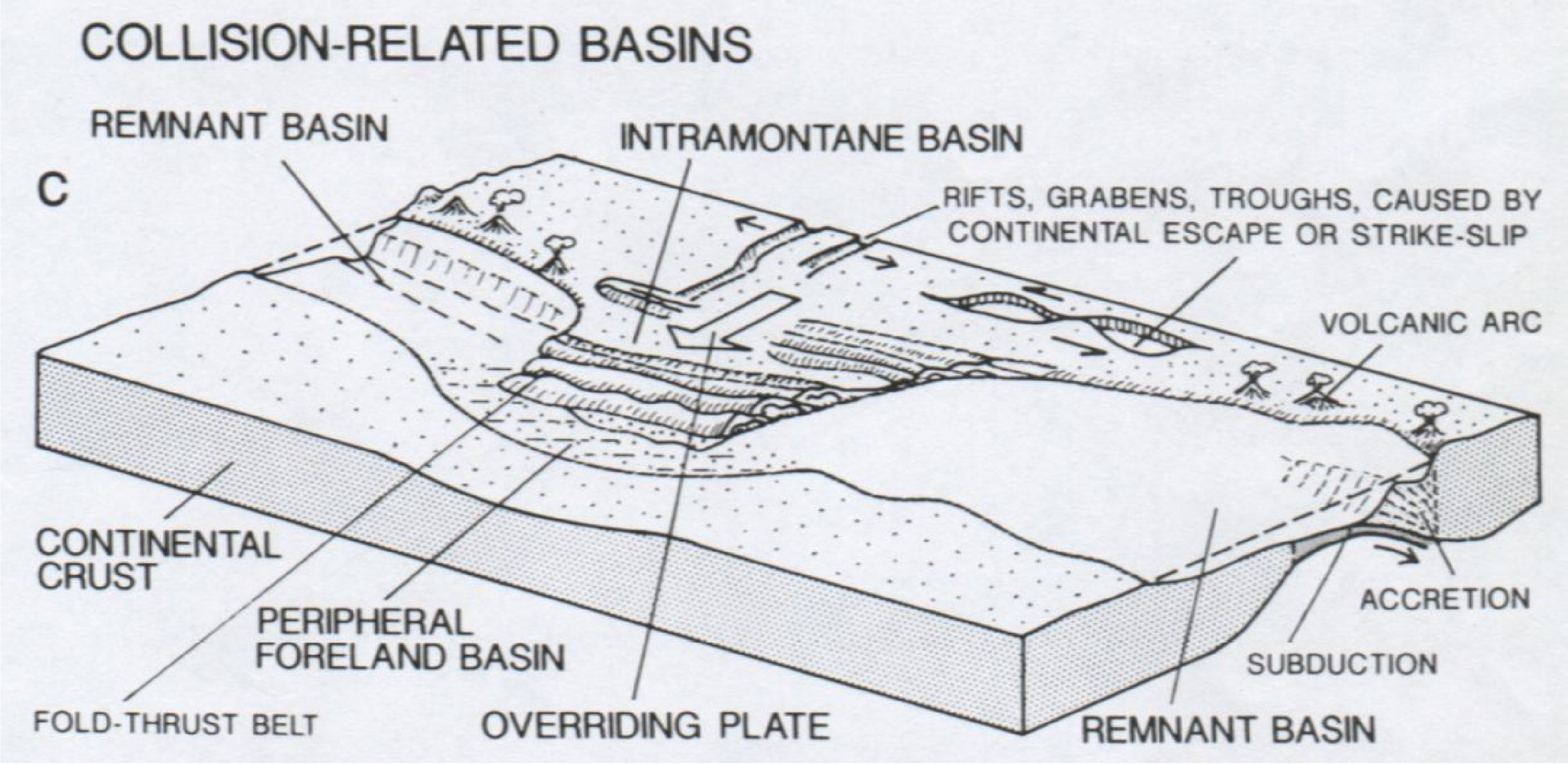
B. Convergent plate margins

- **8. <u>CONTINENTAL COLLISION BELTS & BASINS</u>**
- **E.g. Himalayan mountain chain, European Alps**
- **Origin**
  - long term subduction of oceanic plate under continental margin, will bring "passenger" continent into collision with arc host continent.
  - oceanic basin closes during collision
  - subducting continent under thrust over-riding continent
  - uplift, mountain range, double continental crust thickness
- **Volcanism**
  - subduction related volcanism stop at collision, when subduction stop
  - granitoid plutonism may occur due to extremely thickened crust
    - **magmas won't rise because of compressional stress field**
- **Basin types, environments, facies provenance**
  - foreland basin at foot of fold & thrust belt
  - subject to isostatic subsidence
  - huge sediment flux off mountain belt
  - alluvial fan, braided river, meandering river, lake environments & facies
  - metasedimentary, met. (include high grade plutonic, reflecting deep crustal erosion)

Basins related to collision

- Partial collision of continents with irregular shapes and boundaries which do not fit each other leads to zones of crustal over thrusting and, along strike, to areas where one or more oceanic basins of reduced size still persist (Fig. 1.2c). These *remnant basins* tend to collect large volumes of sediment from nearby rising areas and to undergo substantial synsedimentary deformation (convergence, also often accompanied by strike-slip motions).

Basins related to collision



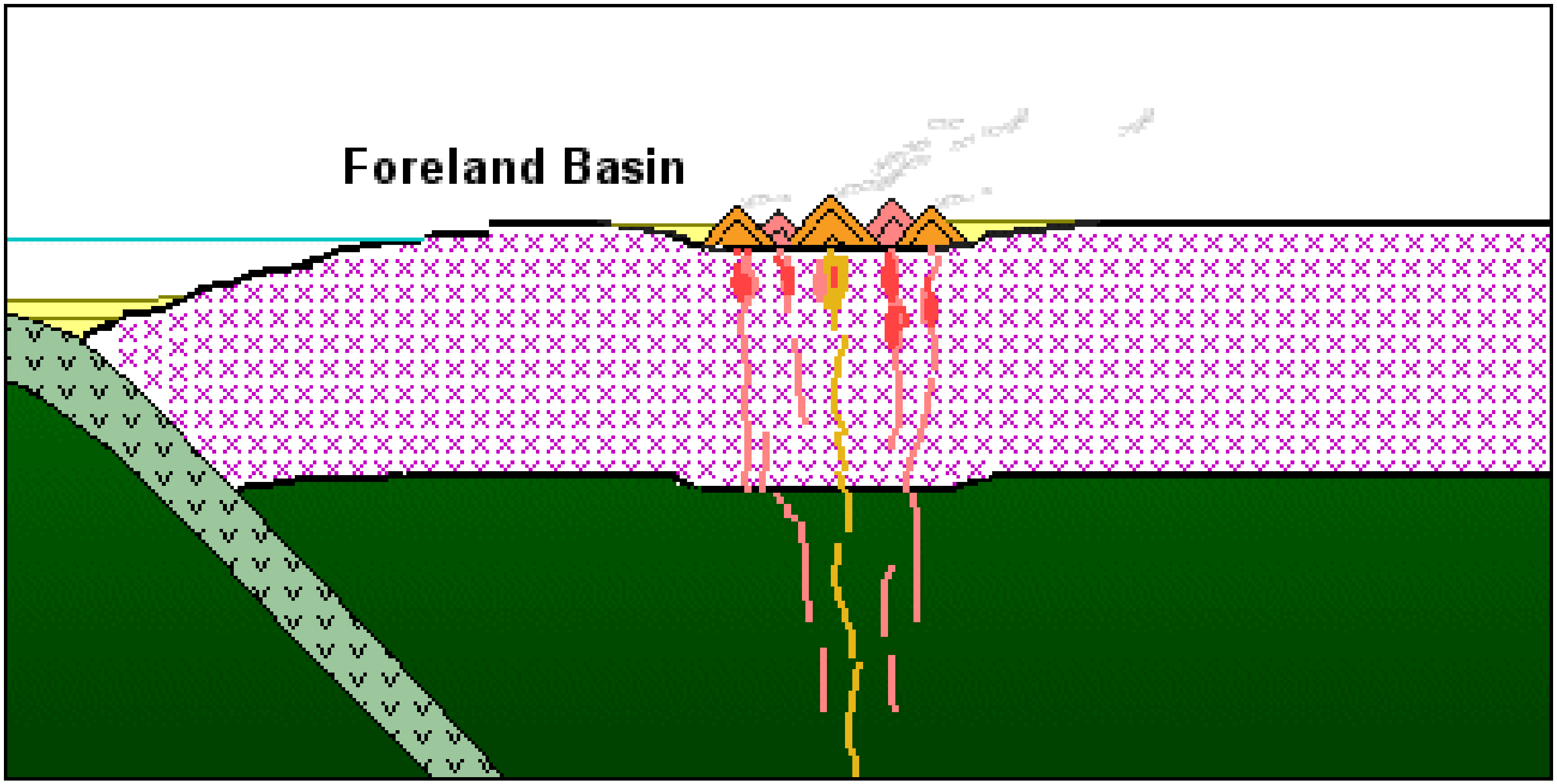
Foreland basin

- *Foreland basins*. and *peripheral basins* in front of a foldthrust belt, are formed by depressing and flexuring the continental crust ("A-subduction", after Ampferer, Alpine-type) under the load of the overthrust mountain belt (Fig. 1.2c and Fig. 1.3a). The extension of these asymmetric basins tends to increase with time, but a resulting large influx of clastic sediments from the rising mountain range often keeps pace with subsidence

Foreland basin

- **Geological Origin:** A depression caused by the weight of a large mountain range pushing the adjacent crust below sea level **Example:** The sediment filled plain south of the Himalayas

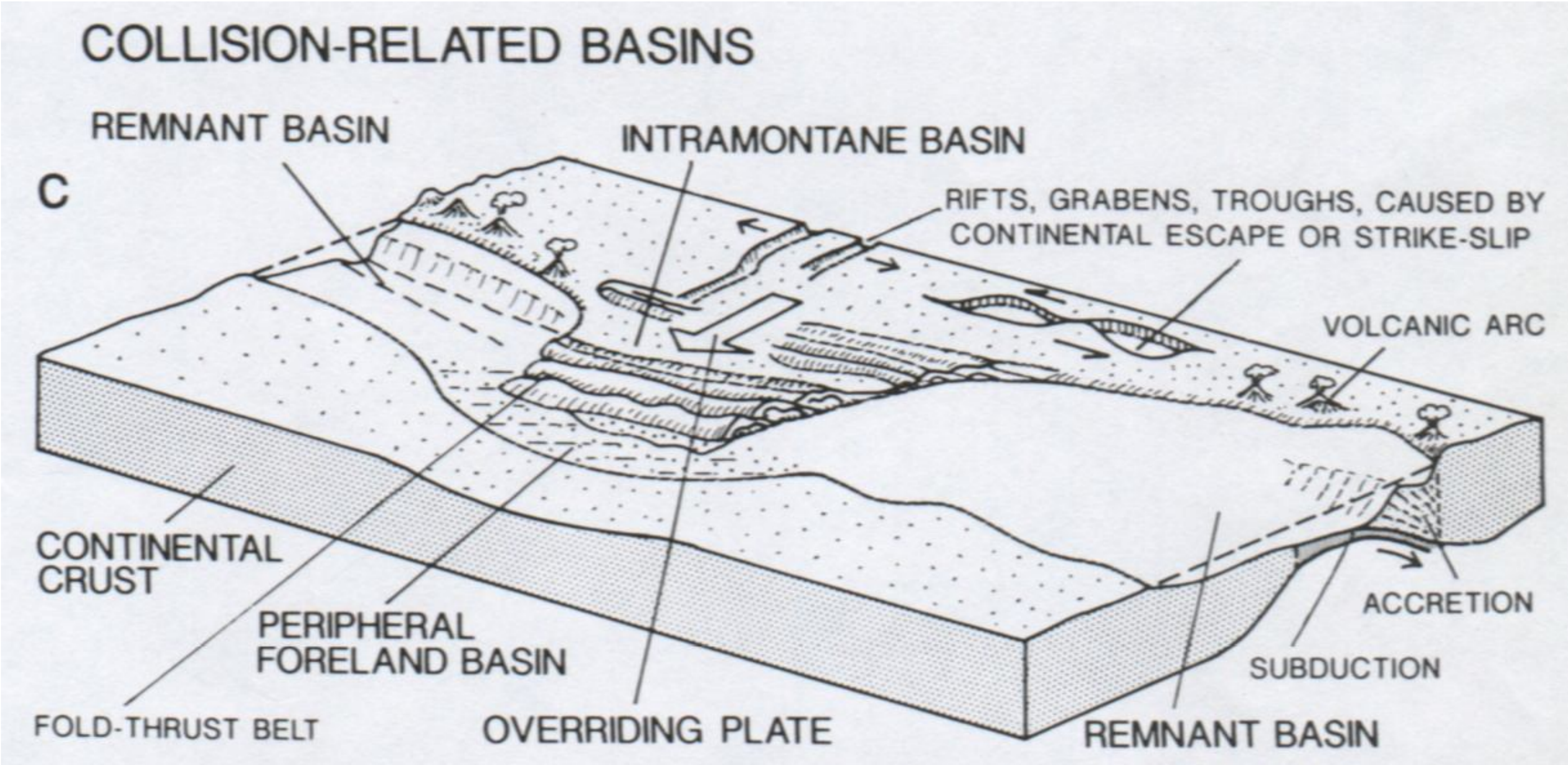
Foreland basin



Basins related to collision

- As a result of the collision of two continental crusts, the overriding plate may be affected by 'continental escape', leading to extensional graben structures or rifts perpendicular to the strike of the fold-thrust belt (Fig. 1.2c).

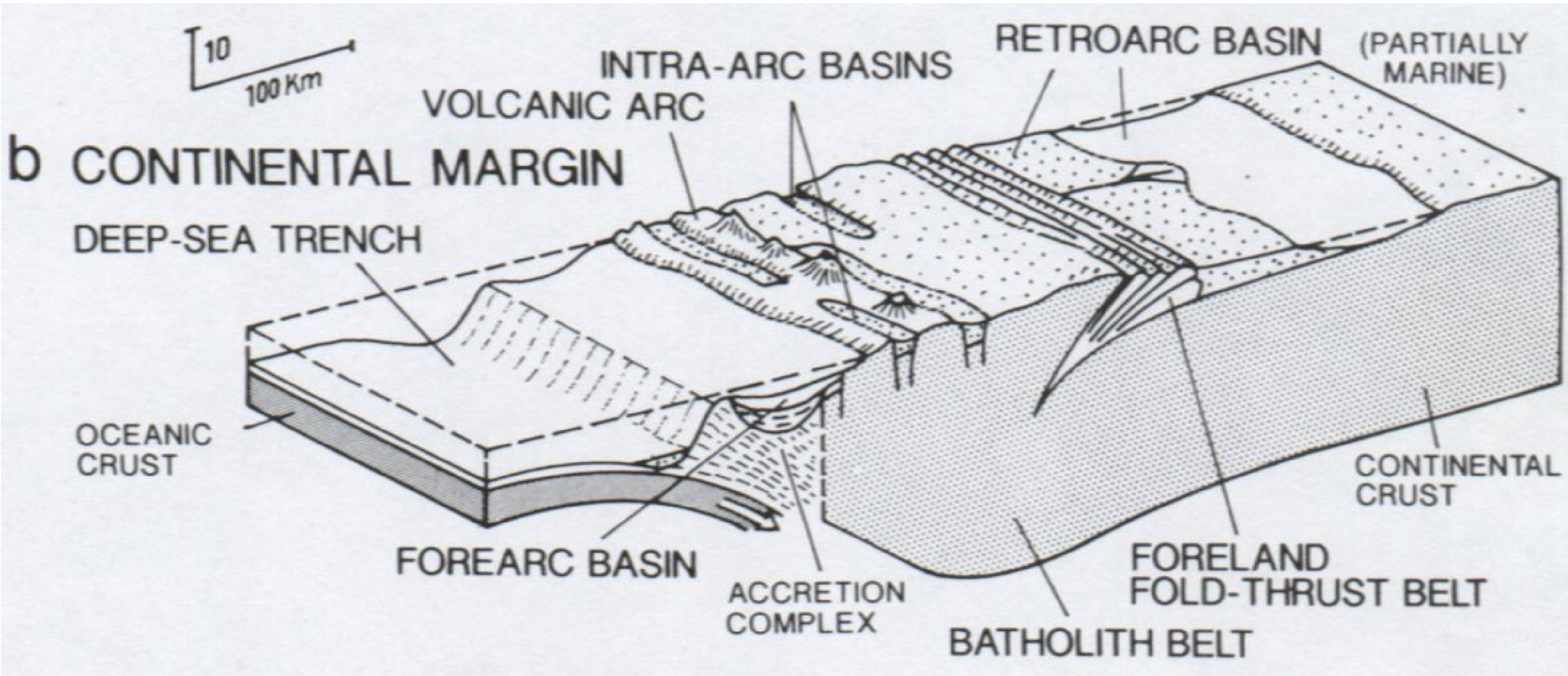
Basins related to collision



Basins related to collision

- *Retroarc or intramontane basins* (Fig. 1.2b) occur in the hinterland of an arc orogen ('B-subduction" zone). They may affect relatively large areas on continental crust. Limited subsidence appears to be caused mainly by tectonic loading in a backarc fold-thrust belt.

Basins related to collision



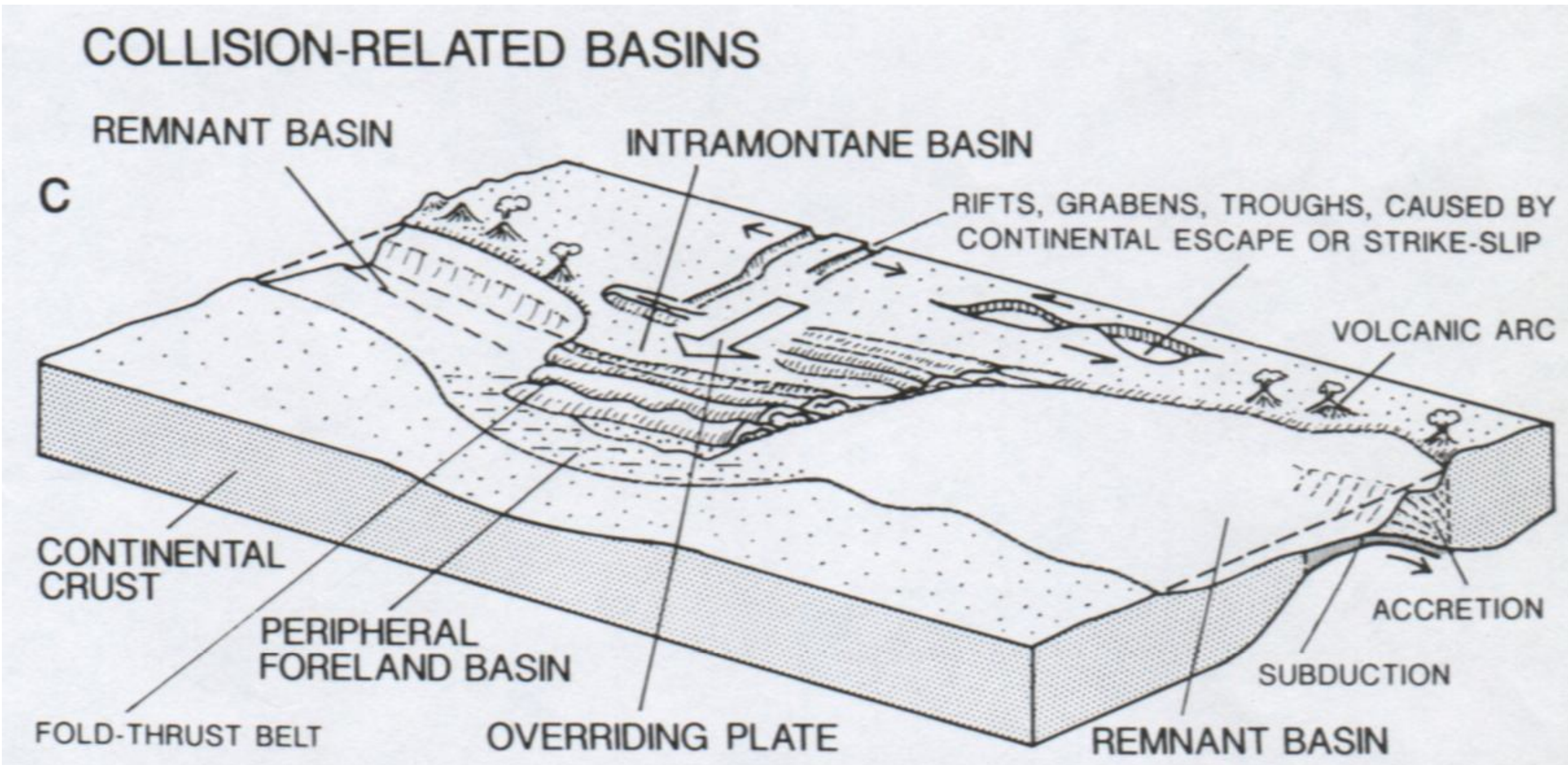
Basins related to collision

- *Pannonian-type basins* originate from post-orogenic divergence between two fold-thrust zones (Fig. 1.3a). They are usually associated with an A-subduction zone and are floored by thinning continental or transitional crust .

Basins related to collision

- During crustal collision, some foreland (and retroarc) basins can get broken up into separate smaller blocks, whereby strike-slip motions may also play a role (Fig. 1.2c). Some of the blocks are affected by uplift, others by subsidence, forming basinal depressions. The mechanics of such *tilted block basins* were studied, for example, in the Wyoming Province of the Rocky Mountain foreland. So-called *Chinese-type basins* result from block faulting in the hinterland of a continent-continent collision.

Basins related to collision

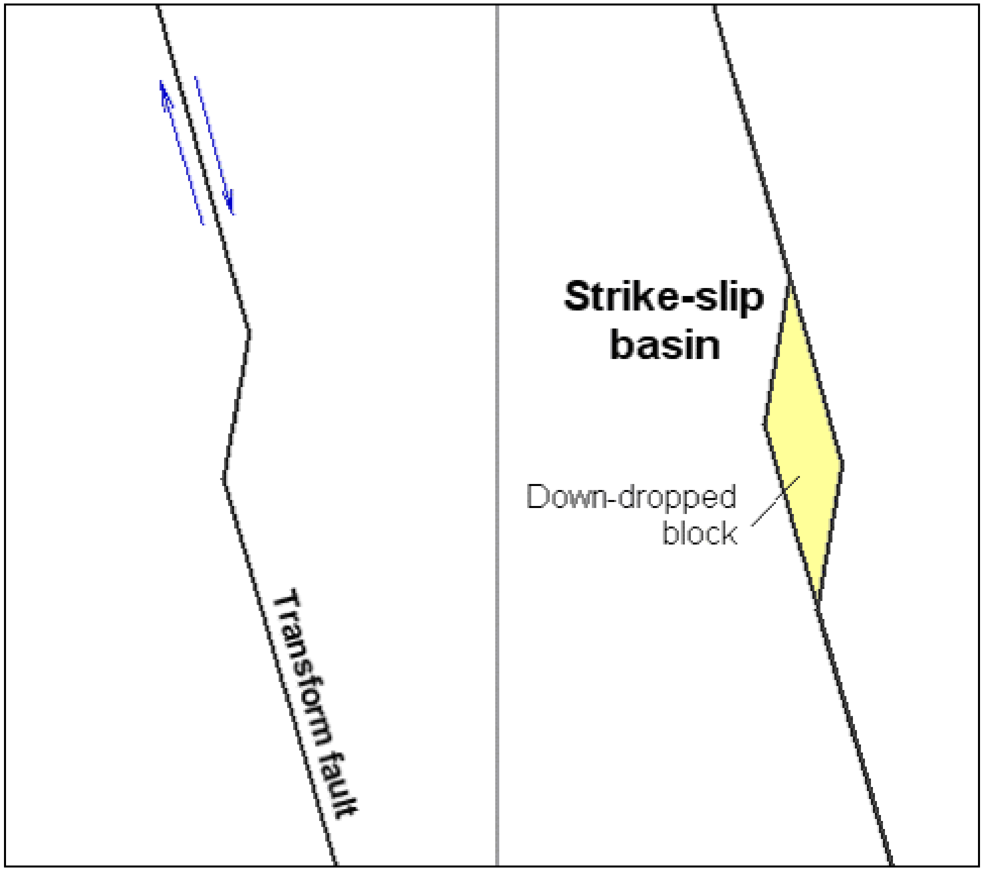


B. Convergent plate margins

- **9. <u>CONTINENTAL STRIKE-SLIP BASINS</u>**
- **E.g. California borderland basins associated with San Andreas strike-slip fault system , Various locations on the San Andreas Fault or the Anatolian Fault**
- **Origin**
  - strike-slip along non-linear faults
  - opening "holes" or basins at fault jogs or bends
  - A pull-apart block (eg. between two transform faults) that subsides significantly
- **Volcanism**
  - usually none, unless "accidental" intraplate
- **Basin types, environments, facies, provenance**
  - "pull-apart" or strike-slip basins
  - alluvial fans, rivers, lakes
  - alluvial, lacustrine, coal, ?evaporite seds.
  - provenance: whatever is being eroded from exposed crust

Transform-fault basins

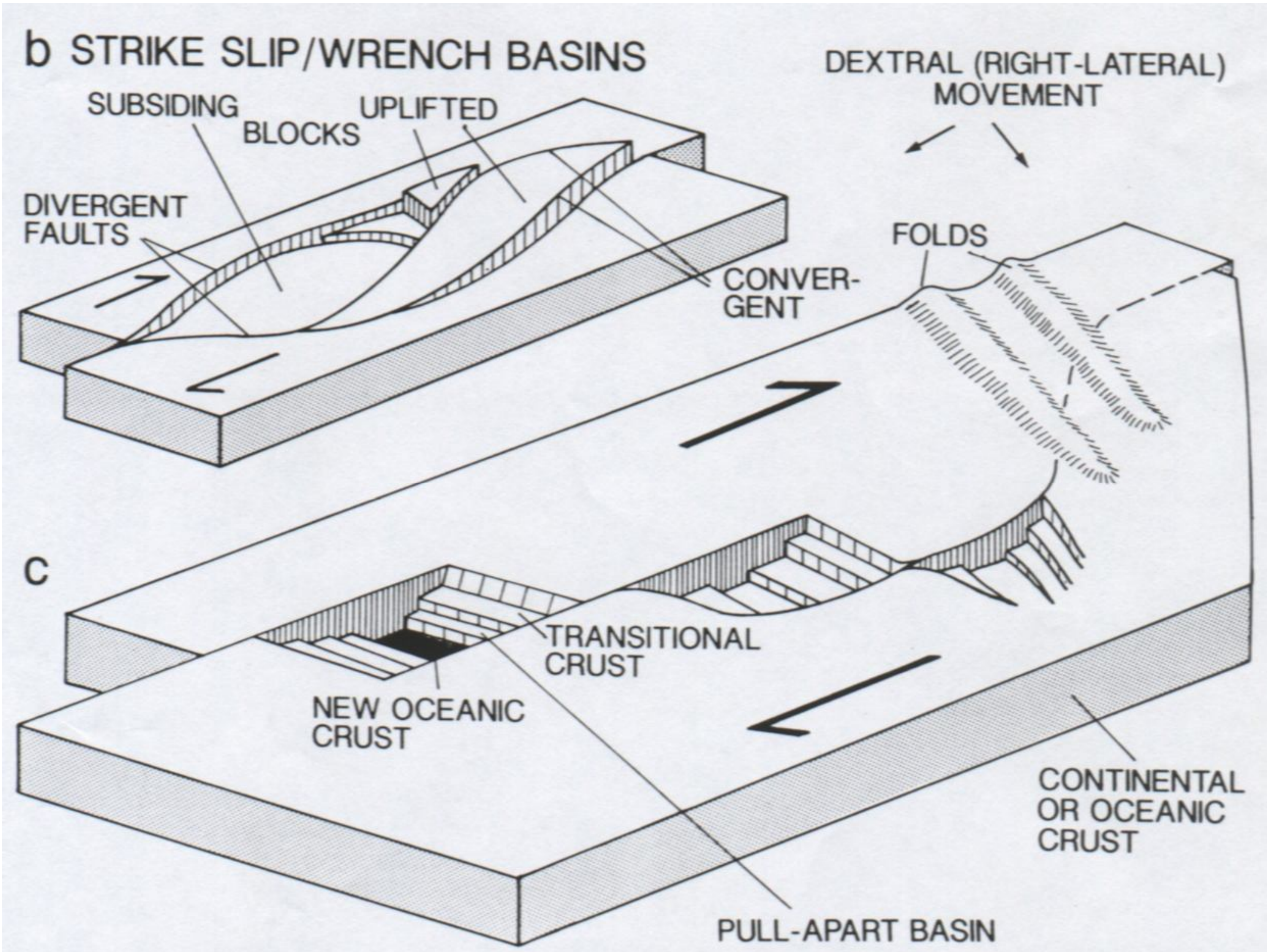
Strike-slip basin



Strike-slip and wrench basins

- Transform motions may be associated either with a tensional component (transtensional) or with a compressional component (transpressional). Transtensional fault systems locally cause crustal thinning and therefore create narrow ،elongate pull-apart basins. If they evolve on continental crust, continuing transform motion may lead to crustal separation perpendicular to the transform faults and initiate accretion of new oceanic crust in limited spreading centers. Until this development occurs, the rate of subsidence is usually high. Transpressional systems generate wrench basins of limited size and endurance. Their compressional component can be inferred from wrench faults and fold belts of limited extent (Fig. 1.3c).

Strike-slip and wrench basins

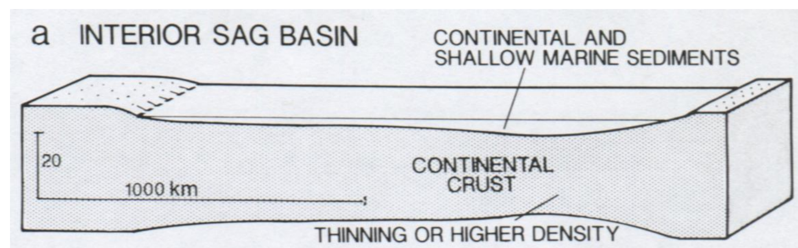


B. Convergent plate margins

- **10. <u>STABLE CONTINENTAL INTERIOR BASIN</u>**
- **E.g. Lake Eyre Basin**
- **Intracratonic (= within stable continental crustal mass)**
- **Long term stability**
- **Flat topography**
- **River, desert, lake environments & facies**
- **Mature basement derived sed. ± evaporites**

Continental or interior sag basins

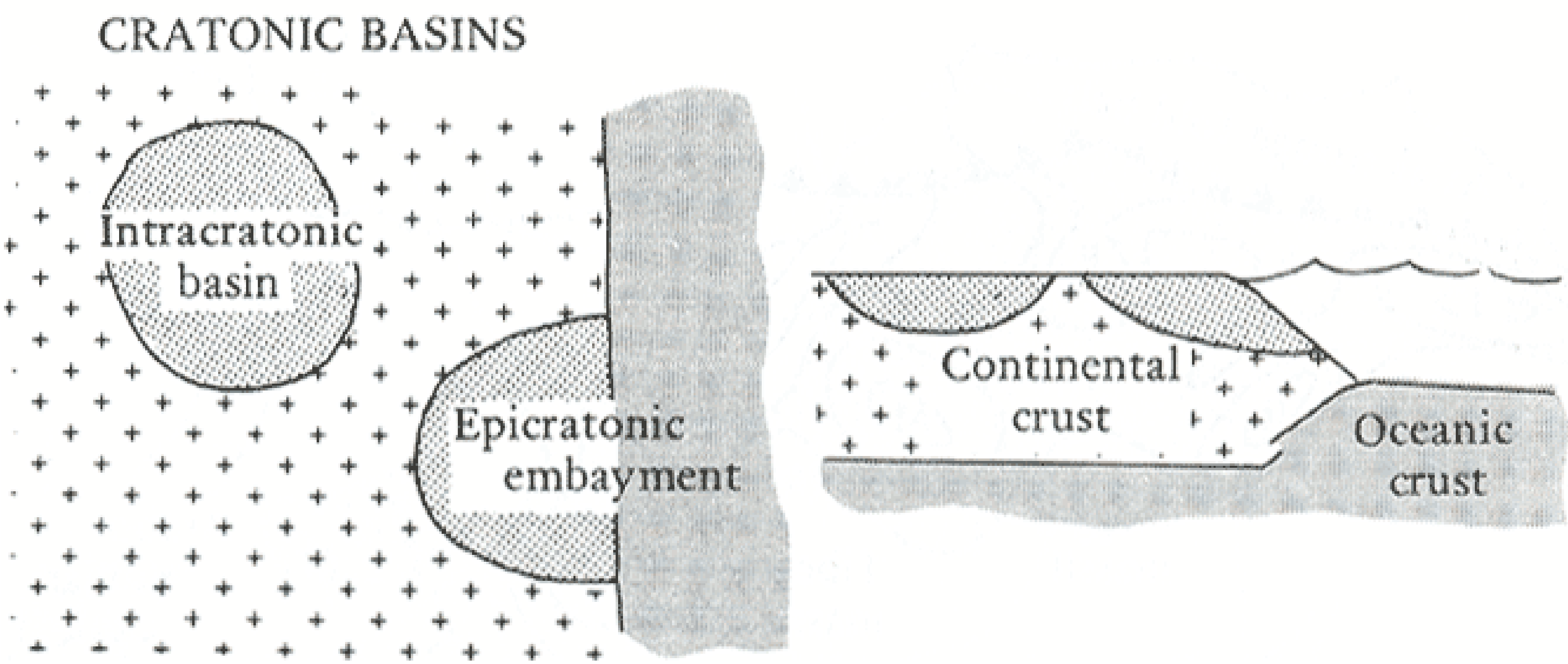
- Basins on continental crust are commonly generated by divergent plate motions and resulting extensional structures and thermal effects. In the case of large interior sag basins, however, major fault systems forming the boundaries of the depositional area or a central rift zone may be absent. Subsidence occurs predominantly in response to moderate crustal thinning or to a slightly higher density of the underlying crust in comparison to neighboring areas.



Continental or interior sag basins

- In addition, slow thermal decay after a heating event and sedimentary loading can promote and maintain further subsidence for a long time. Alternatively, it was recently suggested that long-term subsidence of intracratonic basins may be related to a decrease of the mantle heat flow above a "cold spot", i.e., abnormal cooling (Ziegler 1989). In general, rates of subsidence are low in this geodynamic setting.

Continental or interior sag basins



Subduction Troughs