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Delta

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Definition

A deposit originating from either magmatic or nonmagmatic flow laid down in the form of a sediment wedge at the juxtaposition of a river (valley) and a water (or other nonmagmatic volatile)-filled basin.

Category

A type of ► distributary system deposit.

Related Terms

Delta deposit, delta body, deltaic environment

Description

Deltas are sediment or rock wedges in cross section, thickening and then thinning away from the entry point, usually a river or valley mouth down into the basin. In plan view, the wedge may attain various shapes ranging from almost perfect fan shape to strongly lobate shape. The sediment feed to a delta is commonly by rivers, either deep and single thread or shallow and braiding with multiple thread streams (Galloway 1975; Nemec 1990; Postma 1990). Rivers transport the sediment both as bed load and in suspension, the bed load/suspension load ratio depends on unit discharge and grain size. In some occasions, the sediment feed has no or very little relation with rivers as is the case for valley hugging landslides and debris flows and for pyroclastic and lava flows stemming from volcanic eruptions. There is large variety of delta morphology on Earth, and only a few of these morphologies have been identified on other planets. On Titan sediment transport to delta bodies is inferred to have occurred by methane-ethane liquids flowing down valley slope into standing methane-ethane basins.

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Subtypes

There are two broad delta categories: (a) non-clastic deltas (e.g., lava-fed deltas) and (b) clastic deltas (e.g., Nemec 1990). In the latter category, many subtypes have been recognized. Each subtype reflects delta morphologies related to the interaction of the fluvial regime, defined by the kind of sediment transport bringing the sediment to the delta on the one hand (e.g., bed load/total load ratio), and the basinal regime, characterized by the wave and tidal action on the other (Fig. 1). Delta subtypes may also reflect a specific climate and tectonic setting, in which case no specific delta regime is determined, with the consequence that a climate-related subtype may be characterized by various morphologies. A hierarchy in delta subtypes (numbered 1–11 in Fig. 2) is given in Fig. 2.

(a) **Non-clastic deltas**

Non-clastic subtype deltas include:

(1) *Lava delta*: formed by flowing lava into ponded lava basin (Earth, Venus) and delta formed by lava flowing into a standing water body (Earth, Mars?), such as the Banana Delta in Hawaii (e.g., Skilling 2002)

(b) **Clastic deltas**

Clastic deltas are numerous on Earth, and many studies provided classification schemes ranging from purely process-based (genetic) classifications to purely descriptive. Galloway (1975) grouped genetically deltas into fluvial-, tide-, and wave-dominated categories each with a characteristic morphology. Orton and Reading (1993) combined the genetic classification of Galloway with grain size as the descriptor. Grain size has strong bearing on the delta slope and the sensitivity of the delta deposit to reworking processes like waves and tides. Postma (1990) provided a descriptive delta classification relating various delta morphologies to feeder system characteristics and basin depth. The latter classification is particularly suitable for distinguishing the relatively small, bed-load-dominated, coarse-grained deltas in basins that are not influenced

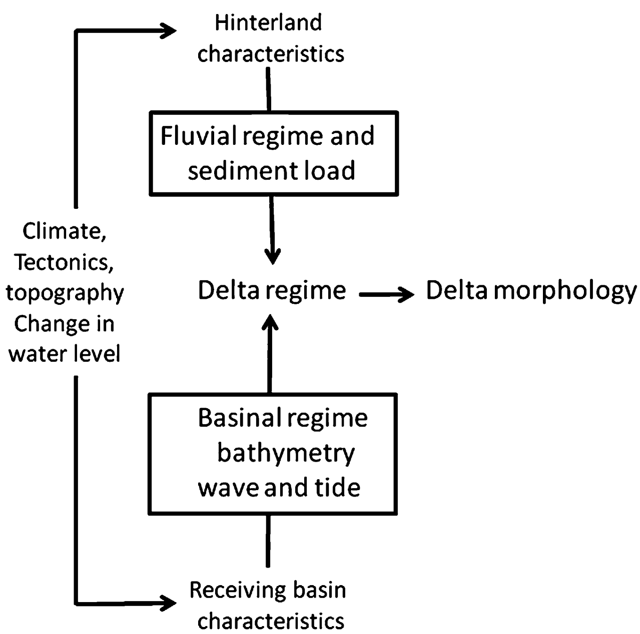

Fig. 1 Conceptual diagram highlighting the parameters that effect delta morphology (Modified from Postma (1990))

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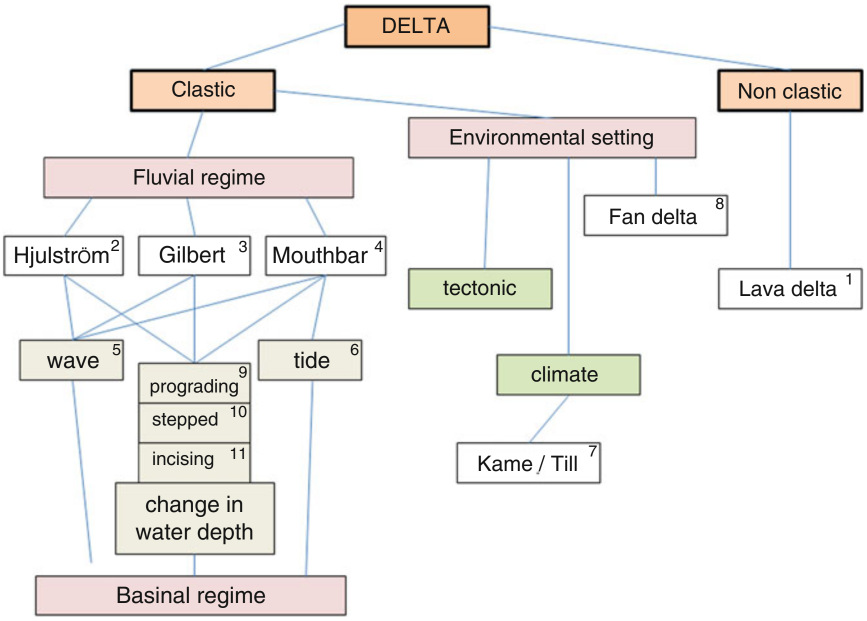

Fig. 2 Delta categories and subtypes in white numbered boxes. Numbers relate to subtypes in the text

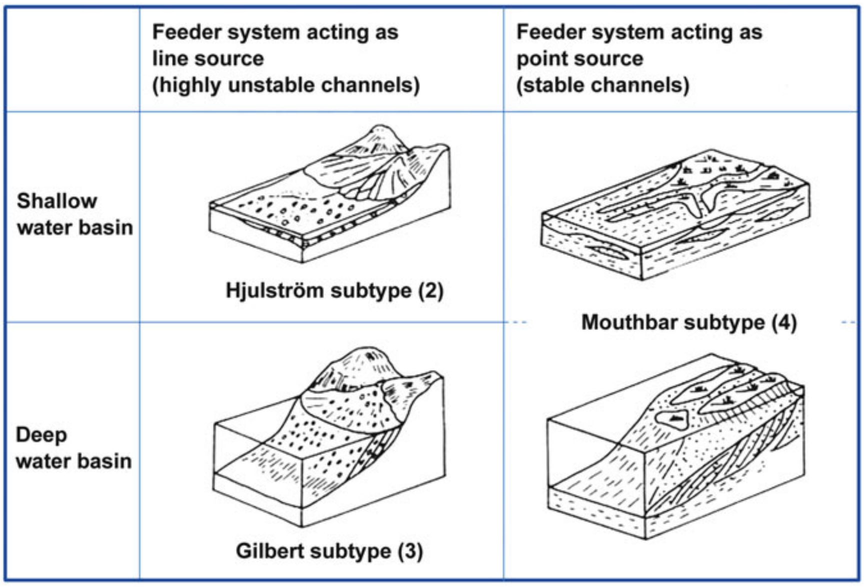

Fig. 3 Hjulström, Gilbert type, and mouth bar delta subtypes (Modified from Postma (1990))

by tides and waves and thus particularly relevant for describing the relatively small deltas found in craters on our planets. Three major subtypes have been distinguished (see Postma 1990; Fig. 3):

(2) *Hjulström-type delta* is fed by mass flow-derived coarse-grained debris and/or rapidly shifting streams that essentially form a line source and progrades into shallow waters. Morphology is characterized by a subaqueous delta foreset having about similar gradient as its delta plain.

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(3) *Gilbert-type delta* (Gilbert 1885, p. 107) is fed by mass flow and/or river-derived sand and gravel that is moved essentially as bed load and progrades into much deeper waters than Hjulström deltas. They are characterized by a delta foreset that is much steeper (up to 35°) than the delta plain (topset). The steep foreset originates from the bed load transported by the river to the river mouth from where it avalanches down the delta foreset by the pull of gravity. The steepness of the foreset depends on static friction angle (angle of repose) of the sediment, which increases with sorting and angularity of grains.

(4) *Mouth-bar-type* delta is fed by stable distributaries (rivers), which form a point source for the delta for considerable amount of time. This type of morphology can characterize delta that progrades in both shallow and deep basins. The shape of the mouth bar deposit is characteristic for the nature of the effluent and its interaction with the basin floor (see Postma 1990). Mouth-bar-type deltas may show very large and straight distributary channels as exemplified by the Mississippi delta, their origin related to hypopycnal (less dense than ambient water) outflow.

If basin energy is high, Hjulström, Gilbert, and mouth bar subtypes can be reworked by basin-related processes such as waves and tides giving rise to modified delta morphologies (Galloway 1975):

(5) *Wave-dominated delta* is reworked by waves into lobate (still river-influenced), cuspate (more wave-dominated), and straight (fully wave-dominated) shoreline configurations.

(6) *Tide-dominated delta i*s reworked by tides into estuarine and funnel-shaped distributary channels perpendicular to the coast. This type is unlikely to be present on, e.g., Mars, since tidal influence is minimal (McMenamin and McGill 2005 and references therein).

Other clastic delta subtypes have been assigned a genetic relation with their environment. For instance:

(7) *Till delta* (► grounding line system) and *kame delta* (► ice-contact delta) are related to the glacial environment, both originating from sediment transport by glacial meltwater. Their morphology may be dominated by postdepositional deformation due to ice movement and ice melting, respectively.

(8) *Fan delta* is a delta fed by an alluvial fan (Nemec and Steel 1988). When fed by small-radius alluvial fans, they often bear the characteristics of the Hjulström- and Gilbert-type deltas.

Clastic delta *subtypes* may also originate from water-level changes (Fig. 4). On Earth, changing water levels in both oceanic and lake basins causes stacking and erosion of delta bodies that give rise to various morphologies (Curray 1964):

(9) *Prograding delta*: characterized by simple and single delta morphology consisting of delta plain and foreset, which form during still stand or slow rise, where sediment supply is sufficient to fill the accommodation over the topset

(10) *Retrograding or stepped (back-stepping) delta:* characterized by staircase morphology and terraced fan morphology, where sediment supply cannot cope with the rising water level forcing the delta to retreat (e.g., de Villiers et al. 2013)

(11) *Incised delta:* originates from water-level fall initiating headward erosion in the feeder system

Hence, Hjulström-, Gilbert-, and mouth-bar-type deltas can obtain additional morphological elements that are related to changes in water level.

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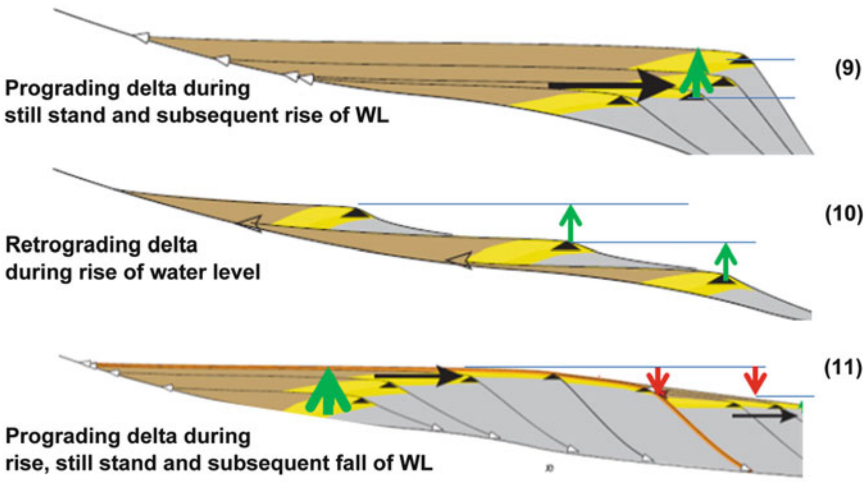

Fig. 4 Delta subtypes related to water-level change. *Brown* is the subaerial part of the delta (delta plain), *gray* is the subaqueous part of the delta (delta foreset), and *yellow* represents coastal deposits; *lines* with *open arrows* demarcate time lines and show delta wedge evolution; *black arrows* indicate progradation; *green arrows* denote aggradation during sea level rise; and *red arrows* denote erosion during sea level fall (Modified from Catuneanu et al. (2009))

Formation

Deceleration of the river outflow into a basin with a standing body of water will lead to loss in capacity and competence of the liquid flow and causes grains to settle, the coarsest grains closest to the river mouth and the finest grains farthest away.

Structural Units

Delta deposits consist of subaerial and subaqueous segments.

Subaerial segment:

(1) Delta plain (topset): fan-shaped low relief area displaying coarse-grained distributary channels and fine-grained, inter-distributary deposits

Subaqueous segments:

(2) Delta front and slope (foreset): most steeply sloping part of the delta, where rapid deposition of the coarse fraction takes place. The delta front gradient is high (up to angle of repose for sediment) for high bed load/total load ratio and large basin depth, and it is low for low bed load/total load ratios and shallow basins. Mouth bars may coalesce to form continuous delta front sand bodies.
(3) Prodelta environment (bottomset): gentle sloping offshore, predominantly fine-grained mud unit originating from suspension fallout from the river plume and from sediment moved down the delta front by hyperpycnal sediment flow (e.g., Hori and Saito 2007 and references therein).

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Composition

Water-fed deltas: rock clasts and grains of all sizes; *lava-fed deltas:* lava. On Mars, some deltas in craters coincide with phyllosilicate mineral enrichments which points to accumulation in a body of standing water (Grant et al. 2011). On Mars, in Jezero crater, the lower level of delta contains iron-magnesium smectite clay (Ehlmann et al. 2008).

Prominent Examples

Stepped delta: Dukhan delta, Coprates Catena terraced deposit, Tyras delta (two superimposed delta lobes), Mars; Emme delta, Earth (de Villiers et al. 2010; Kleinhans et al. 2010; Hauber et al. 2013); Gilbert delta: Nepenthes delta (Hauber et al. 2013).

Distribution

Venus (Fig. 5), Earth (Fig. 8), Mars (Fig. 6), Titan (Fig. 7). Beyond Earth, the greatest variety of various fan-shaped features are present on Mars (de Villiers et al. 2013).

Regional Variations

Venus: Deltas on Venus are outward radiating distributary channels at the mouth of lava channels (found at both canali and outflow channels) prograding into temporary lava lakes that later solidified. Lava deltas are composed of smooth (probably pahoehoe) surface lavas (Kargel et al. 1994). Some Venusian lava deltas, however, do show anastomosing distributary channels with similar morphology as the periglacial deltas of Yukon and Lena (Kargel et al. 1994 and references therein; Fig. 5).

Mars: Martian deltas have similar elements to their terrestrial analogs, including lobes, terraces, and incised fronts (Kraal et al. 2008; Kleinhans et al. 2010; de Villiers et al. 2010; Hauber et al. 2013). Their size is between 5 and 30 km; the slope angle is between 1 and 10° (de Villiers et al. 2010). Most deltas are present in ancient craters without an outlet valley (Hauber et al. 2013). Morphologies of delta-like features on Mars are similar either to terrestrial fan deltas (Fig. 6b), or Gilbert-type deltas (Fig. 6f; Kraal et al. 2008; Ori et al. 2000), or to stepped deltas (Kraal et al. 2008; Hauber et al. 2013; Fig. 6). On Mars, multiple-scarped, stepped (terraced) delta morphologies combined with short valley lengths likely formed by short and energetic suspension-dominated aqueous transport processes from steep and short valleys (Fig. 6e; Kraal et al. 2008; Hauber et al. 2013). Local fluctuations in sediment feed enhance the formation of lobate stepped morphology (Kraal et al. 2008; Kleinhans et al. 2010). The finger-like delta lobes of deltas (Mouth bar type) on Mars are inferred to have formed in saline basin waters (McMenamin and McGill 2005).

On Mars, it is still a debate whether deltas formed by stream flow (e.g., the Italian school, Pondrelli et al. 2008a, b; Ori et al. 2010) or by catastrophic-type flow events more related to sudden meltwater releases (the Utrecht school, Kraal et al. 2008; de Villiers et al. 2013) or by short-lived aqueous processes from water mobilized locally from the cryosphere (Hauber et al. 2013) are lava deltas (McMenamin and McGill 2005). Different delta-like features may have formed by different processes. Deltas and associated ► Amphitheater-headed valley (Mars, Earth) around Chryse Planitia and in Xanthe Terra formed over a very long period of time ranging from 3.6 to 0.3 Ga

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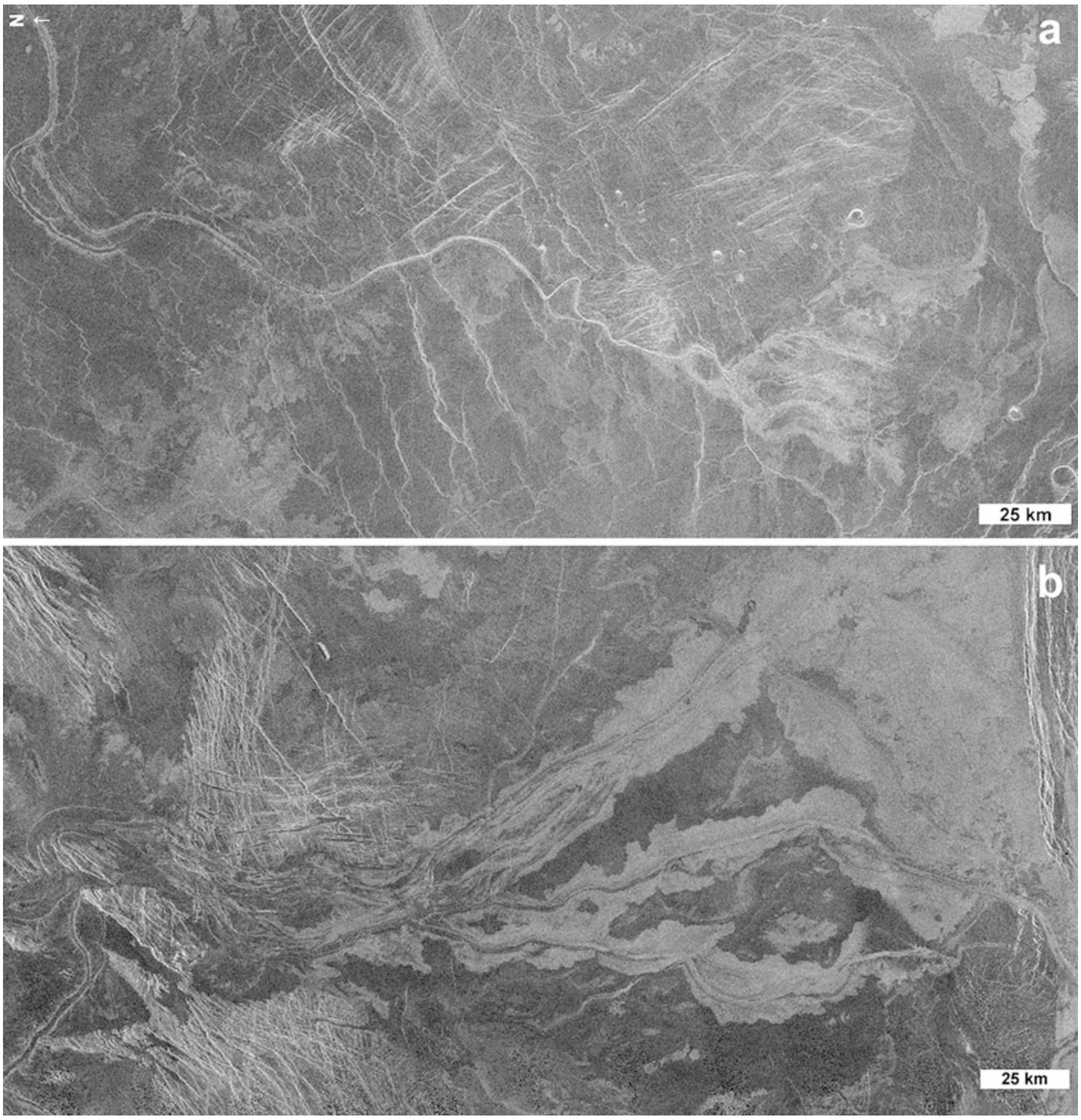

Fig. 5 Canali deltas on Venus: (**a**) Bayara Vallis canale delta. 71 × 94 km. F-MIDRP 45 N019;1. (**b**) Kallistos Vallis outflow channel delta, 130 km wide. F-MIDRP 50S021;1 (Kargel et al. 1994) Magellan left-look radar (NASA/JPL)

(Hauber et al. 2013) and are proposed to have formed by short-lived, energetic processes (Fig. 6d, e). The Mangala Valles delta on Mars is proposed to be a lava delta, inferred from the presence of pits and mounds and the lack of distributary channels on its surface (McMenamin and McGill 2005). On Mars, many deltas are arranged along an equipotential surface around the margins of the northern lowlands (di Achille and Hynek 2010) consistent with the presence of a paleo-shoreline. Aeolis Dorsa deltas also support this hypothesis (DiBiase et al. 2013; Fig. 6b).

Examples of deltas include Eberswalde (Pondrelli et al. 2008b; Fig. 6a), relatively small stepped intracrater deltas (Fassett and Head 2005; Kraal et al. 2008; Kleinhans et al. 2010; de Villiers et al. 2013; Popa et al. 2010; Hauber et al. 2013), also including mesas that are interpreted as relics of the Ma'adim Delta in Gusev Crater (Schneeberger 1989; Irwin et al. 2004).

Titan: In the southern polar lake Ontario Lacus, lobate deposit connected to a channel is interpreted as shallow-water delta. It may have formed due to low sediment discharge, which is a consequence of low sediment supply, slow flow velocity, and a low sediment transport capacity

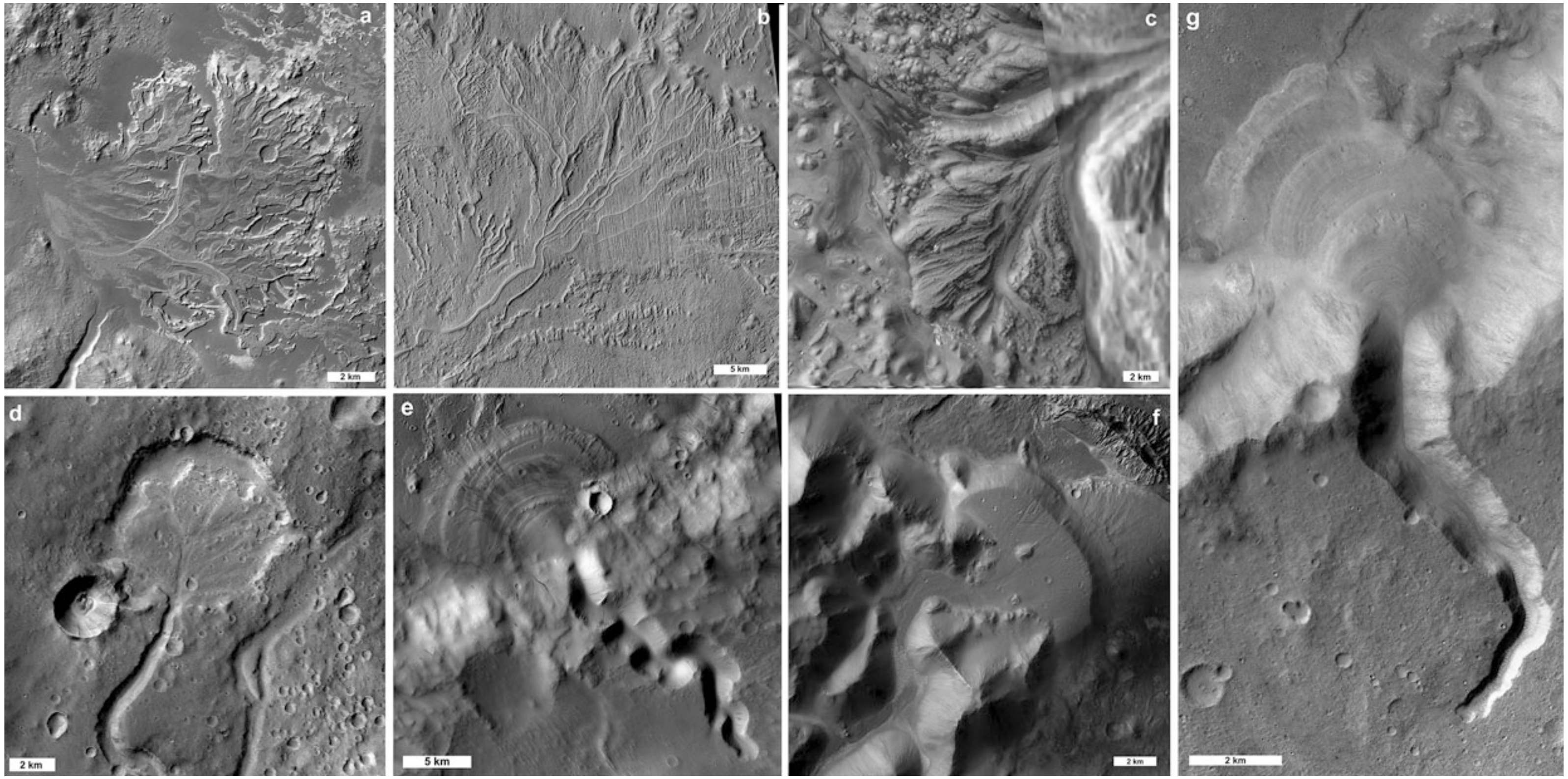

Fig. 6 Delta-like features on Mars. (**a**) The 138 km^2 large Eberswalde delta displaying exhumed and inverted channels with migrating bends and meanders (Pondrelli et al. 2008a; Hauber et al. 2013). It consists of six depositional lobes. Distributaries are 100–240 m wide (Wood 2006); (**b**) a fan-shaped delta-like structure at Aeolis Mensae, showing sinuous ridges interpreted as inverted channels (e.g., DiBiase et al. 2013); (**c**) delta-like structure in Aram Chaos; (**d**) Nanedi Vallis delta in a 6 km diameter crater. Single-scarped, branched, prograding delta (de Villiers et al. 2013). Unlike most other intracarter deltas, its host crater has an outlet valley (Hauber et al. 2013); (**e**) multiple-scarped, stepped delta fed by a short and deep valley without tributaries (de Villiers et al. 2010; Kraal et al. 2008; Kleinhans et al. 2010; Hauber et al. 2013), explained as retrograding delta (de Villiers et al. 2013) formed by short-lived transport (Hauber et al. 2013); (**f**) Nepenthes delta, a 300 m thick Gilbert-type delta with steep frontal scarp; (**g**) Dukhan back-stepped delta (Hauber et al. 2013). CTX images: (a) B22_018267_1558_XN_24S033W at 24.2°S 326.4°E; (b) B16_015913_1739_XN_06S208W at 6.5°S, 151°E; (c) P17_007599_1833_XN_03N019W at 3°N, 341°E; (d) B17_016250_1870_XN_07N047W at 8.6°N 312°E; (e) CTX: P02_001644_1713_XI_08S159W at 8.69°S 200.75°E; (f) G22_026885_1844_XN_04N238W at 2°N, 121°E; (g) G01_018544_1878_XN_07N039W at 7.8°N 321°E (NASA/JPL-Caltech/MSSS)

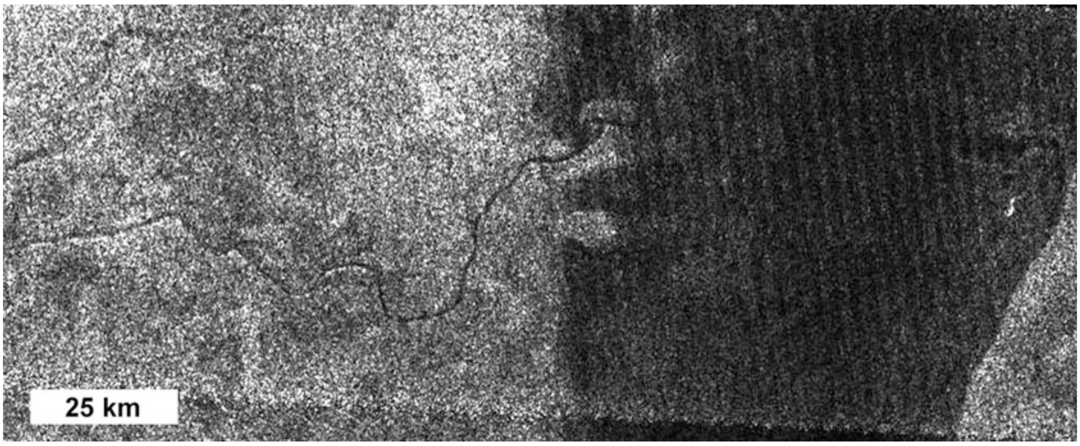

Fig. 7 Ontario Lacus, Titan. A delta-like feature around the middle of the image with two lobes: one with a channel and the other without visible channel, probably a result of channel ► avulsion. Cassini RADAR SAR T58 (NASA/JPL-Caltech/Cassini RADAR Team)

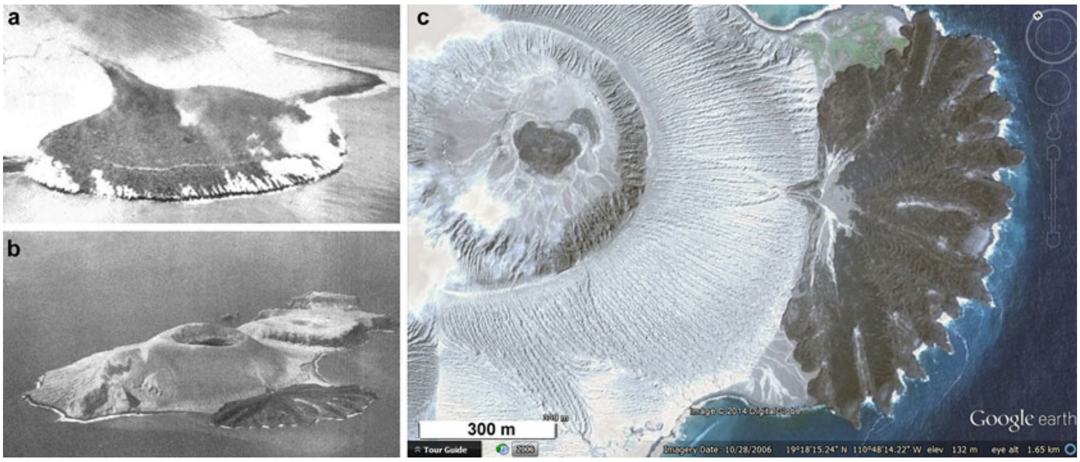

Fig. 8 The 300 m wide Delta Lávico lava delta, on Bárcena cinder cone volcano, San Benedicto Island, west of México, at 19°N, 110°W. (**a**) On December 11, 1952 (Photo by AF Richards, pl. XVI from Richards 1959), (**b**) on March 1955 when wave erosion has truncated the ends of flow tongues (Photo by AF Richards, pl. XIX from Richards (1959)), (**c**) in 2006 (Google Earth/DigitalGlobe). Cf. Artemis-Imdr festoon (Venus); ► alluvial fan

(Wall et al. 2010; Langhans et al. 2011) (see figure ► Flooded valley (Titan), ► radar-bright valley Titan).

Significance

Clastic deltas provide evidence for past standing bodies of water. Gilbertian-type deltas help in estimating the depth of ancient water-filled lakes (Mangold and Ansan 2006) including the change of water level (Di Achille et al. 2006).

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Astrobiological Significance

Deltaic/lacustrine deposits are of high astrobiological interest. On Earth they are currently, and on Early Mars they may have been sites of concentration and preservation of biosignatures, including organic compounds (Summons et al. 2010; Farmer and Des Marais 1999). These locations are high priority targets in landing site selection (Grant et al. 2011).

Place Names

Informal names of deltas on Mars are given after the name of the crater or other landform hosting the delta (Hauber et al. 2013).

Origin of Term

Named for the triangular shape of the Nile delta, which resembles the Greek letter delta (Δ).

See Also

- ► Alluvial Fan
- ► Delta, Ria, Estuary
- ► Grounding Line System
- ► Ice-Contact Delta
- ► Lava-Fed Delta

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