FLUVISOLS (FL)

The Reference Soil Group of the Fluvisols accommodates genetically young, azonal soils in alluvial deposits. The name 'Fluvisols' is misleading in the sense that these soils are not confined to river sediments (L. fluvius means 'river') but occur also in lacustrine and marine deposits. Many international soil names refer to this group, for example: 'Alluvial soils' (Russia, Australia), 'Fluvents' (USDA Soil Taxonomy), 'Fluvisols' (FAO), Auenböden (Germany) and 'Sols minéraux bruts d'apport alluvial ou colluvial' or 'Sols peu évolués non climatiques d'apport alluvial ou colluvial' (France).

Definition of Fluvisols

Soils having
1   a thickness of 25 cm or more; **and**
2   fluvic soil material starting within 50 cm from the soil surface; **and**
3   no diagnostic horizons other than a histic, mollic, ochric, takyric, umbric, yermic, salic or sulfuric horizon.

Common soil units:

Thionic, Histic, Gelic, Salic, Gleyic, Mollic, Umbric, Arenic, Tephric, Stagnic, Humic, Gypsiric, Calcaric, Takyric, Yermic, Aridic, Skeletic, Sodic, Dystric, Eutric, Haplic.

Summary description of Fluvisols

Connotation: soils developed in alluvial deposits; from L. <u>fluvius</u>, river.

Parent material: (predominantly) recent, fluvial, lacustrine or marine deposits.

Environment: periodically flooded areas (unless empoldered) of alluvial plains, river fans, valleys and (tidal) marshes, on all continents and in all climate zones.

Profile development: AC-profiles with evidence of stratification; weak horizon differentiation but a distinct Ah-horizon may be present. Redoximorphic features are common, in particular in the lower part of the profile.

Use: Fluvisols are planted to food crops and orchards and many are used for grazing. Flood control, drainage and/or irrigation is normally required. Thionic Fluvisols suffer from severe soil acidity and high levels of noxious Al-ions.

Regional distribution of Fluvisols

Fluvisols occur on all continents and in all climates. They occupy some 350 million hectares worldwide of which more than half are in the tropics. Major concentrations of Fluvisols are found:

1. along rivers and lakes, e.g. in the Amazon basin, the Ganges plain of India, the plains near Lake Chad in Central Africa, and the marsh lands of Bolivia and northern Argentina;
2. in deltaic areas, e.g. the deltas of the Ganges/Brahmaputra, Indus, Mekong, Mississippi, Nile, Niger, Orinoco, Rio de la Plata, Po, Rhine and Zambesi;
3. in areas of recent marine deposits, e.g. the coastal lowlands of Sumatra, Kalimantan and Irian (Indonesia).

Major areas of Thionic Fluvisols ('*Acid Sulfate Soils*') are found in the coastal lowlands of southeast Asia (Indonesia, Vietnam, Thailand), West Africa (Senegal, the Gambia, Guinea Bissau, Sierra Leone, Liberia) and along the north-eastern coast of South America (Venezuela, the Guyanas). Figure 1 shows the worldwide distribution of Fluvisols.

Dominant Associated Inclusions Miscellaneous lands

Figure 1. Fluvisols worldwide.

Associations with other Reference Soil Groups

Fluvisols occur alongside other 'typical' soils of aqueous sedimentary environments such as Arenosols, Cambisols, Gleysols and Solonchaks, and with weakly developed soils such as Leptosols and Regosols.

Genesis of Fluvisols

Fluvisols are young soils that have 'fluvic soil properties'. For all practical purposes this means that they receive fresh sediment during regular floods (unless empoldered) and (still) show stratification and/or an irregular organic matter profile.

Fluvisols in upstream parts of river systems are normally confined to narrow strips of land adjacent to the actual riverbed. In the middle and lower stretches, the flood plain is normally wider and has the classical arrangement of levees and basins, with coarsely textured Fluvisols on the levees and more finely textured soils in backswamps further away from the river.
In areas with marine sediments, relatively coarse-textured Fluvisols occur on barriers, cheniers, sand flats and crevasse splays; finely textured Fluvisols are found on clayey tidal flats and in chenier plains. Where rivers carry only fine-grained material to the sea, coastal plains (and their Fluvisols) are entirely clayey.
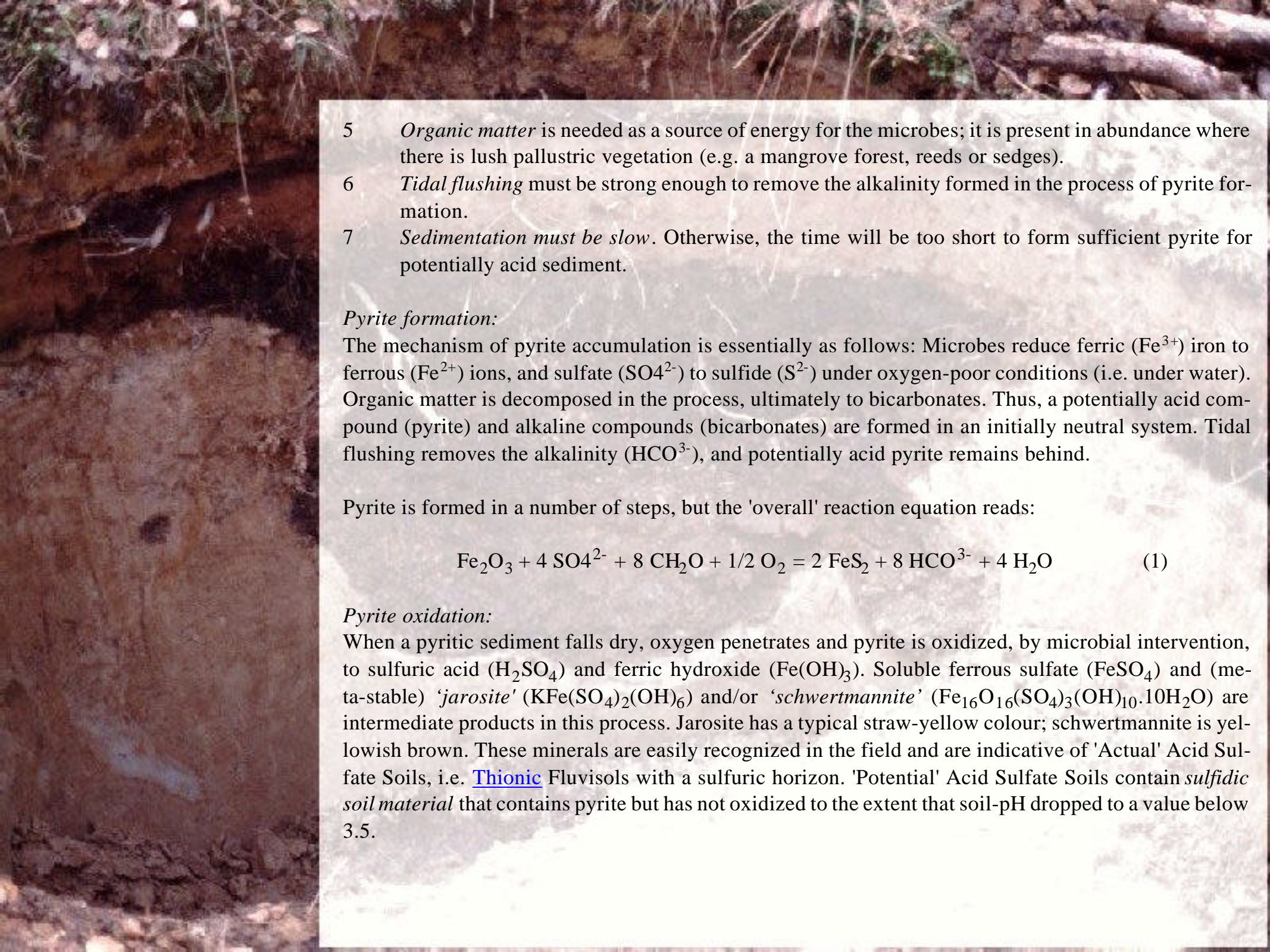Permanent or seasonal saturation with water preserves the stratified nature of the original deposits but when soil formation sets in, a cambic subsurface horizon will quickly form, transforming the Fluvisol into a Cambisol or Gleysol (depending on the water regime).

Genesis of Thionic Fluvisols ('Acid Sulfate Soils')
The only difference between the parent material of Thionic Fluvisols and that of other Fluvisols is the presence of pyrite (FeS_2) in the former.

Formation of pyrite can take place during sedimentation in a marine environment if the following conditions are met:
1   *Iron* must be present. Most coastal sediments contain easily reducible iron oxides or hydroxides.
2   *Sulfur* must be present. Seawater and brackish water contain sulfates.
3   *Anaerobic conditions* must prevail to allow reduction of sulfate and iron oxides. This condition is met in fresh coastal sediments.
4   *Iron- and sulfate-reducing microbes* must be present; these occur in all coastal sediments.

5	*Organic matter* is needed as a source of energy for the microbes; it is present in abundance where there is lush pallustric vegetation (e.g. a mangrove forest, reeds or sedges).
6	*Tidal flushing* must be strong enough to remove the alkalinity formed in the process of pyrite formation.
7	*Sedimentation must be slow*. Otherwise, the time will be too short to form sufficient pyrite for potentially acid sediment.

Pyrite formation:
The mechanism of pyrite accumulation is essentially as follows: Microbes reduce ferric (Fe^{3+}) iron to ferrous (Fe^{2+}) ions, and sulfate ($SO4^{2-}$) to sulfide (S^{2-}) under oxygen-poor conditions (i.e. under water). Organic matter is decomposed in the process, ultimately to bicarbonates. Thus, a potentially acid compound (pyrite) and alkaline compounds (bicarbonates) are formed in an initially neutral system. Tidal flushing removes the alkalinity (HCO^{3-}), and potentially acid pyrite remains behind.

Pyrite is formed in a number of steps, but the 'overall' reaction equation reads:

$$Fe_2O_3 + 4\ SO4^{2-} + 8\ CH_2O + 1/2\ O_2 = 2\ FeS_2 + 8\ HCO^{3-} + 4\ H_2O \qquad (1)$$
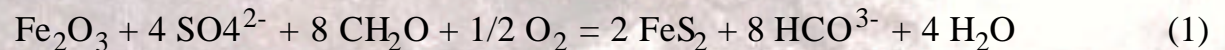
Pyrite oxidation:
When a pyritic sediment falls dry, oxygen penetrates and pyrite is oxidized, by microbial intervention, to sulfuric acid (H_2SO_4) and ferric hydroxide ($Fe(OH)_3$). Soluble ferrous sulfate ($FeSO_4$) and (meta-stable) *'jarosite'* ($KFe(SO_4)_2(OH)_6$) and/or *'schwertmannite'* ($Fe_{16}O_{16}(SO_4)_3(OH)_{10}.10H_2O$) are intermediate products in this process. Jarosite has a typical straw-yellow colour; schwertmannite is yellowish brown. These minerals are easily recognized in the field and are indicative of 'Actual' Acid Sulfate Soils, i.e. Thionic Fluvisols with a sulfuric horizon. 'Potential' Acid Sulfate Soils contain *sulfidic soil material* that contains pyrite but has not oxidized to the extent that soil-pH dropped to a value below 3.5.

The following reaction equations describe successive steps in pyrite oxidation. The mineral 'jarosite' will be followed in this text; it is formed at soil-pH < 3.5 if sufficient K^+-ions are present:

$$FeS_2 + 7/2\ O_2 + H_2O = Fe^{2+} + 2\ SO_4^{2-} + 2\ H^+ \tag{2}$$
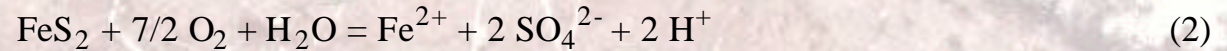
In the presence of carbonates, no lowering of the pH takes place even though much acidity is released.

$$CaCO_3 + 2\ H^+ = Ca^{2+} + H_2O + 6\ CO_2 \tag{3}$$
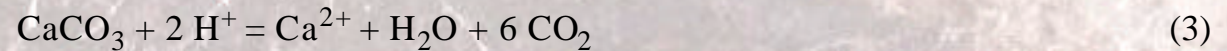
In strongly calcareous soils or in very dry conditions, gypsum may precipitate:

$$Ca^{2+} + SO_4^{2-} + 2\ H_2O = CaSO_4.2H_2O \tag{4}$$
$$(gypsum)$$
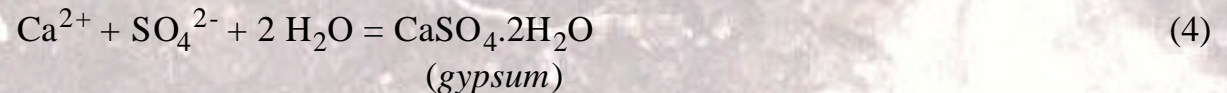
In the absence of carbonates, hydrogen produced is not neutralized and the pH of the sediment falls sharply. The soluble ferrous iron produced according to equation (2) is mobile; it oxidizes to jarosite in places where oxygen is present, i.e. in cracks and along root channels:

$$Fe^{2+} + 2/3\ SO_4^{2-} + 1/3\ K^+ + 1/4\ O_2 + 3/2\ H_2O = 1/3\ jarosite + H^+ \tag{5}$$
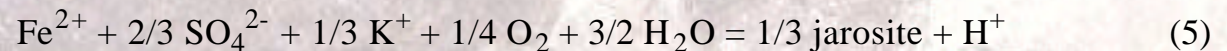
With time, the hydrogen ions are removed from the system by percolation or lateral flushing, and jarosite is hydrolyzed to ferric hydroxide:

$$1/3\ jarosite + H_2O = 1/3\ K^+ + Fe(OH)_3 + 2/3\ SO_4^{2-} + H^+ \tag{6}$$
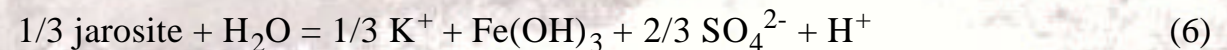
The (poorly crystallized) ferric hydroxide will eventually transform to goethite:

$$Fe(OH)_3 = FeOOH + 3H_2O \tag{7}$$
$$(goethite)$$

The stability of the various iron minerals formed in the process of pyrite oxidation is strongly influenced by the redox potential of the soil material (a measure of the quantity of oxygen present) and the soil-pH. Figure 2 presents a diagram of the stability of iron compounds in relation to redox potential (pe) and soil-pH.

The foregoing shows that aeration of fresh, non-calcareous pyritic sediments, e.g. by forced drainage, results in large quantities of H+ions being released to the soil solution. These H^+-ions lower the pH of the soil and exchange with bases at the cation exchange complex. Once the soil-pH has fallen to a level between pH 3 and pH 4, the clay minerals themselves are attacked. Mg, Fe and, in particular, Al are released from the clay lattices, and noxious Al^{3+} ions become dominant in the soil solution and at the exchange complex.

Figure 3 shows the physiographic structure of the Mekong delta in Vietnam. The figure illustrates the relation between physiography and the occurrence of Fluvisols, and of Thionic Fluvisols in particular.
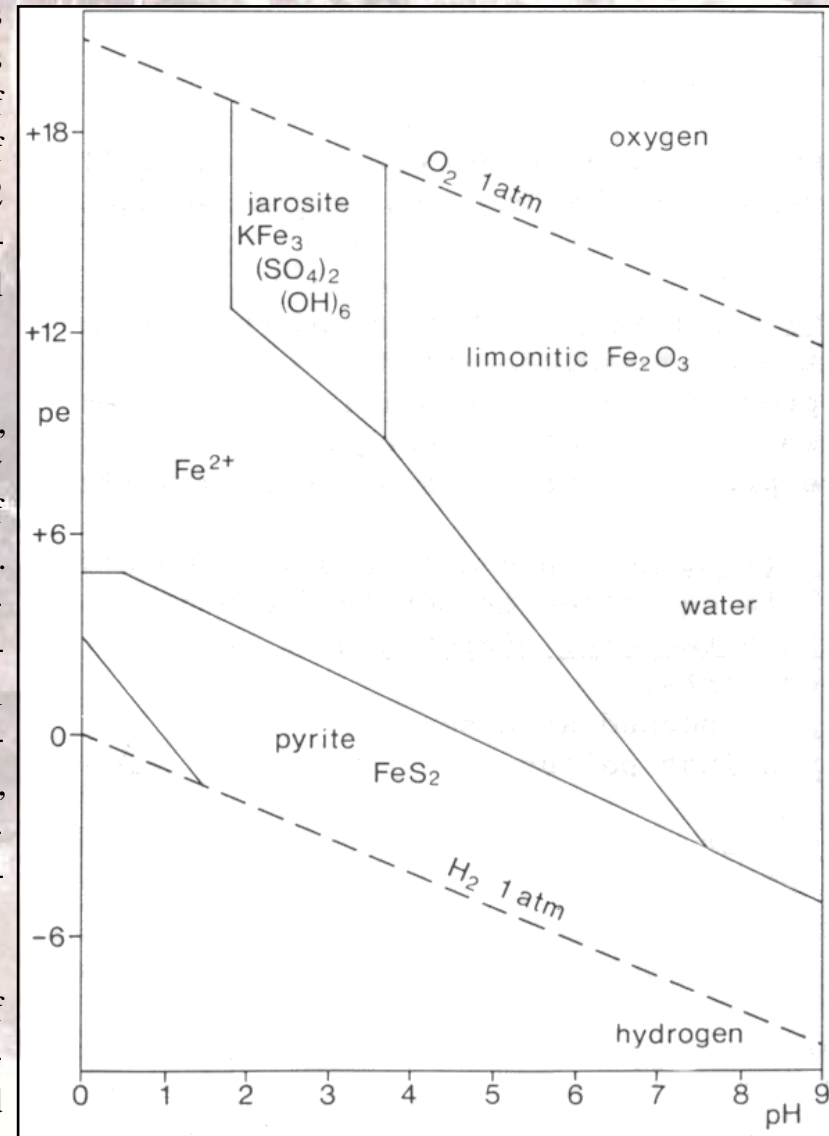

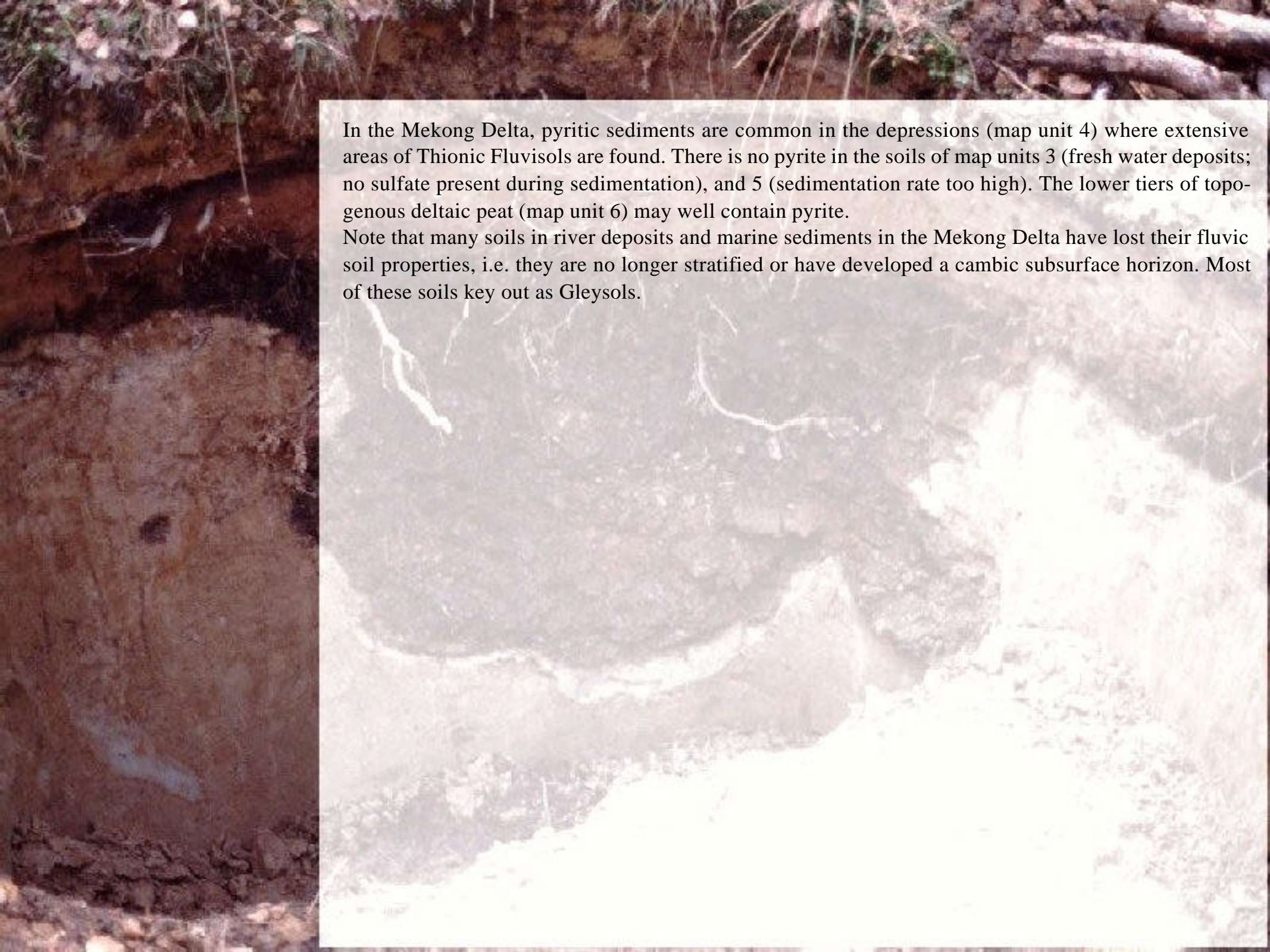**Figure 2**: pe:pH diagram of pyrite, limonitic Fe_2O_3, jarosite and dissolved K^+, SO_4^{2-}, Fe^{2+} and Fe^{3+} at $\log[SO_4^{2-}] = -2.3$, $\log[K^+] = -3.3$, $\log[Fe^{2+}+Fe^{3+}] = -5$ and 1 atm. total pressure. Source: Miedema, Jongmans & Slager, 1973.

Figure 3. Physiographic sketch map of the Mekong Delta, Vietnam.

Legend:
(1) Granite hills
(2) Pleistocene alluvial terraces
(3) Holocene complex of river levees and basins
(4) Holocene brackish water sediments in wide depressions
(5) Holocene marine sand ridges and clay plains
(6) Holocene peat dome.

Country boundary
Provincial boundary
Road
River
City

50 km
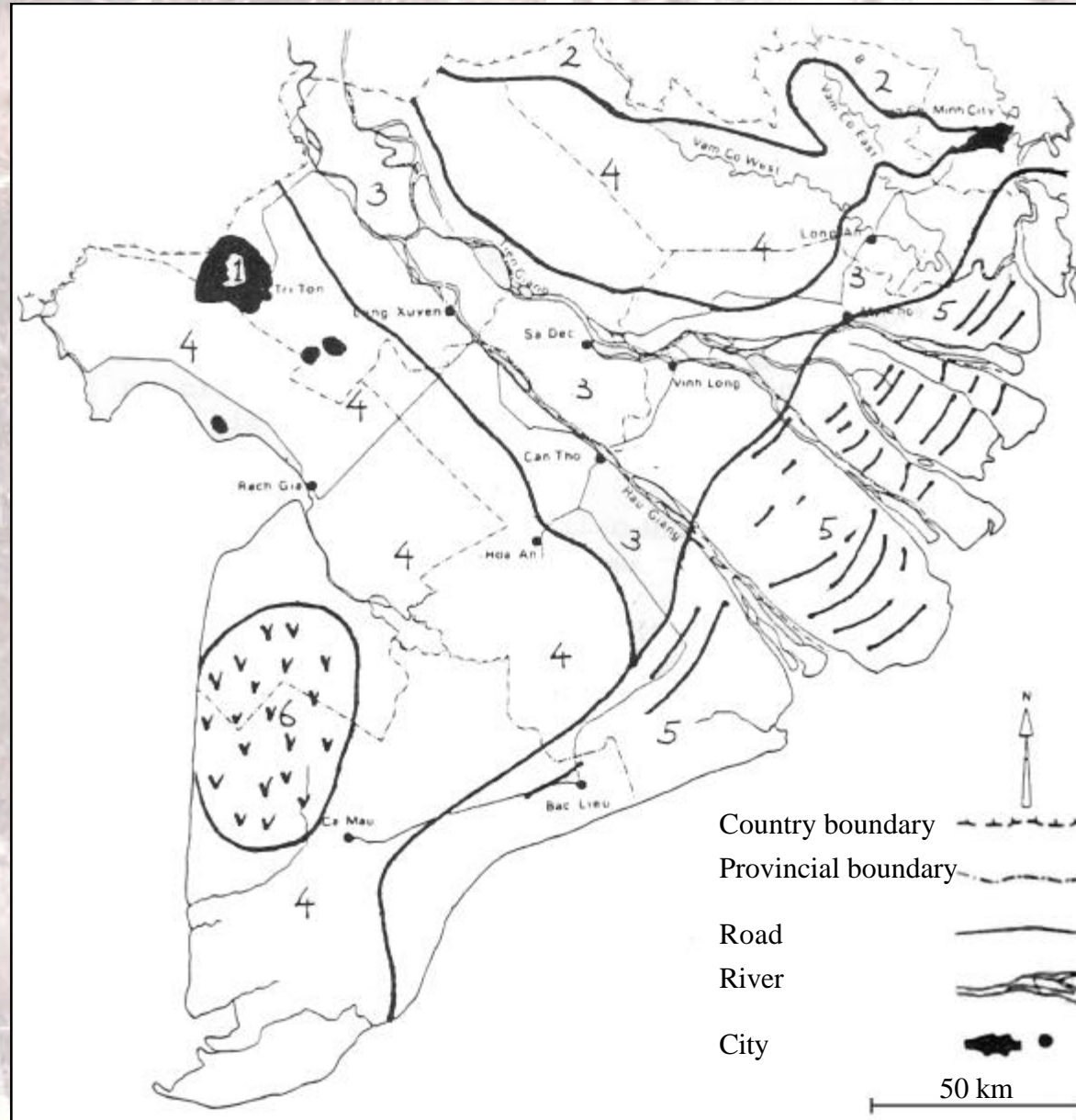
In the Mekong Delta, pyritic sediments are common in the depressions (map unit 4) where extensive areas of Thionic Fluvisols are found. There is no pyrite in the soils of map units 3 (fresh water deposits; no sulfate present during sedimentation), and 5 (sedimentation rate too high). The lower tiers of topogenous deltaic peat (map unit 6) may well contain pyrite.

Note that many soils in river deposits and marine sediments in the Mekong Delta have lost their fluvic soil properties, i.e. they are no longer stratified or have developed a cambic subsurface horizon. Most of these soils key out as Gleysols.

Characteristics of Fluvisols

Morphometric characteristics

Fluvisols are very young soils with weak horizon differentiation; they have mostly AC-profiles and are predominantly brown (aerated soils) and/or grey (waterlogged soils) in colour. Their texture can vary from coarse sand in levee soils to heavy clays in basin areas. Most Fluvisols show mottling due to alternating reducing and oxidizing conditions. However, even if '*gleyic colour patterns*' occur in the upper 50 cm of the profile, the soils are not classified as Gleysols because their fluvic properties have priority in the 'Key to Reference Soil Groups'.
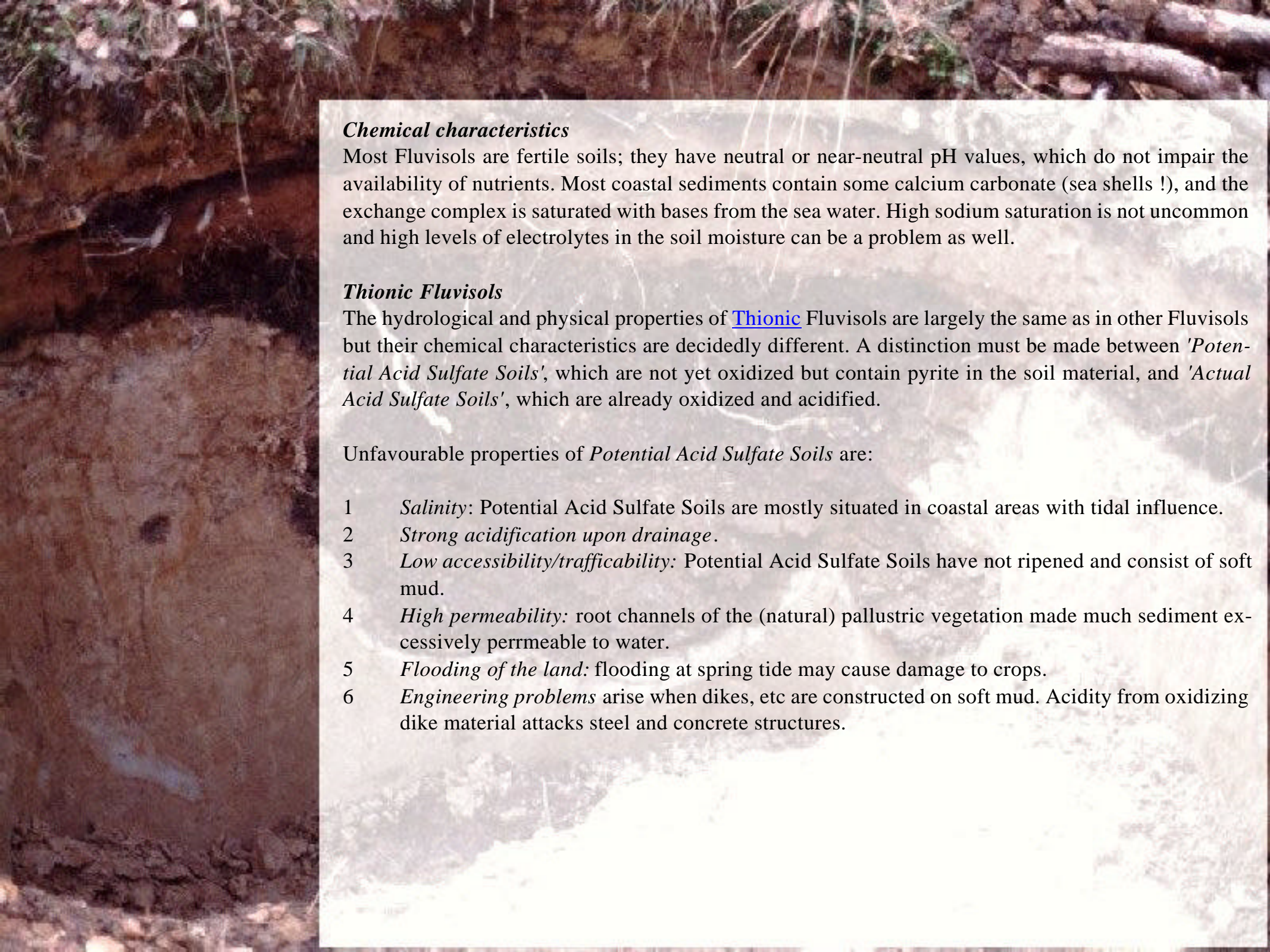
It is evident that the characteristics of Fluvisols are dominated by their recent sedimentation and wetness: stratification, beginning ripening, chemical properties influenced by alternate reducing and oxidizing conditions, and in some environments also soil salinity. Rather special are the characteristics of Thionic Fluvisols; they will be addressed in some detail.

Hydrological characteristics

Most Fluvisols are wet in all or part of the profile due to stagnating groundwater and/or flood water from rivers or tides. Terraces are a part of many river systems but are much better drained than the active flood plain; terrace soils are normally well homogenized and lack fluvic properties.

Physical characteristics

The 'ripening stage' of sedimentary material is judged by sqeezing a lump of soil material through one's fingers and interpreting the resistance felt. Wet clays and silt soils that have lost little water since deposition are soft and 'unripe'. Such soils pose problems for agricultural use; they have a low 'bearing capacity' and machines cannot be used on them. Many clayey Fluvisols have few pores and low hydraulic conductivity. However, many coastal landforms were at one time colonized by pallustric vegetation (e.g. mangroves or reeds) that left large tubular pores in the sediment. Fluvisols on river levees and coastal sand ridges are porous and better drained than soils in low landscape positions.

Chemical characteristics

Most Fluvisols are fertile soils; they have neutral or near-neutral pH values, which do not impair the availability of nutrients. Most coastal sediments contain some calcium carbonate (sea shells !), and the exchange complex is saturated with bases from the sea water. High sodium saturation is not uncommon and high levels of electrolytes in the soil moisture can be a problem as well.

Thionic Fluvisols

The hydrological and physical properties of Thionic Fluvisols are largely the same as in other Fluvisols but their chemical characteristics are decidedly different. A distinction must be made between *'Potential Acid Sulfate Soils'*, which are not yet oxidized but contain pyrite in the soil material, and *'Actual Acid Sulfate Soils'*, which are already oxidized and acidified.

Unfavourable properties of *Potential Acid Sulfate Soils* are:

1   *Salinity*: Potential Acid Sulfate Soils are mostly situated in coastal areas with tidal influence.
2   *Strong acidification upon drainage*.
3   *Low accessibility/trafficability:* Potential Acid Sulfate Soils have not ripened and consist of soft mud.
4   *High permeability:* root channels of the (natural) pallustric vegetation made much sediment excessively perrmeable to water.
5   *Flooding of the land:* flooding at spring tide may cause damage to crops.
6   *Engineering problems* arise when dikes, etc are constructed on soft mud. Acidity from oxidizing dike material attacks steel and concrete structures.

Unfavourable properties of *Actual Acid Sulfate Soils* are:

1. *Low soil-pH:* most plants can tolerate pH values as low as pH 4, but only if the supply of nutrients is well balanced.
2. *Aluminium toxocity* can occur at a soil-pH below 4.5; generally valid toxicity limits cannot be given as toxicity is co-determined by such factors as 'crop/variety', 'availability of nutrients', 'growth stage of the plants', etc.
3. *Salinity:* salts from seawater can cause high electrolyte levels; in addition, sulfate levels can build up in the soil solution to the extent that the soil is to be regarded saline.
4. *Phosphorus deficiency:* high aluminum levels in the soil solution cause precipitation of insoluble Al-phosphates.
5. *Ferrous iron (Fe^{2+}) toxicity* is a common problem where rice is cultivated on Actual Acid Sulfate Soils. Insoluble ferric iron compounds are oxidized to soluble ferrous iron compounds in flooded rice fields.
6. *Acidification of surface water:* when Actual Acid Sulfate Soils are flooded for rice cultivation, soluble ferrous iron can diffuse to the surface water and be oxidized to ferric iron.
    $$2\ Fe^{2+} + \tfrac{1}{2}\ O_2 + 5\ H_2O = 2\ Fe(OH)_3 + 4\ H^+$$
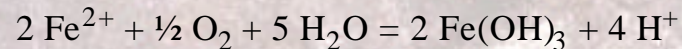
    This acidifies the surface water and can cause irreparable damage to structures and fish in a very short time.
7. *N-deficiency:* mineralization of organic matter by microbial action is slow in (wet, cold) Actual Acid Sulfate Soils.
8. *Engineering problems:* acidity from surface water attacks steel and concrete structures.
9. *H_2S toxicity* becomes a problem where Actual Acid Sulfate Soils are flooded for long periods (a year or longer). Sulfate will then be reduced to H_2S, which is toxic at very low concentrations.

Management and use of Fluvisols

The good natural fertility of most Fluvisols (young soils!) and attractive dwelling sites on river levees and on higher parts in marine landscapes were recognized already by pre-historic man. Later, great civilizations developed in river landscapes and on marine plains.
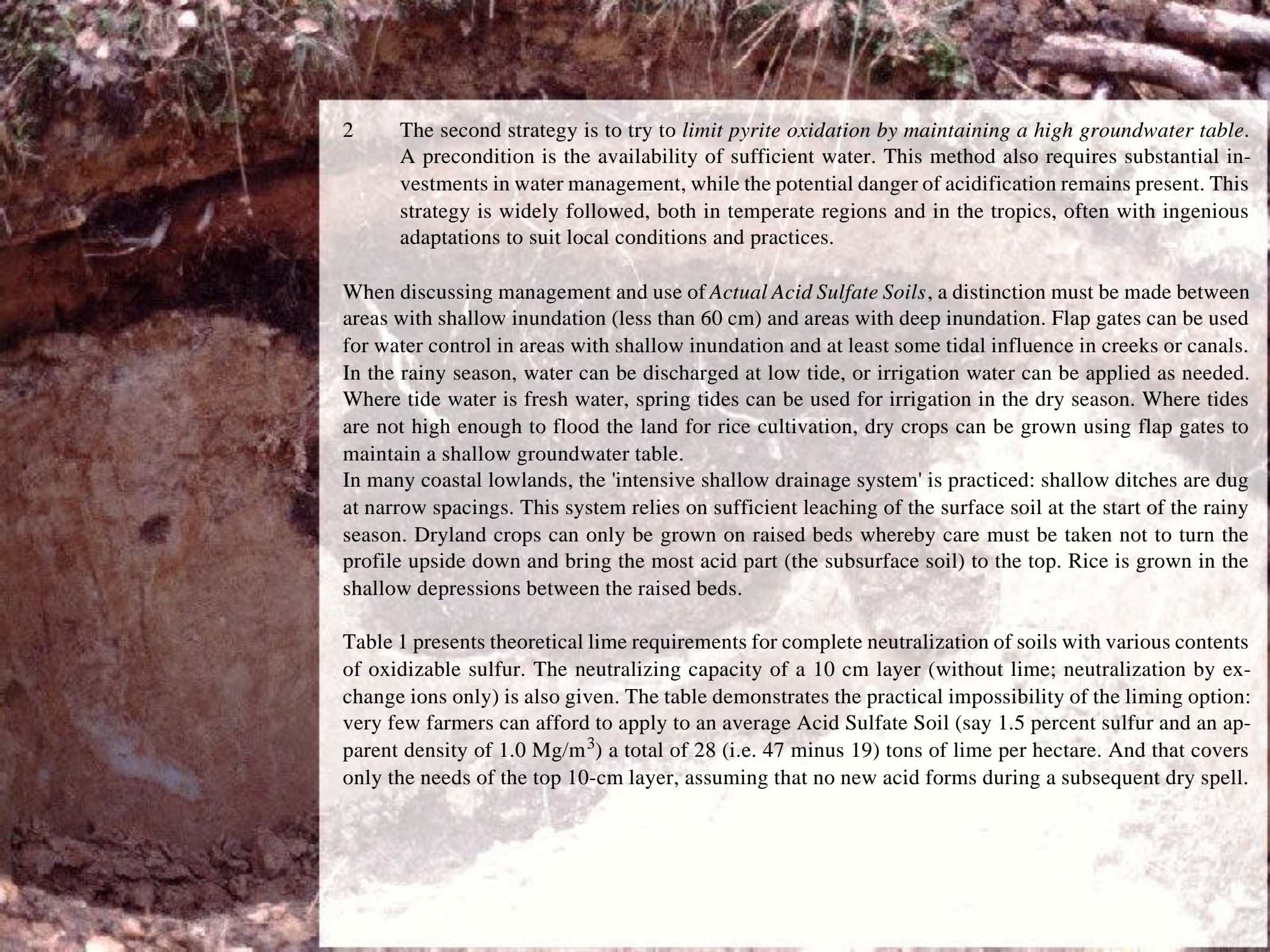
Landuse on Fluvisols in the tropics:
Paddy rice cultivation is widespread on tropical Fluvisols with satisfactory irrigation and drainage. Paddy land should be dry for at least a few weeks every year, to prevent the soil's redox potential from becoming so low that nutritional problems (iron, H_2S) arise. A dry period also stimulates microbial activity and promotes mineralization of organic matter. Many dryland crops are grown on Fluvisols as well, normally with some form of artificial water control.
Tidal lands that are strongly saline are best kept under mangroves or some other salt tolerant vegetation. Such areas are ecologically valuable and can be used (with caution!) for fishing, hunting, salt pans, or woodcutting for charcoal or firewood.

There are two (opposite) strategies thinkable for 'reclaiming' and using *Potential Acid Sulfate Soils:*

1   The first strategy is to *drain and completely oxidize the soil, and then flush the acidity* formed out of the soil. Leaching can initially be done with saline or brackish water; this will not only remove soluble acidity, but also expel undesirable aluminium ions from the exchange complex. This strategy solves the problem once and for all but has severe disadvantages: it is expensive, poses a threat to the environment (acid drain water !) and depletes the soil of useful elements together with the undesirable ones. The method has been applied with some success in coastal rice growing areas in Sierra Leone and in areas with fishponds in the Philippines. It proved disastrous in Senegal, where insufficient water was available for leaching, and in the Netherlands where the first generation of settlers barely survived the construction of the Haarlemmermeer polder.

2   The second strategy is to try to *limit pyrite oxidation by maintaining a high groundwater table*. A precondition is the availability of sufficient water. This method also requires substantial investments in water management, while the potential danger of acidification remains present. This strategy is widely followed, both in temperate regions and in the tropics, often with ingenious adaptations to suit local conditions and practices.

When discussing management and use of *Actual Acid Sulfate Soils*, a distinction must be made between areas with shallow inundation (less than 60 cm) and areas with deep inundation. Flap gates can be used for water control in areas with shallow inundation and at least some tidal influence in creeks or canals. In the rainy season, water can be discharged at low tide, or irrigation water can be applied as needed. Where tide water is fresh water, spring tides can be used for irrigation in the dry season. Where tides are not high enough to flood the land for rice cultivation, dry crops can be grown using flap gates to maintain a shallow groundwater table.

In many coastal lowlands, the 'intensive shallow drainage system' is practiced: shallow ditches are dug at narrow spacings. This system relies on sufficient leaching of the surface soil at the start of the rainy season. Dryland crops can only be grown on raised beds whereby care must be taken not to turn the profile upside down and bring the most acid part (the subsurface soil) to the top. Rice is grown in the shallow depressions between the raised beds.

Table 1 presents theoretical lime requirements for complete neutralization of soils with various contents of oxidizable sulfur. The neutralizing capacity of a 10 cm layer (without lime; neutralization by exchange ions only) is also given. The table demonstrates the practical impossibility of the liming option: very few farmers can afford to apply to an average Acid Sulfate Soil (say 1.5 percent sulfur and an apparent density of 1.0 Mg/m^3) a total of 28 (i.e. 47 minus 19) tons of lime per hectare. And that covers only the needs of the top 10-cm layer, assuming that no new acid forms during a subsequent dry spell.

Table 1. Lime requirements for complete neutralization of a 10-cm soil layer.
After Dent & Raiswell, 1982.

Apparent soil density (Mg/m^3)	Lime requierement for a 10 cm layer in tons of lime/ha						Neutralising capacity of the 10 cm layer (no lime present) in a clayey soil
	0.5	1	1.5	2	3	4	
0.6	9	19	28	37	56	74	11
0.8	12	25	37	50	74	112	14
1.0	16	31	47	62			19
1.2	19	37	56	74			22

Many lands with Actual Acid Sulfate Soils are not used for agriculture at all. Such hostile 'wet desert' lands have an adapted vegetation, a limited fauna, and acid surface water, especially early in the wet season when acid substances dissolve. The situation seems to be a little less bleak in the equatorial climatic zone than in monsoon climates. There, Acid Sulfate Soils will not dry out as easily as in the monsoon area, and more water is available for management measures throughout the year.