USING BASALT POWDER FOR REMEDIATION OF SODIUM CONTAMINATED SOILS; A NOVEL APPROACH TO SOIL RESTORATION

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AGENDA

Background
Sodium Effects on Soil
Gypsum Soil Amendment
Basalt
Field Study
Questions

SODIUM IMPACT TO SOILS AT ALBERTA OIL AND GAS WELLS

- Alberta has been producing oil and gas for over 100 years, 75 years before advent of environmental regulations
- It is estimated that >619,000 wells have been drilled in Alberta.
  - 469,000 licensed wells are in existence (July 2024)
  - 156,900 active
  - 300,000 in other life cycle stages; inactive (16.6%), reclaimed (30.0%), abandoned (19.7%)
- AB spills database search 10 years shows >43% spills contained *salt, *produced water (AER, 2024)
- Surface spills to prairie soils:

High levels Na^+ → Soil dispersion

→ Impaired hydraulic conductivity

→ Reduced capacity of soil for plant growth

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EFFECTS OF SODIUM ON SOIL

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<u>CATION EXCHANGE IN SODIUM-IMPACTED SOILS</u>

- $CaSO_4$ (gypsum) provides exchangeable Ca^{2+} to displace Na^+
- Cation exchange for Ca^{2+} displacing Na^+ $\frac{1}{2}\,Ca^{2+} + Na^+\text{-}X = \frac{1}{2}\,Ca\text{-}X_2 + Na^+$

Radius	Unit	Na^+	K^+	NH_4^+	Mg^{2+}	Ca^{2+}	Al^{3+}
Non-hydrated	nm	0.095	0.133	0.143	0.066	0.099	0.050
Hydrated	nm	0.360	0.330	0.330	0.430	0.410	0.480

Shon et al., 2010

- Gypsum requirement (GR) developed for agricultural land (2-~8 t/ha)

$$GR = 0.086 \times F \times depth \times BD \times CEC \times (initial\ ESP - desired\ final\ ESP)$$

Oster and Jayawardane (1998)

- Theoretical gypsum requirement (TGR) (max 50 t/ha)

$$TGR = 0.00335 \cdot (Na\ (meq/L))^2 \cdot \left[\frac{1}{(target\ SAR)^2}\right] - \left[\frac{1}{(Sample\ SAR)^2}\right] \cdot (Saturation\ \%)$$

Ashworth et al., 1999

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GYPSUM SOIL AMENDMENT

- Solubility of gypsum 2.5 g/L (@ 25℃, & 1 atm) - slightly soluble
- Water activation; 400 mm precipitation or 400,000L precipitation to dissolve 1 t/ha

- Challenges include runoff, multiple applications, excess calcium inhibiting plant growth

An alternate soil amendment is basalt

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WHAT IS BASALT?

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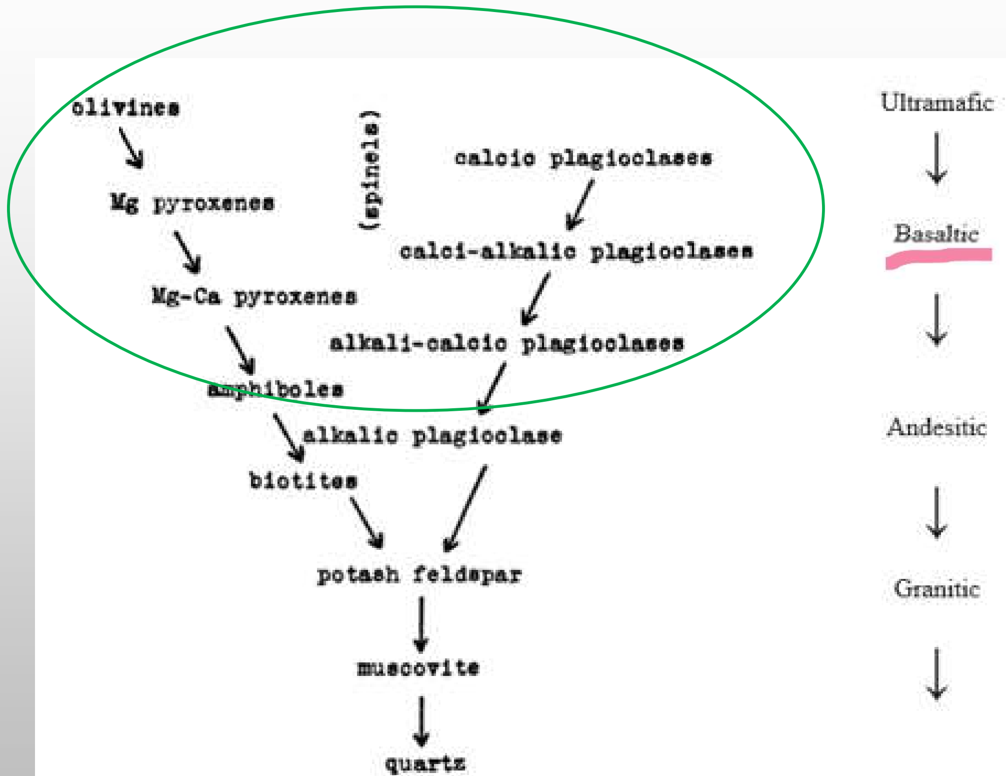
BASALT MINERALOGY



Source: Modified from Bowen, 1922.

Primary basalt minerals

- pyroxene minerals $[(Ca,Na)(Mg,Fe,Al)(Si,Al)_2O_6]$
- plagioclase minerals $[(Ca,Na)AlSi_2O_8]$
- olivine minerals $[(Mg_{2,}Fe2)SiO4]$.

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MINERAL WEATHERING

Physical Weathering

Abrasion
Freeze/Thaw
Pressure
Wind/rain, snow
Plant roots
Crystal growth
Animals

Chemical Weathering

Dissolution (water, acid)
Alteration of minerals
Oxidation
Reduction
Hydrolysis
Hydration
Carbonation
Biological

* *important for basalt are surface area and mineral composition*

BASALT WEATHERING

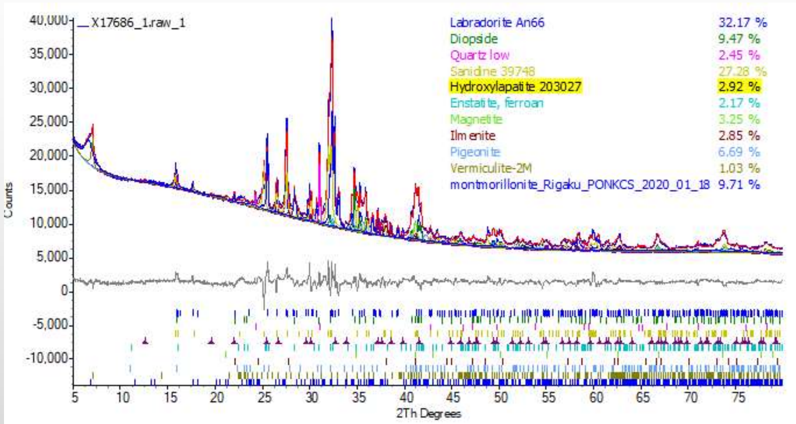
Dissolution Reactions and Aqueous Species of Basalt Primary Minerals

Mineral	Composition[a]	Reaction
Olivine	Fo_{100}	$Mg_2SiO_4 + H^+ = 2Mg^{2+} + H_4SiO_4^0$
	Fa_{100}	$Fe_2SiO_4 + H^+ = 2Fe^{2+} + H_4SiO_4^0$
	$Fo_{80}Fa_{20}$	$(Mg_{0.80}Fe_{0.20})_2SiO_4 + H^+ = 1.60Mg^{2+} + 0.40Fe^{2+} + H_4SiO_4^0$
	$Fo_{43}Fa_{53}$	$(Mg_{0.43}Fe_{0.57})_2SiO_4 + H^+ = 0.86Mg^{2+} + 1.14Fe^{2+} + H_4SiO_4^0$
Pyroxene	En_{100}	$MgSiO_3 + 2H^+ + H_2O = Mg^{2+} + H_4SiO_4^0$
	Fs_{100}	$FeSiO_3 + 2H^+ + H_2O = Fe^{2+} + H_4SiO_4^0$
	Di_{100}	$Mg_{0.5}Ca_{0.5}SiO_3 + 2H^+ + H_2O = 0.5Ca^{2+} + 0.5Mg^{2+} + H_4SiO_4^0$
	Hed_{100}	$Fe_{0.5}Ca_{0.5}SiO_3 + 2H^+ + H_2O = 0.5Ca^{2+} + 0.5Fe^{2+} + H_4SiO_4^0$
	$En_{38}Fs_{62}$	$Mg_{0.38}Fe_{0.62}SiO_3 + 2H^+ + H_2O = 0.38Mg^{2+} + 0.62Fe^{2+} + H_4SiO_4^0$
	$Di_{45}Hed_{25}En_{19}Fs_{11}$	$Ca_{0.35}Mg_{0.42}Fe_{0.23}SiO_3 + 2H^+ + H_2O = 0.35Ca^{2+} + 0.42Mg^{2+} + 0.23Fe^{2+} + H_4SiO_4^0$
Plagioclase	An_{100}	$CaAl_2Si_2O_8 + 8H_2O = Ca^{2+} + 2Al(OH)_4^- + 2H_4SiO_4^0$
	Ab_{100}	$NaAlSi_3O_8 + 8H_2O = Na^+ + Al(OH)_4^- + 3H_4SiO_4^0$
	$An_{70}Ab_{30}$	$Ca_{0.70}Na_{0.30}Al_{1.70}Si_{2.30}O_8 + 8H_2O = 0.70Ca^{2+} + 0.30Na^+ + 1.70Al(OH)_4^- + 2.30H_4SiO_4^0$
	$An_{29}Ab_{71}$	$Ca_{0.29}Na_{0.71}Al_{1.29}Si_{2.71}O_8 + 8H_2O = 0.29Ca^{2+} + 0.71Na^+ + 1.29Al(OH)_4^- + 2.71H_4SiO_4^0$

Source: From Stefánsson, 2001

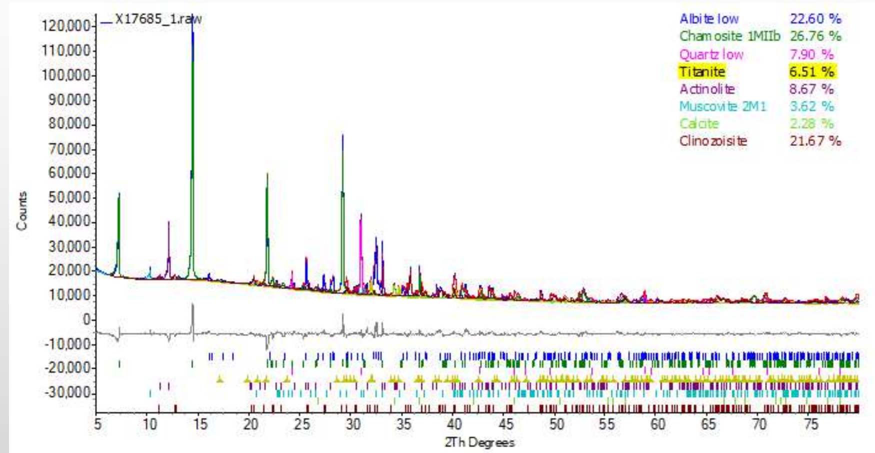
TWO BASALTS – XRD ANALYSIS

Oregon



Phase	Weight Percentages
Plagioclase	32
Diopside	9
Quartz	2
K-spar	27
Hydroxylapatite	3
Enstatite, ferroan	2
Magnetite	3
Ilmenite	3
Pigeonite	7
Clay 1 – Vermiculite?	1
Clay 2 – Swelling Clay – Bentonite	10
Total	**99**
Rwp	**3.4**

Blue Ridge



Phase	Weight Percentages
Plagioclase	23
Chlorite	27
Quartz	8
Titanite	7
Actinolite	8
Dioctahedral Mica 2M1	4
Calcite	2
Epidote	22
Total	**101**
Rwp	**3.8**

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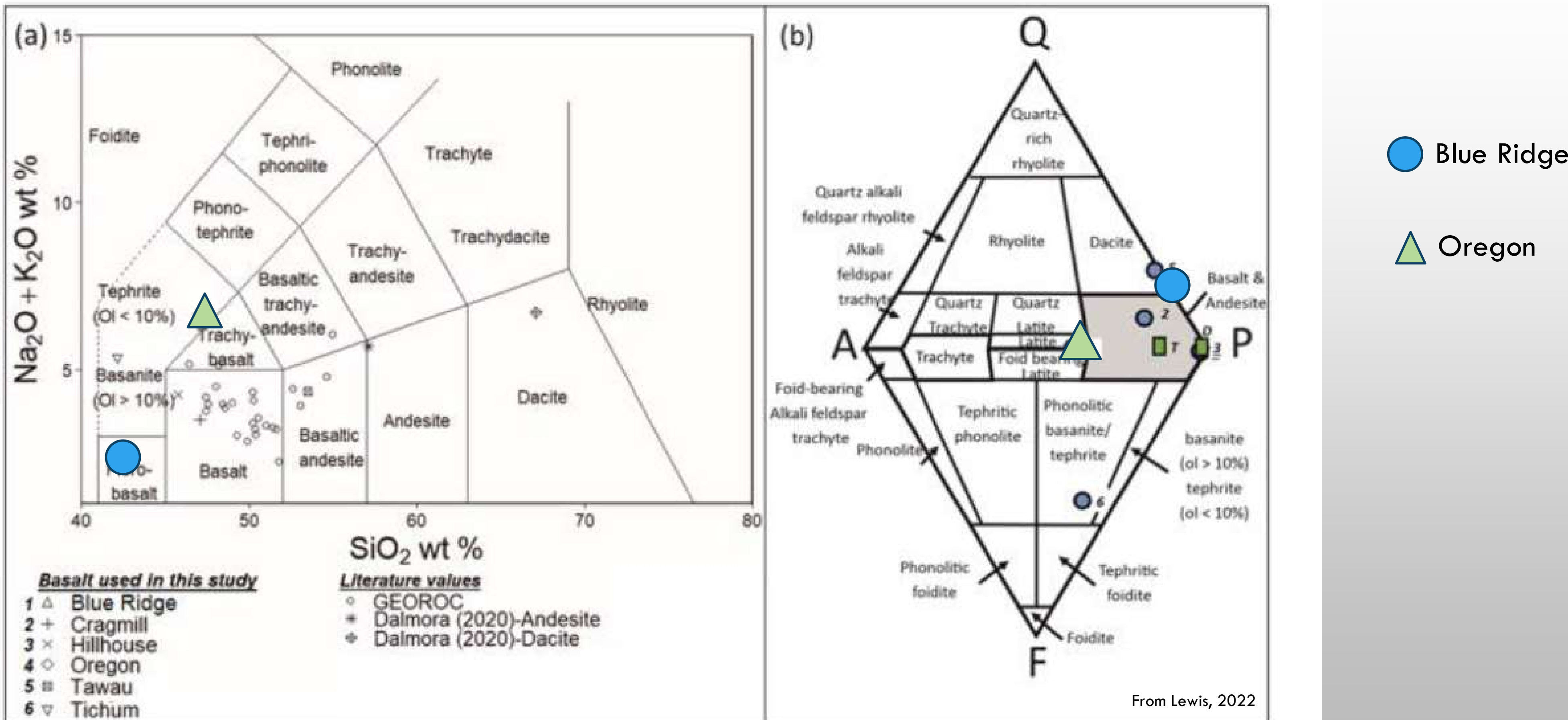
BASALT COMPOSITION



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FIELD STUDY

How will basalt powder amendment perform under natural conditions?

Sodium-impacted well site in Alberta – 2 year study

- SAR from 8-120
- Basalt powder (<850 µm)
- Gypsum
- Supplemental water

Source: Carbon Drawdown Initiative

Example of small plot basalt treatment experiment in Germany

FIELD STUDY

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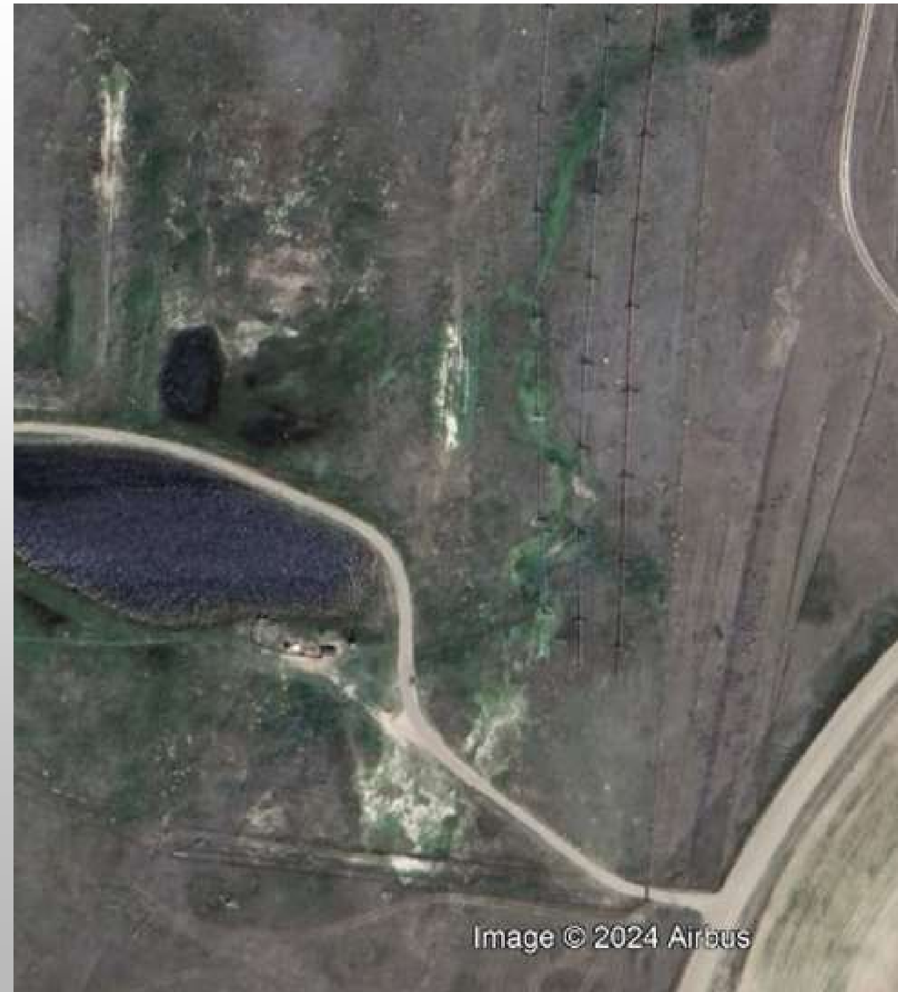
FIELD STUDY



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FIELD STUDY

FIELD STUDY

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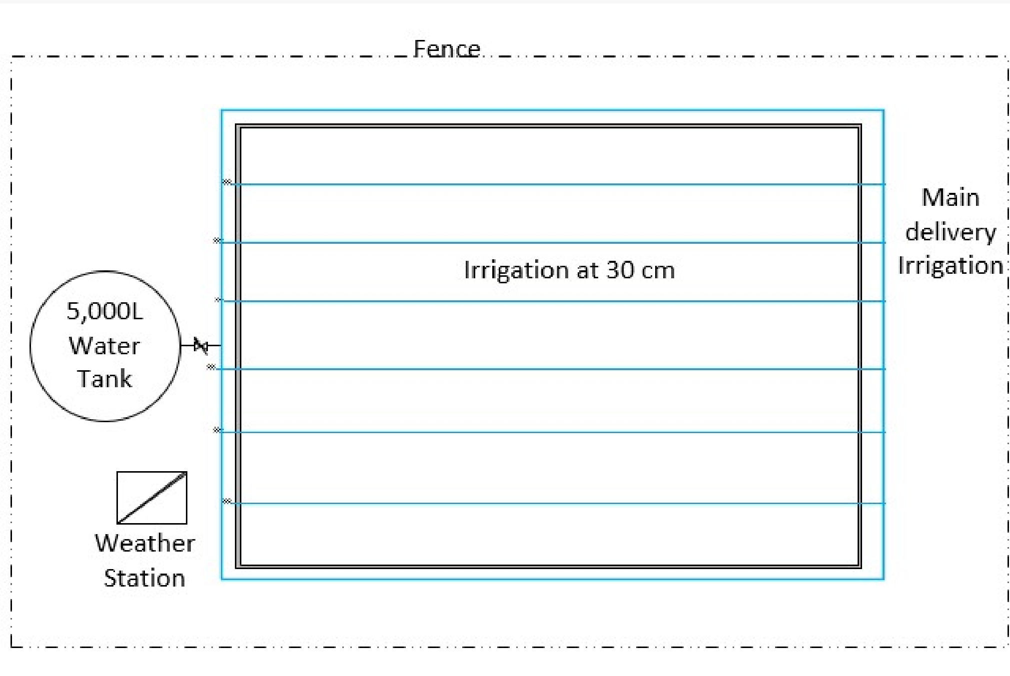
SMALL FIELD PLOTS



Layout

B1		B2		B3		B4	
T1	T2	T2	T1	T2	T1	T1	T2
T2	T1	T1	T2	T1	T2	T2	T1
T2	T1	T1	T2	T1	T2	T2	T2
T2	T1	T2	T1	T2	T1	T1	T1
T1	T2	T2	T2	T1	T2	T2	T1
T2	T1	T1	T1	T2	T1	T1	T2

T1 = basalt T2 = gypsum

Merci
Questions?

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