AN OVERVIEW OF THE CHEMICAL COMPOSITION OF BIOMASS*

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Published in FUEL, 2010, 89: 913-933; available online 10 November 2009

Introduction and Scope

JRC-IE is conducting a detailed review of the biomass literature (≥370 references) plus some key investigations related to biomass use in bioenergy with two fundamental objectives:

(1) to extend and improve the basic knowledge on composition and properties
(2) to apply this knowledge for the most advanced and environmentally safe utilization

Increased use of biomass for bioenergy will have an environmental impact, but what might be that impact ?

Question: Can methodology for characterisation of coal be applied to biomass ?
Question: What is an appropriate methodology for full characterisation of biomass for bioenergy, particularly co-firing applications ?

Basic Methodology

Initial Step:

- establish the bulk chemical composition of biomass:

  traditionally this should include –

  proximate analysis (FC, VM, A, M),

  ultimate analysis (C, O, H, S, N),

  ash analysis (Si, Al, Fe, Ca, S, Mg, K, Ti, Na and P oxides)

Unfortunately, complete datasets for many varieties of biomass are quite limited (only for 86 varieties of biomass could be used for the present study after consideration of 280 references)

Aims of the Work

This includes:

- evaluating the chemical composition of 86 varieties of biomass and their ashes based on the 19 parameters, plus additional data for Cl and Mn
- conducting some chemical comparisons between biomass and 38 Solid Fossil Fuels (SFF)
- establishing some basic trends/relationships based on biomass chemical analysis data
- proposing possible initial classifications and potential applications of the results

General classification of biomass

According to origin

Biomass group	Biomass sub-groups, varieties and species
1. Wood and woody biomass	**Coniferous or deciduous; soft or hard; stems, branches, foliage, bark, chips, pellets, briquettes, sawdust, sawmill and others from various wood species**
2. Herbaceous and agricultural biomass	**Annual or perennial and field-based or processed-based such as:** *2.1. Grasses and flowers* **(alfalfa, arundo, bamboo, bana, brassica, cane, miscanthus, switchgrass, timothy…)** *2.2. Straws* **(barley, flax, oat, rape, rice, rye, wheat…)** *2.3. Other residues* **(fruits, shells, husks, pits, seeds, coir, stalks, cobs, bagasse, food, fodder, pulps…)**
3. Aquatic biomass	**Marine or freshwater algae; macroalgae or microalgae; blue, green, blue-green, brown, red, seaweed, kelp, lake weed, water hyacinth…**
4. Animal and human biomass wastes	**Bones, meat-bone meal, chicken litter, various manures…**
5. Contaminated biomass and industrial biomass wastes (semi-biomass)	**Municipal solid waste, demolition wood, refuse-derived fuel, sewage sludge, hospital waste, paper-pulp sludge, waste papers, paperboard waste…**
6. Biomass mixtures	**Blends from the above varieties**

Matter	State and type	Phases and components
Organic matter	*Solid, non-crystalline*	**Structural ingredients, mainly cellulose, hemicellulose, lignin**
	Solid, crystalline	**Organic minerals such as Ca-Mg-K-Na oxalates, others**
Inorganic matter	*Solid, crystalline*	**Mineral species from phosphates, carbonates, silicates, chlorides, sulphates, oxyhydroxides, nitrates, and other mineral classes**
	Solid, semi-crystalline	**Poorly crystallized forms of some silicates, phosphates, hydroxides, others**
	Solid, amorphous	**Amorphous phases such as various glasses, silicates, others**
Fluid matter	*Fluid, liquid, gas*	**Moisture, gas and gas-liquid inclusions associated with both organic and inorganic matter**

Origin of Phases in Biomass

Process	Place	Time	Formation mechanism
Natural	*Authigenic* **(formed in biomass)**	*Syngenetic* **(during plant growing)**	**Generated by biogenic processes**
		Epigenetic **(after plant died)**	**Originated by natural processes**
	Detrital **(formed outside biomass, but fixed in/on biomass)**	*Pre-syngenetic* **(before plant growing)**	**Pre-existing and finely dispersed mineral grains (commonly <1 µm) introduced into the plant by water suspensions during syngenesis**
		Pre-syngenetic, syngenetic or epigenetic	**Pre-existing and fine-grained particles (normally <10-100 µm) introduced by water and wind on plant surfaces**
Anthropogenic	*Technogenic* **(formed outside or inside biomass and fixed in/on biomass)**	*Post-epigenetic* **(during and after plant collecting)**	**Natural and/or industrial components introduced in biomass during collecting, handling, transport and subsequent processing**

Proximate and ultimate analyses data recalculated on dry and daf basis, respectively, results in different enrichment - depletion trends :

In decreasing order of abundance, the elements in biomass are normally:
(1) **major (>1.0%)**: C, O, H, N, Ca, K
(2) **minor (0.1-1.0%)**: Si, Mg, Al, S, Fe, P, Cl, Na
(3) **trace elements (<0.1%):** Mn, Ti and others

Biomass group and sub-group	Enriched in	Depleted in
1. Wood and woody biomass (WWB)	**Ca, Mg, Mn, VM**	**A, Cl, N, P, S, Si**
2. Herbaceous and agricultural biomass (HAB)	**FC, K, O, VM**	**C, H, Ca**
2.1. Grasses (HAG)	**K, O, Si, VM**	**Al, C, Ca, H, Na**
2.2. Straws (HAS)	**Cl, K, O, Si**	**C, H, Na**
2.3. Other residues (HAR)	**FC, K, Mg, P**	**Cl**
3. Animal biomass (AB)	**A, C, Ca, Cl, H, N, Na, P, S**	**Al, Fe, M, Mg, Mn, O, Si, Ti, VM**
4. Contaminated biomass (CB)	**A, Al, C, Cl, Fe, H, N, S, Ti**	**FC, K, P**

Intermediate Conclusions

- Chemical composition of natural biomass is simpler than that of Solid Fossil Fuels
- However, processing results in incorporation of numerous non-biomass materials

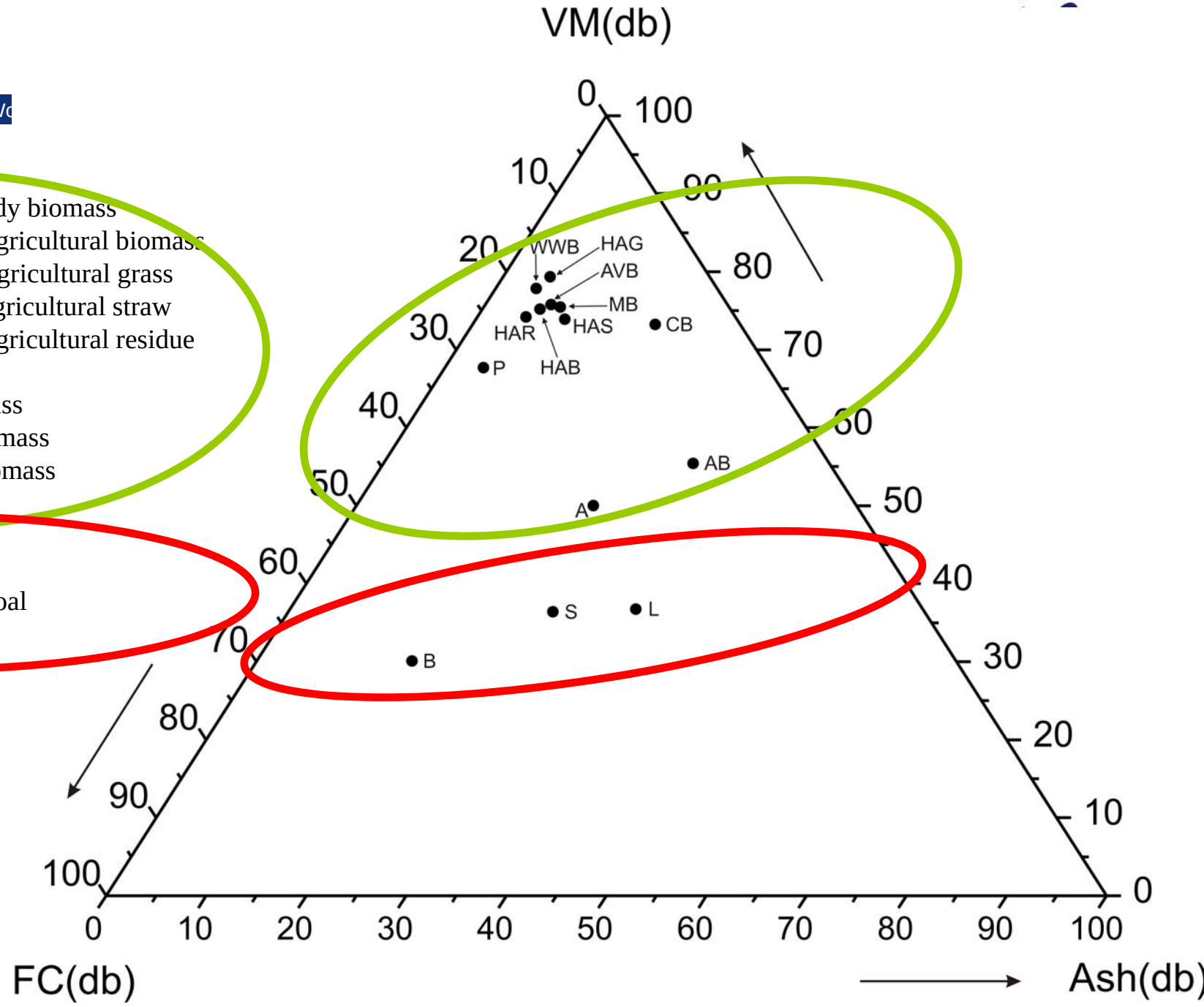
- Biomass composition is significantly different from that of SFFs
- The variations among biomass composition are greater than for coal. In comparison with coal, natural/virgin biomass (78 varieties) commonly shows:

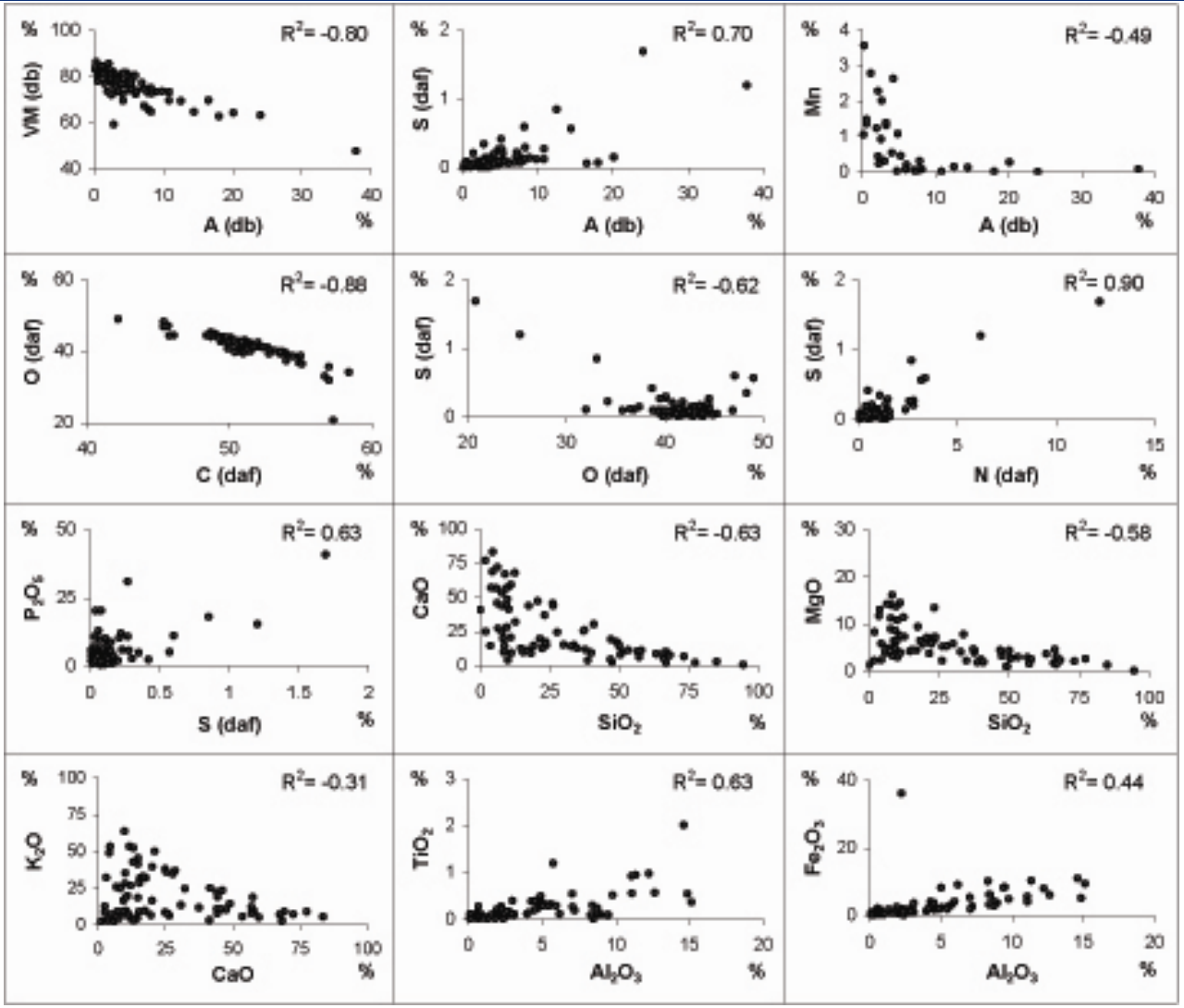
  (1) enrichment in Mn > K > P > Cl > Ca > (Mg, Na) > O > VM > H

  (2) depletion in S > (A, Al, Ti) > FC > (Fe, Si) > C > N

WWB - wood and woody biomass
HAB - herbaceous and agricultural biomass
HAG - herbaceous and agricultural grass
HAS - herbaceous and agricultural straw
HAR - herbaceous and agricultural residue
AB - animal biomass
MB - mixture of biomass
CB - contaminated biomass
AVB - all varieties of biomass
A - algae
P - peat
L - lignite
S - sub-bituminous coal
B - bituminous coal

Proximate Analysis (wt%)





Five strong correlations for natural/ biomass system (78 varieties):

(1) C - H
(2) N - S - Cl
(3) Si - Al - Fe - Na -Ti
(4) Ca - Mg - Mn
(5) K - P - S - Cl

Fig. 2. Some significant correlations among the chemical composition of biomass (wt.%)

WWB - wood and woody biomass
HAB - herbaceous and agricultural biomass
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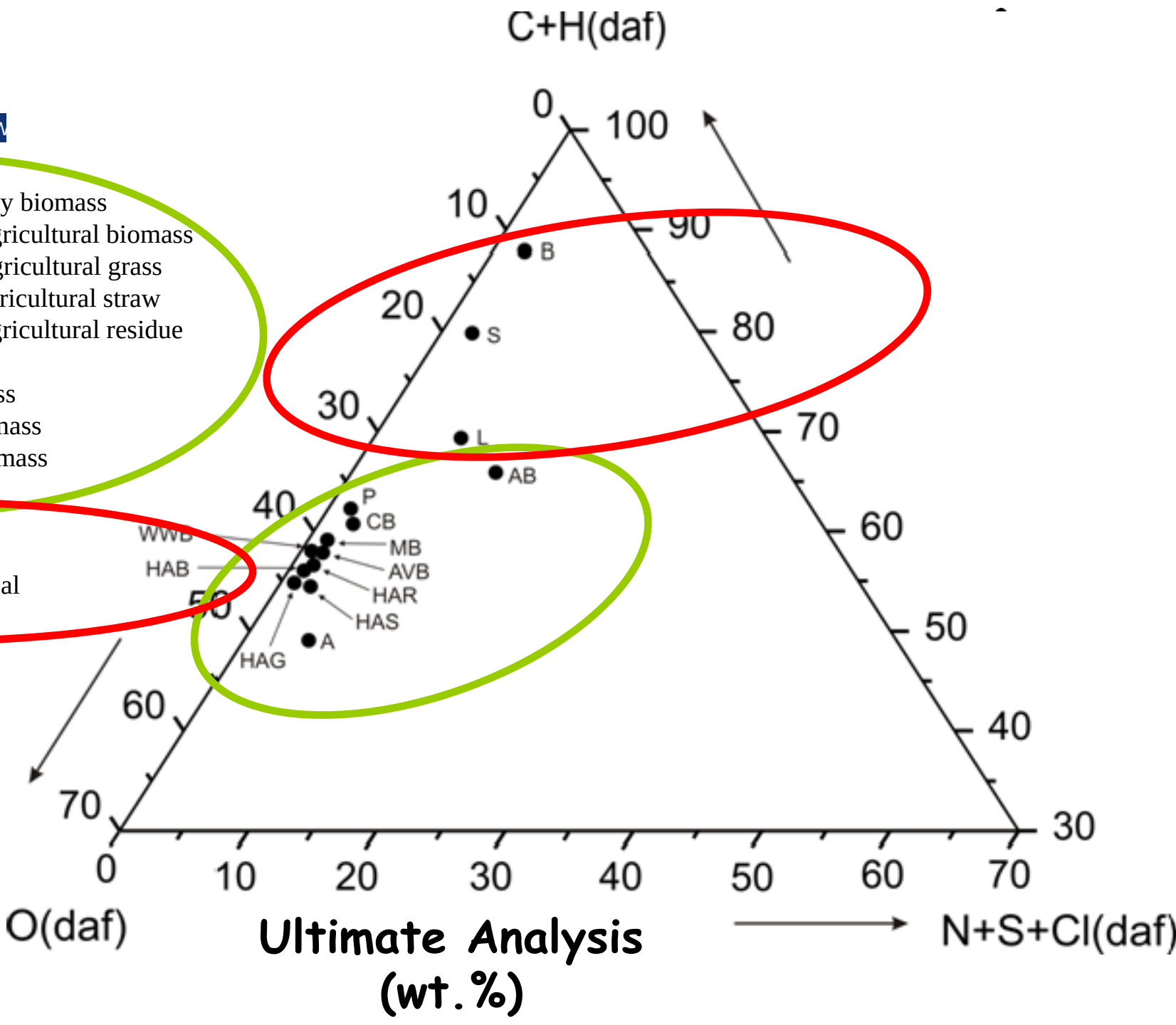
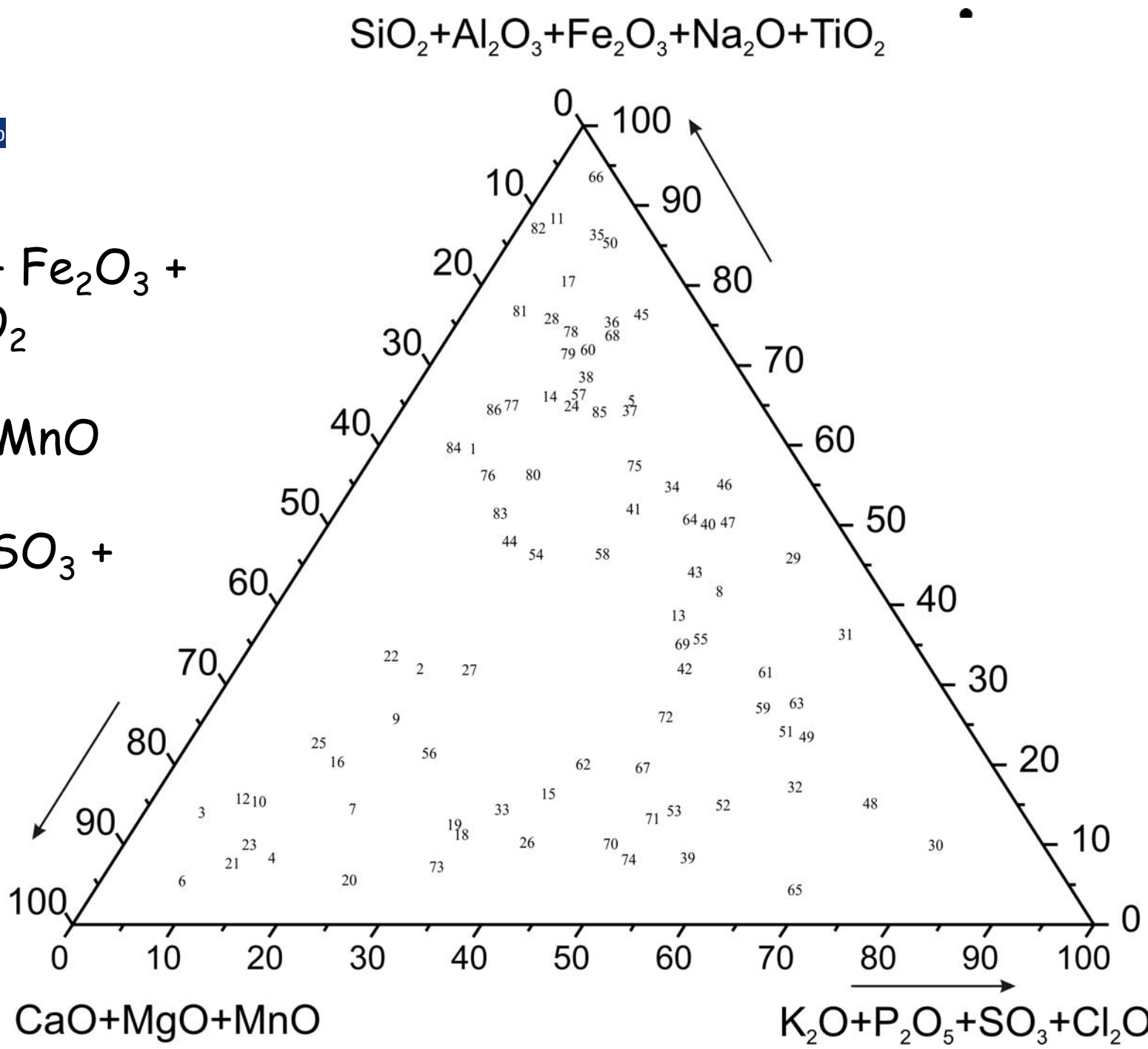


biomass ash:

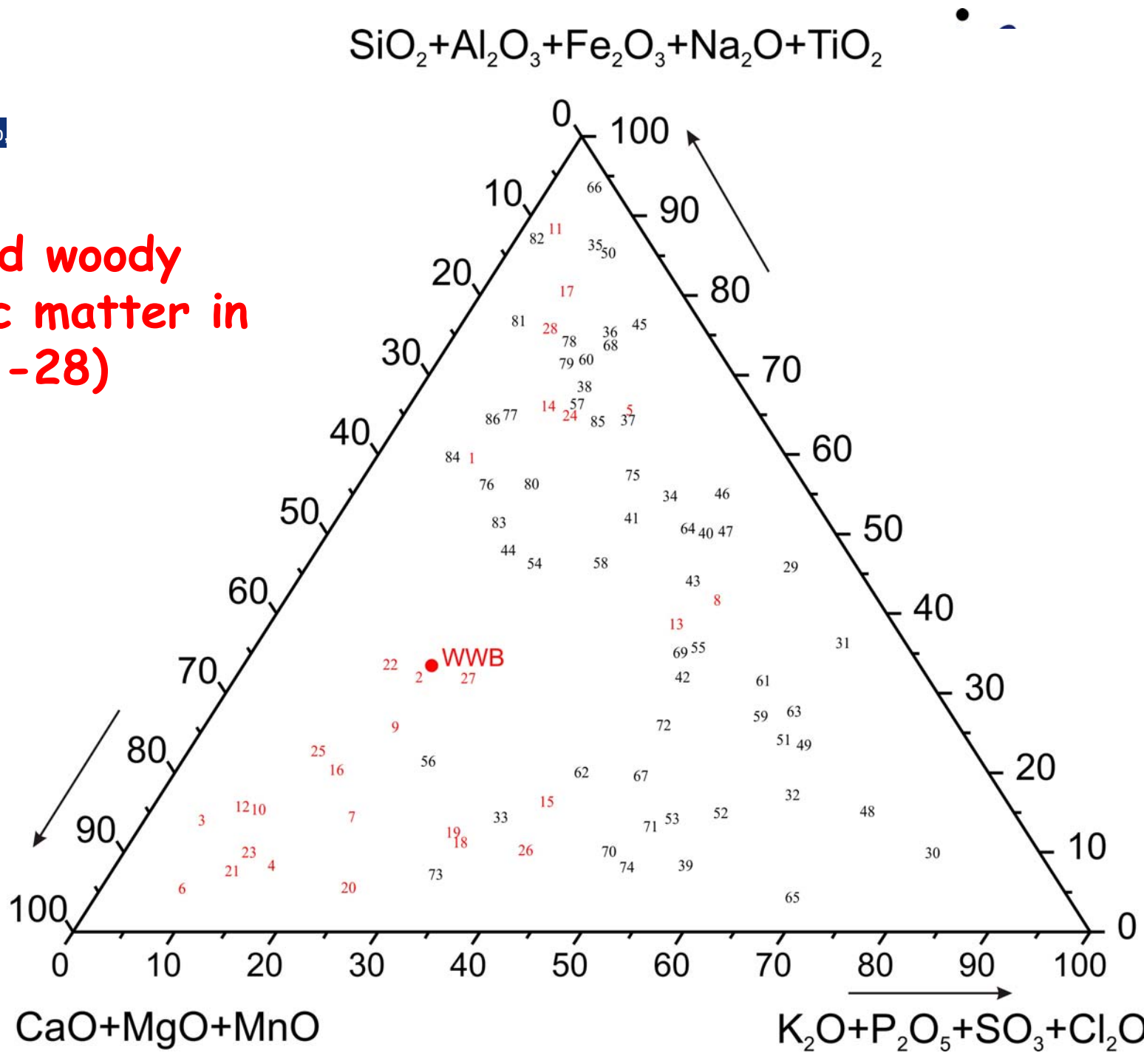
(1) $SiO_2 + Al_2O_3 + Fe_2O_3 + Na_2O + TiO_2$

(2) $CaO + MgO + MnO$

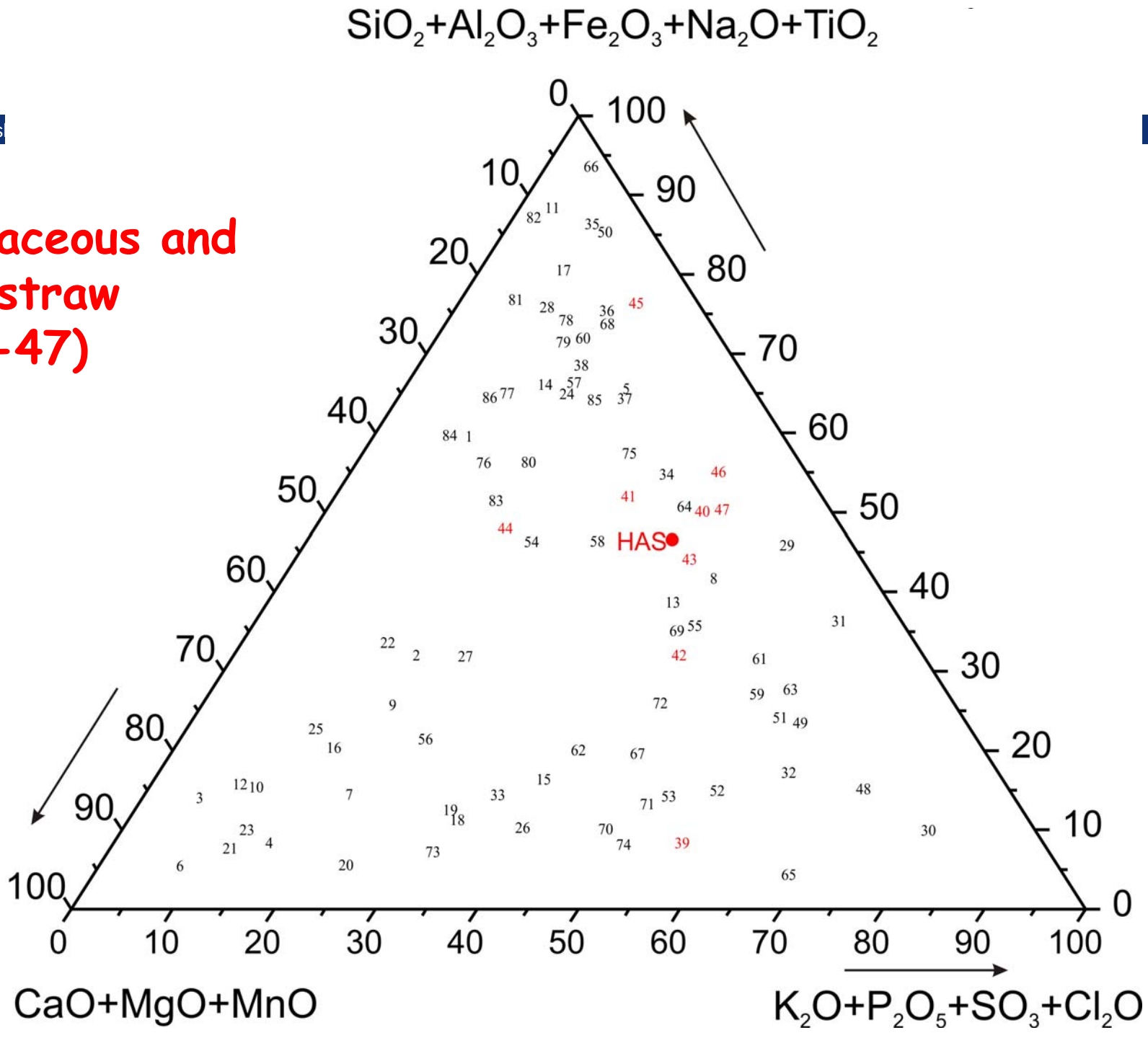
(3) $K_2O + P_2O_5 + SO_3 + Cl_2O$



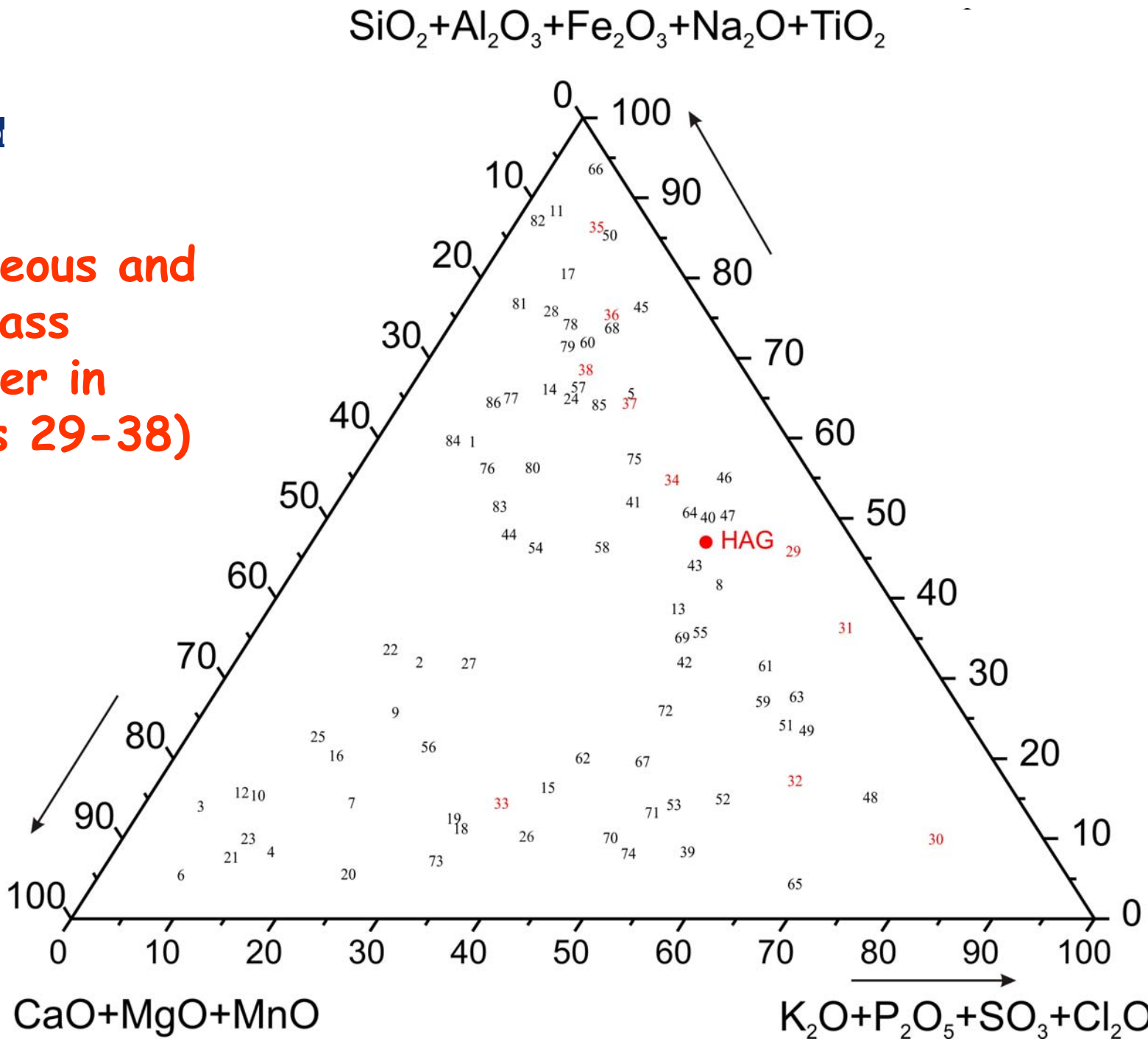
WWB - wood and woody biomass inorganic matter in ashes (samples 1-28)



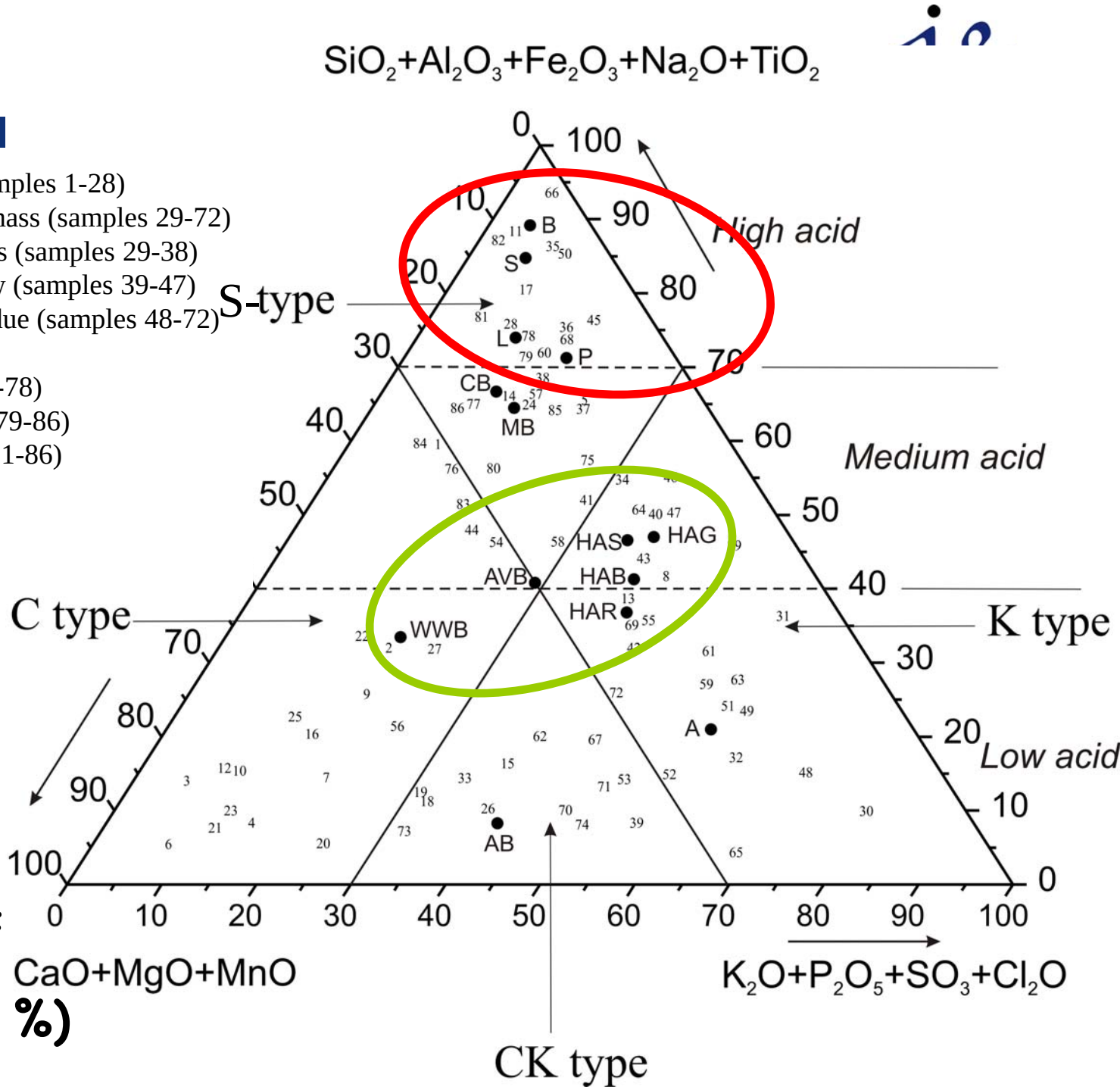
HAS - herbaceous and agricultural straw (samples 39-47)



HAG - herbaceous and agricultural grass inorganic matter in ashes (samples 29-38)

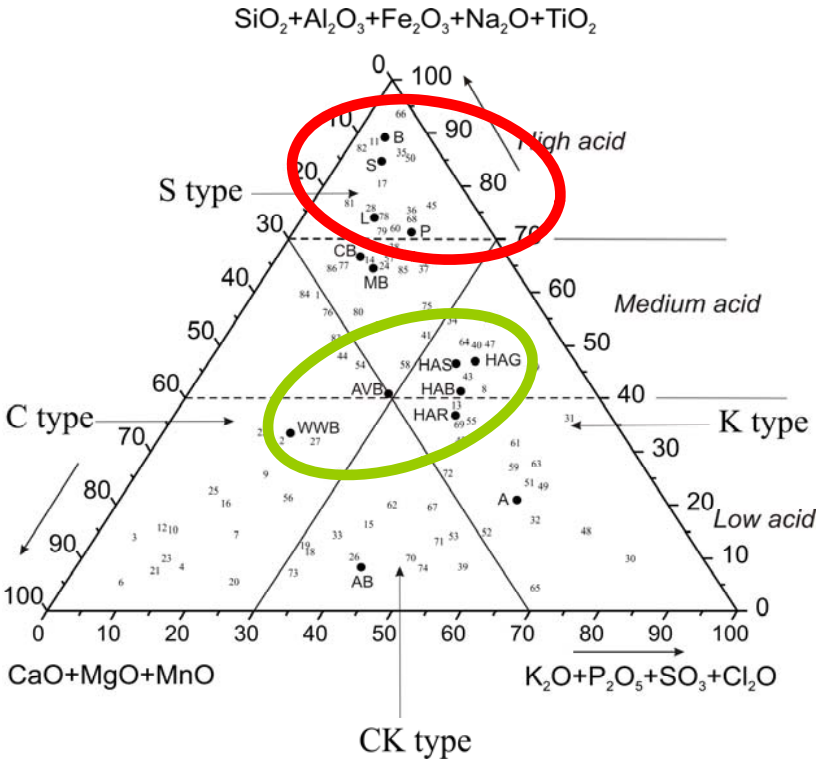


WWB - wood and woody biomass (samples 1-28)
HAB - herbaceous and agricultural biomass (samples 29-72)
HAG - herbaceous and agricultural grass (samples 29-38)
HAS - herbaceous and agricultural straw (samples 39-47)
HAR - herbaceous and agricultural residue (samples 48-72)
AB - animal biomass (samples 73-74)
MB - mixture of biomass (samples 75-78)
CB - contaminated biomass (samples 79-86)
AVB - all varieties of biomass (samples 1-86)
A - algae
P - peat
L - lignite
S - sub-bituminous coal
B - bituminous coal



All 78 varieties of biomass ashes (wt %)

Preliminary Classification



Preliminary chemical classification system for the inorganic matter of biomass:

(1) **all varieties of biomass** (close to the centre of the triangular graph);

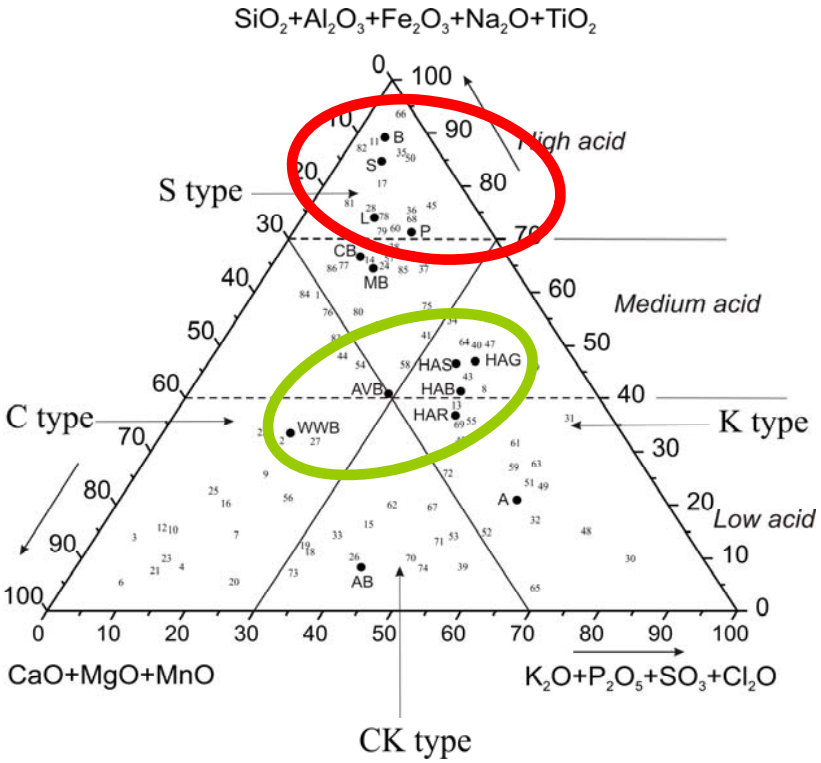
(2) **WWB** (Ca + Mg + Mn oxides above 30%);

(3) **HAB** (K + P + S + Cl oxides above 30%);

(4) **SFFs** (Si + Al + Fe + Na + Ti oxides above 70%);

(5) **CB** (Si + Al + Fe + Na + Ti oxides between 40 and 70%)

Observations



(1) closer position of peat to coals than biomass (in contrast to proximate and ultimate composition)

(2) differentiations among the biomass groups and some similarities for HAB sub-groups (HAG and HAS could be combined into one sub-group)

(3) possibility for identification of some contamination in biomass fuels (unusual position of some samples 1, 5, 8, 11, 13, 14, 17, 24, 28, 57, 68)

(4) position of marine macroalgae in "K ash type" with low acid tendency and highly enriched in Cl, S, Na, and Mg in comparison with the terrestrial biomass

Conclusions & Future Work

The bulk chemical composition of biomass provides little information about the properties of biomass

Significant knowledge of the phase-mineral composition of biomass is essential in determining properties (analysis of biomass dry and dry ash-free bases essential)

Correlations exist between compounds and these correlations can be used to build a classification system (classification used for comparison with solid fossil fuels – for co-firing applications – application of ashes)

Future work will extend database for biomass and biomass ash for characterization of their:

(1) phase-mineral composition and modes of element occurrence
(2) thermal behaviour of phases and minerals
(3) trace element contents and occurrences
(4) traditional uses of ashes and consideration of innovative uses
(5) potential advanced and environmentally safe applications

Thank you for your attention

HAR - herbaceous and agricultural residue (samples 48-72)

X

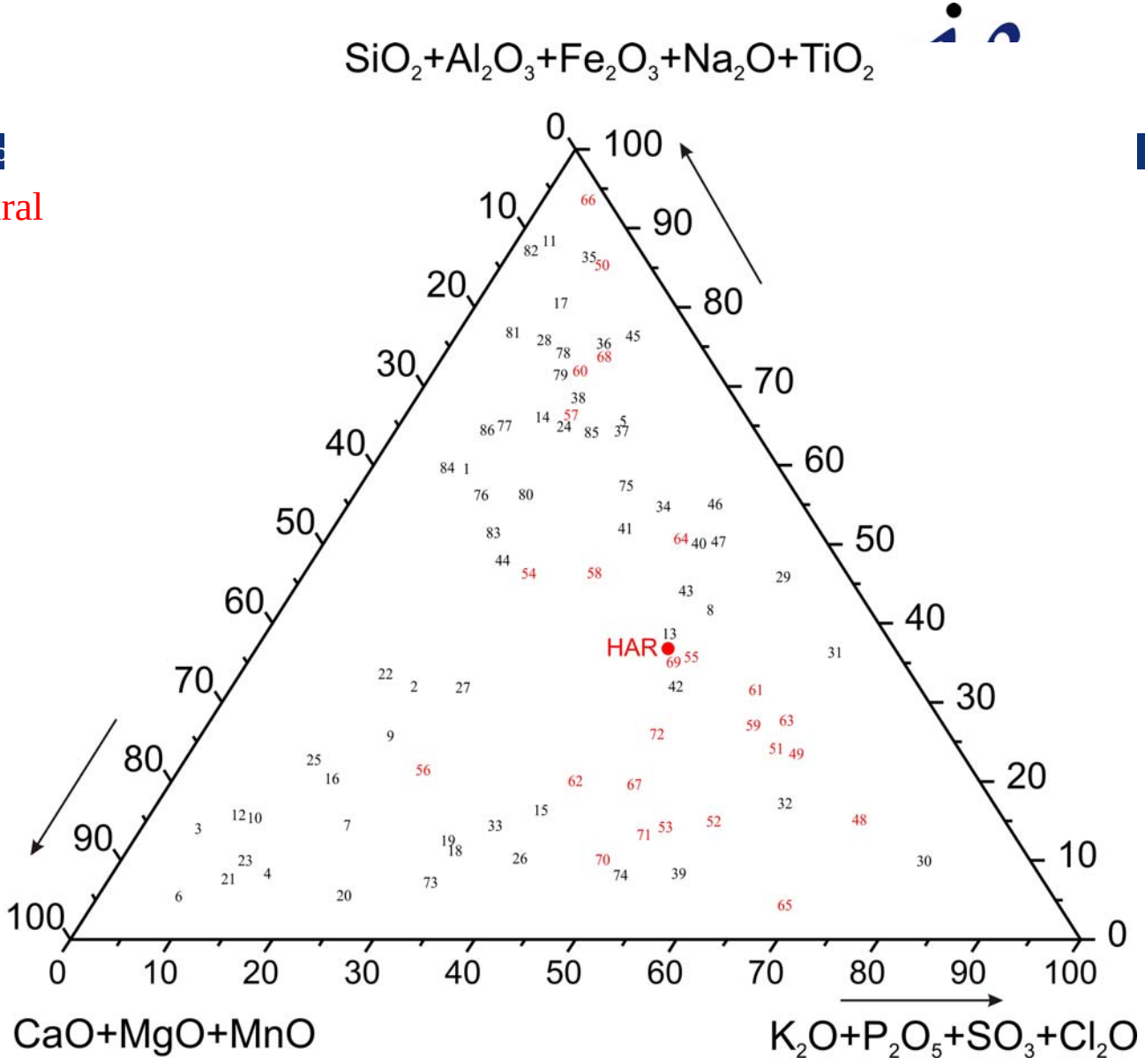
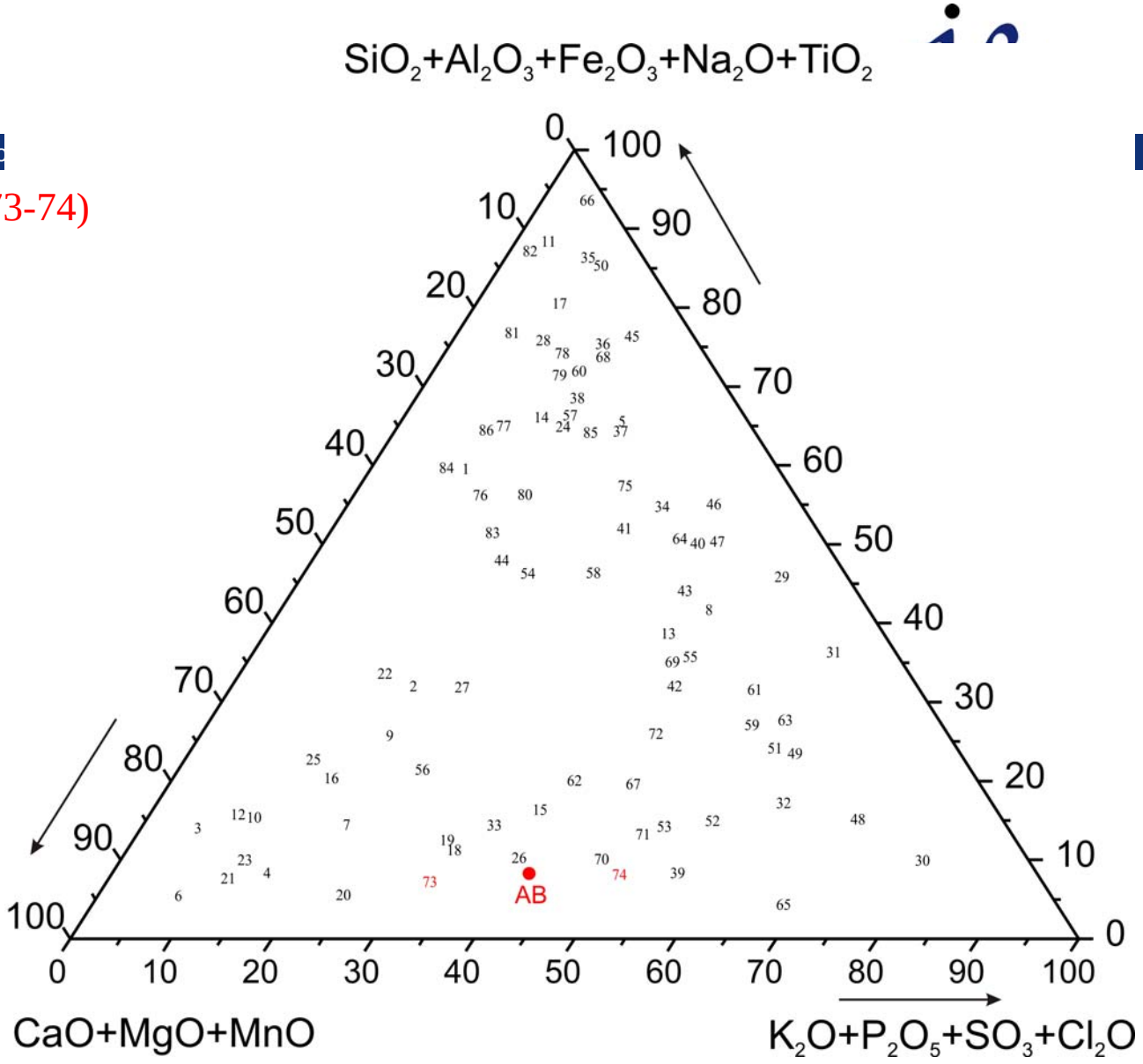


Fig. 4. Chemical classification system of the inorganic matter in biomass ashes based on 78 varieties of biomass (wt %)

AB - animal biomass (samples 73-74)

X



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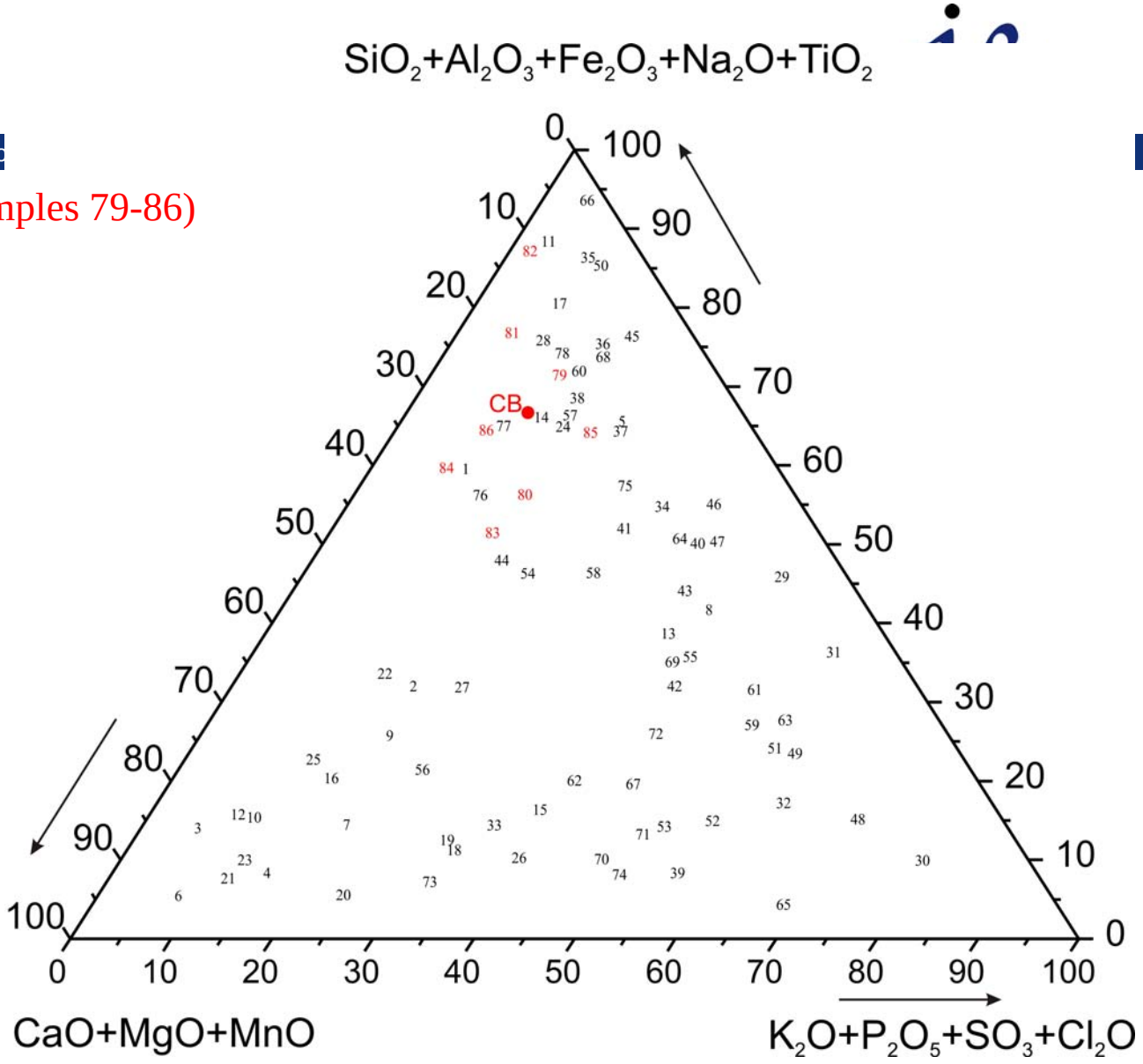
CB - contaminated biomass (samples 79-86)

X



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