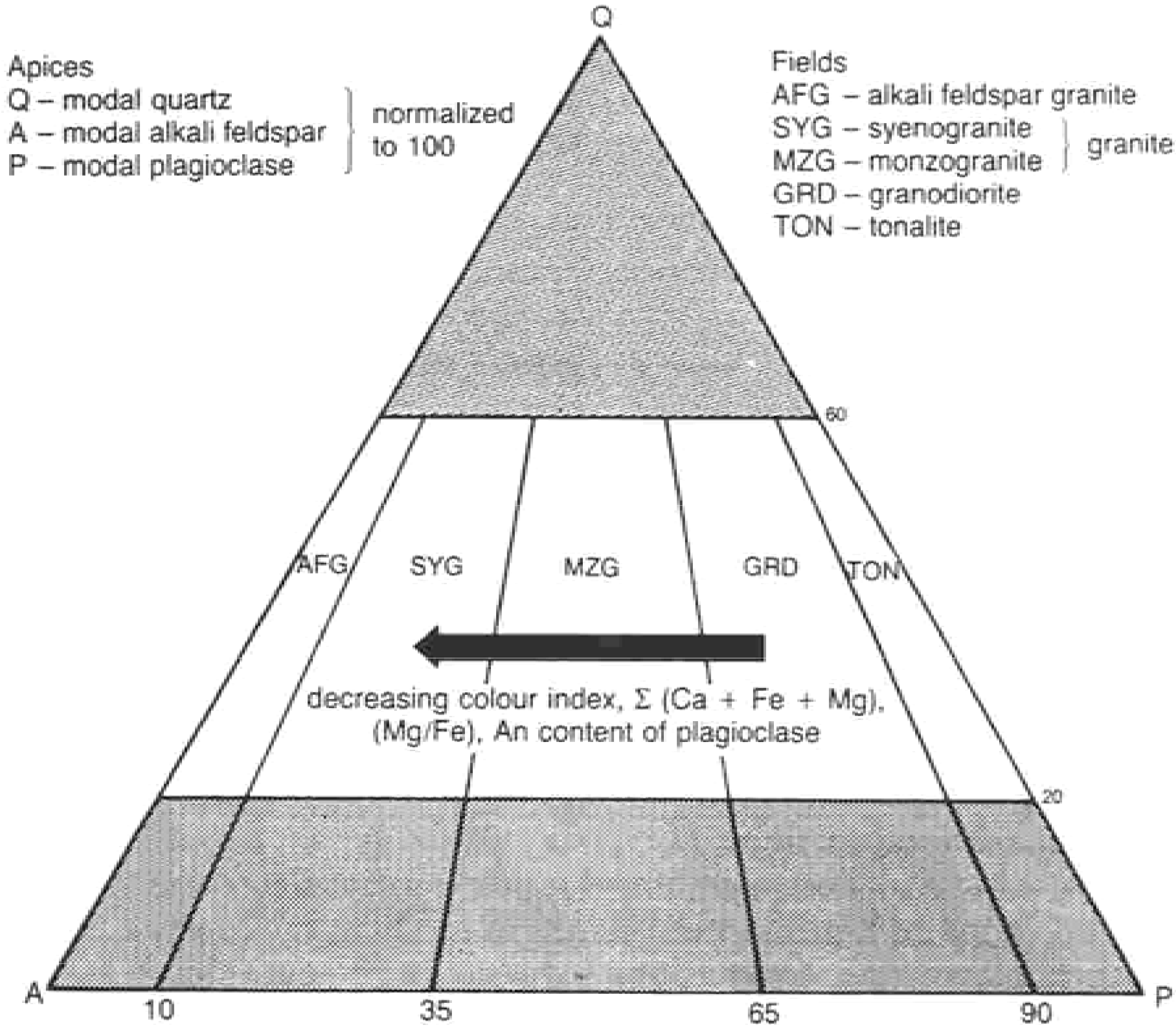


Fig. 1.2 The QAP classification of the granitoid family after Streckeisen (1976). Trondhjemite (≡ plagiogranite) (not labelled) is defined as a leucotonalite (Barker, 1979).

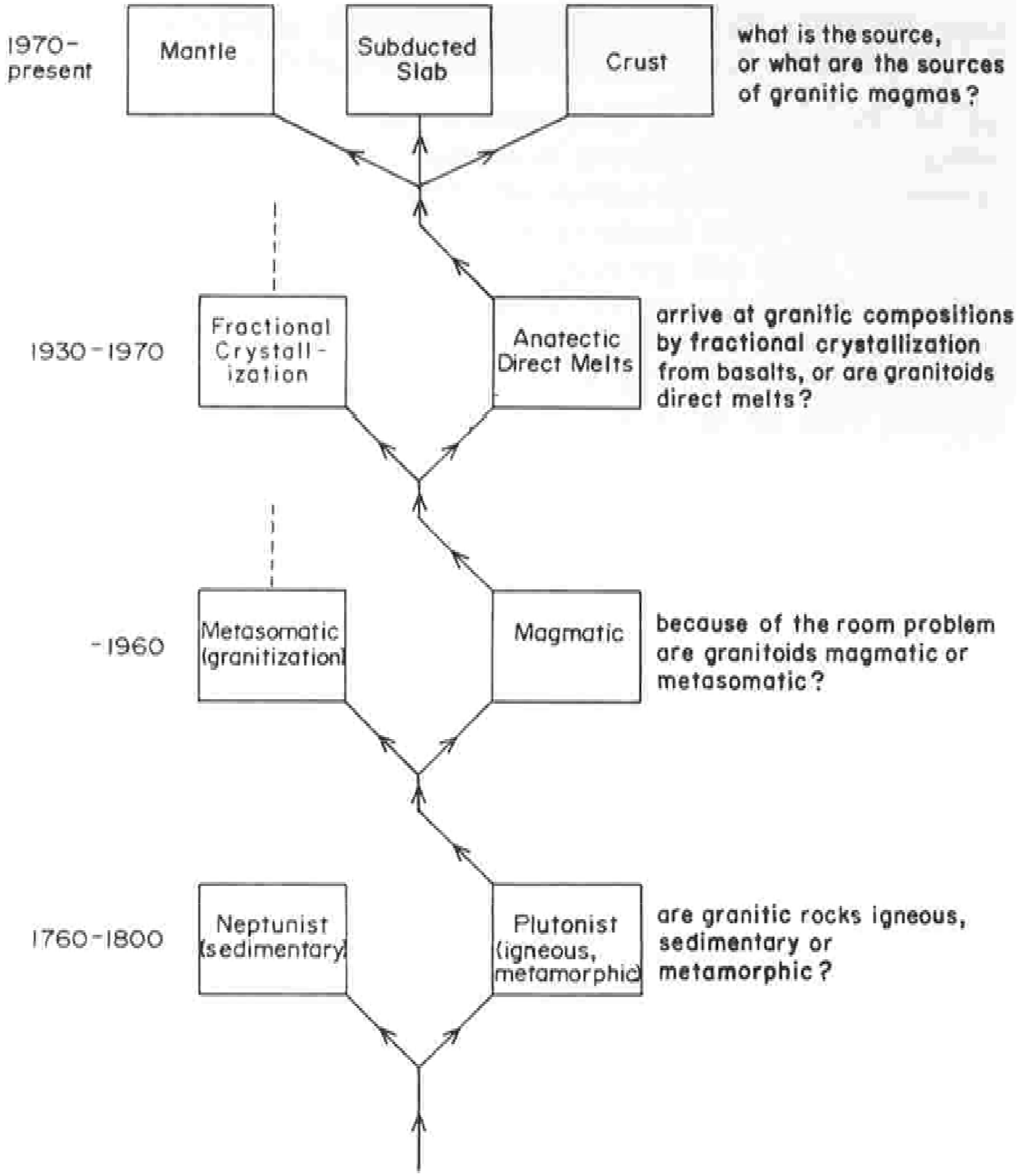
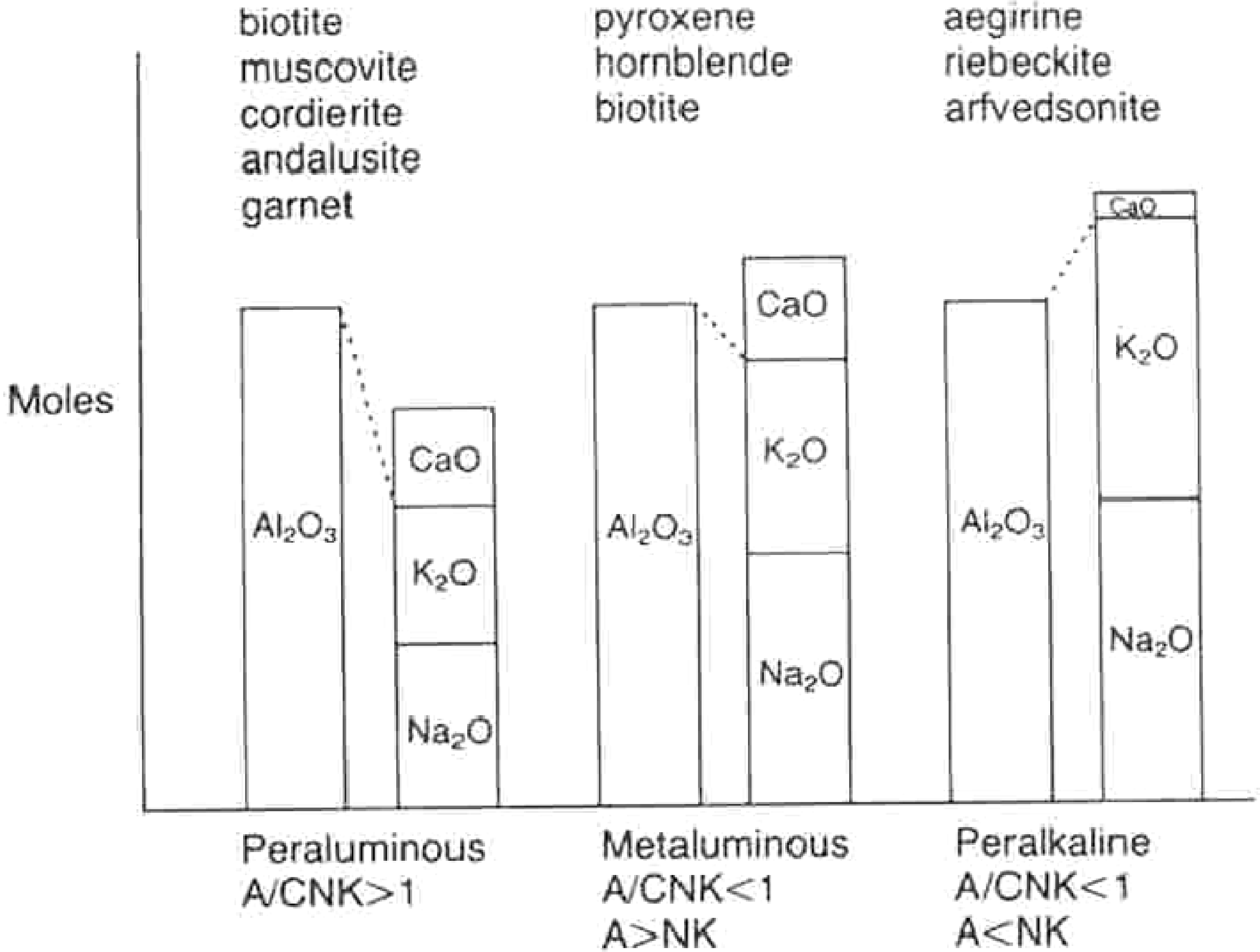
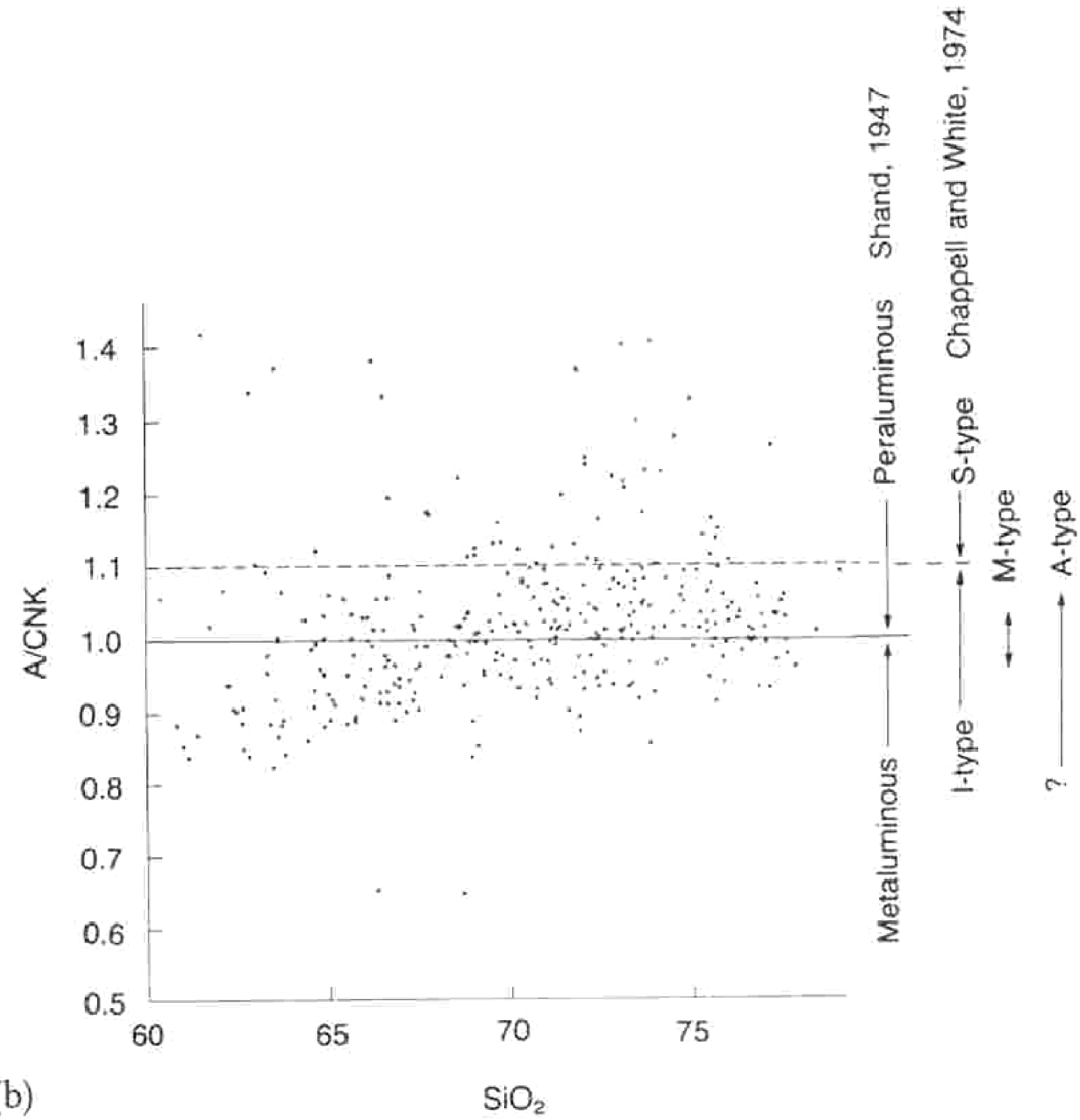


Fig. 1.6 Schematic flow chart to show the evolution of the granite problem over the past 200 years. Philosophical dead-ends have no exits; ideas that are largely discredited as general explanations, but which may still apply in specific cases, have dashed exit lines.

Table 1.1 Tripartite chemical classification of granitic rocks

	*The granitoid family**		
	QAP *60% > Quartz > 20%* *Alkali-feldspar/(Alkali-feldspar + Plagioclase) = 0–1*		
	Peraluminous	*Metaluminous*	*Peralkaline*
Definition (Shand, 1947)	A > CNK**	CNK > A >NK**	A < NK**
Characteristic minerals (*Chapter 3*)	aluminosilicates, cordierite, garnet, topaz, tourmaline, spinel, corundum	orthopyroxene, clinopyroxene, cummingtonite, hornblende, epidote	fayalitic olivine, aegirine, arfvedsonite, riebeckite
Other common minerals	biotite, muscovite	biotite, minor muscovite	minor biotite
Oxide minerals	ilmenite, tapiolite	magnetite	magnetite
Accessory minerals	apatite, zircon, monazite	apatite, zircon, titanite, allanite	apatite, zircon, titanite, allanite, fluorite, cryolite, pyrochlore
Other chemical features	F/Cl > 3	–	low CaO, Al_2O_3, H_2O, Ba, Sr, Eu high SiO_2, Fe/Mg, Na + K, Zr, Nb, Ta, ΣREEs, Y F/Cl < 3


biotite
muscovite
cordierite
andalusite
garnet
pyroxene
hornblende
biotite
aegirine
riebeckite
arfvedsonite
Moles
Al_2O_3
CaO
K_2O
Na_2O
Peraluminous
A/CNK>1
Metaluminous
A/CNK<1
A>NK
Peralkaline
A/CNK<1
A<NK

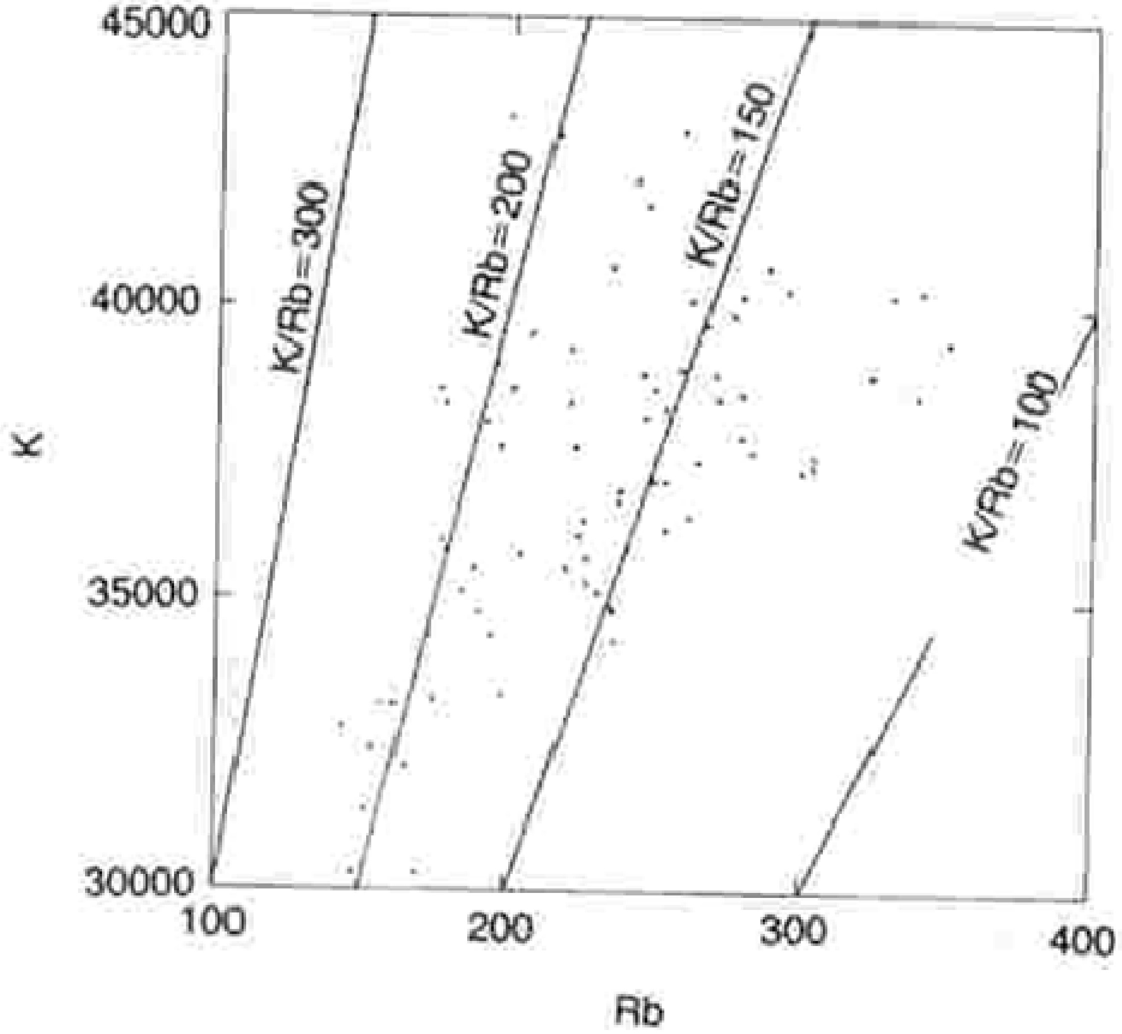


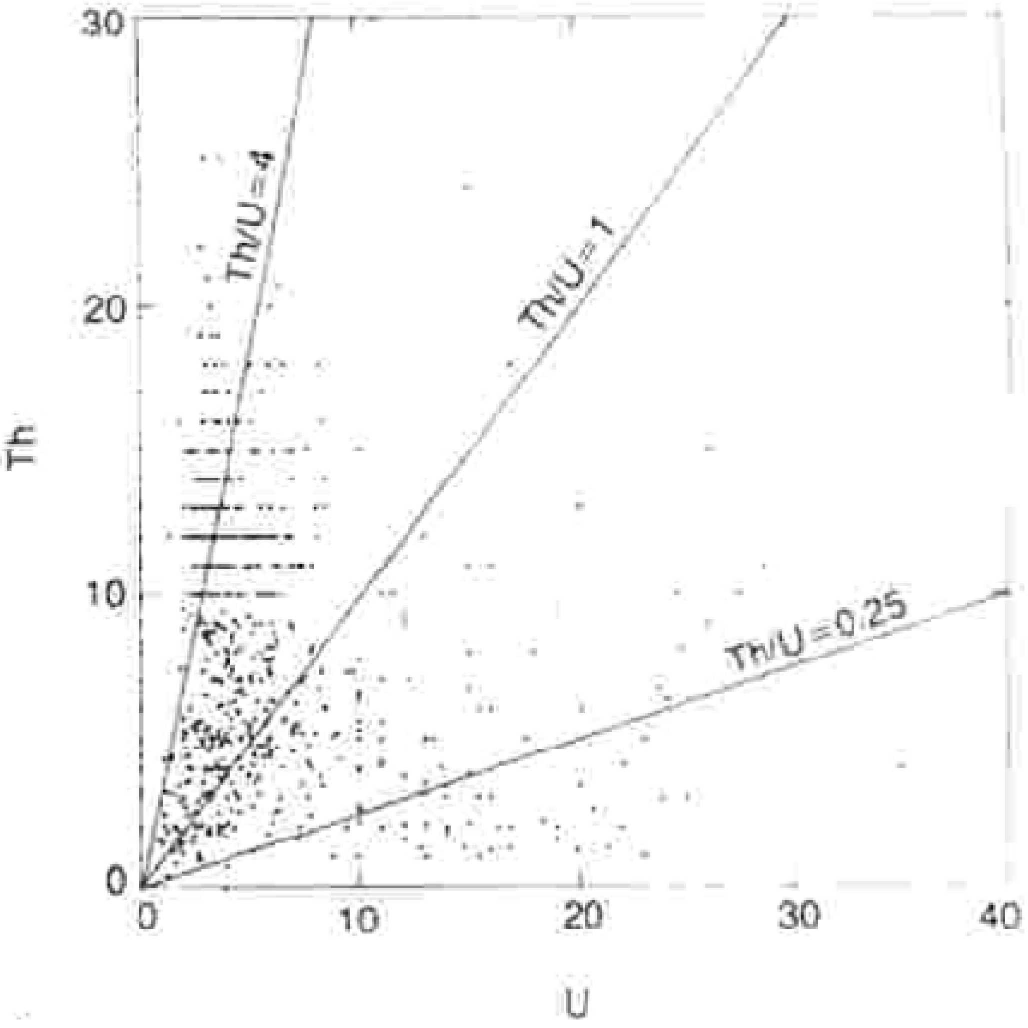
A/CNK
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
60
65
70
75
SiO2
Shand, 1947
Peraluminous
Metaluminous
Chappell and White, 1974
S-type
I-type
M-type
A-type
?

(b)

Table 1.2 Selected average compositions of peraluminous (Chayes, 1985), metaluminous (Chayes, 1985) and peralkaline (Chayes, 1985, with additional data) granitoid rocks

	Peraluminous	*Metaluminous*	*Peralkaline*
n	199	158	25
SiO_2	71.45	67.43	74.01
TiO_2	0.32	0.55	0.23
Al_2O_3	14.76	14.67	11.59
FeO_T	2.49	4.13	3.08
MnO	0.13	0.12	0.10
MgO	0.78	1.64	0.55
CaO	2.01	3.53	0.48
Na_2O	3.72	3.72	4.33
K_2O	3.52	3.20	5.09
P_2O_5	0.14	0.17	0.06
Total	99.32	99.16	99.52
A/CNK	1.10	0.93	0.86
NK/A	0.67	0.65	1.09


45000
40000
35000
30000
K
100
200
300
400
Rb
K/Rb=300
K/Rb=200
K/Rb=150
K/Rb=100



30
20
10
0
Th
0
10
20
30
40
U
Th/U=4
Th/U=1
Th/U=0.25

Table 4.4 Summary of the use of geochemical data to interpret the origin and evolution of granitoid rocks. The more capitalization in the 'Use' column, the greater the degree of usefulness of the elements

Elements	*Considerations*	*Use*
Major element concentrations	variation in major element concentrations normally reflects melt–crystal–fluid differentiation processes and contamination, but effectiveness to reveal information even about differentiation declines as the magma becomes trapped at the low temperature invariant point (Chapter 6); only if granitoids are primary magmas (unlikely) can the bulk compositions yield some indirect information about the source region	PROCESSES source
Trace element concentrations	trace element concentrations (ppm) are a function of their concentration in the source, the degree and style of partial melting, and all of the subsequent processes of melt–cystal–fluid differentiation	PROCESSES Source
Trace element ratios	with high degrees of partial melting of the source region (likely in the case of voluminous granitoids), trace element ratios in the melt fraction may be identical to those in the source and will remain so until some differentiation process removes one element relative to the other; identification of exactly which trace element ratios in the granitoid are still reliable indicators of the source is problematic	Processes Source

Table 4.4 *Continued*

Elements	*Considerations*	*Use*
Stable isotopic ratios	oxygen and sulphur isotopic ratios should reflect the ratios in the source region, but are highly vulnerable to contamination by, and re-equilibration with, the host rocks	Processes Source
Radiogenic isotopic ratios	no internal process of differentiation, except possibly for Soret diffusion or long times of evolution, should affect the radiogenic isotopic ratios (Sr, Nd, Pb); therefore the ratios should reflect those of the source region (except possibly for small degrees of partial melting not considered appropriate for granitoids); external reaction with wall-rocks (contamination) may disturb isotopic ratios inherited from source	processes SOURCE

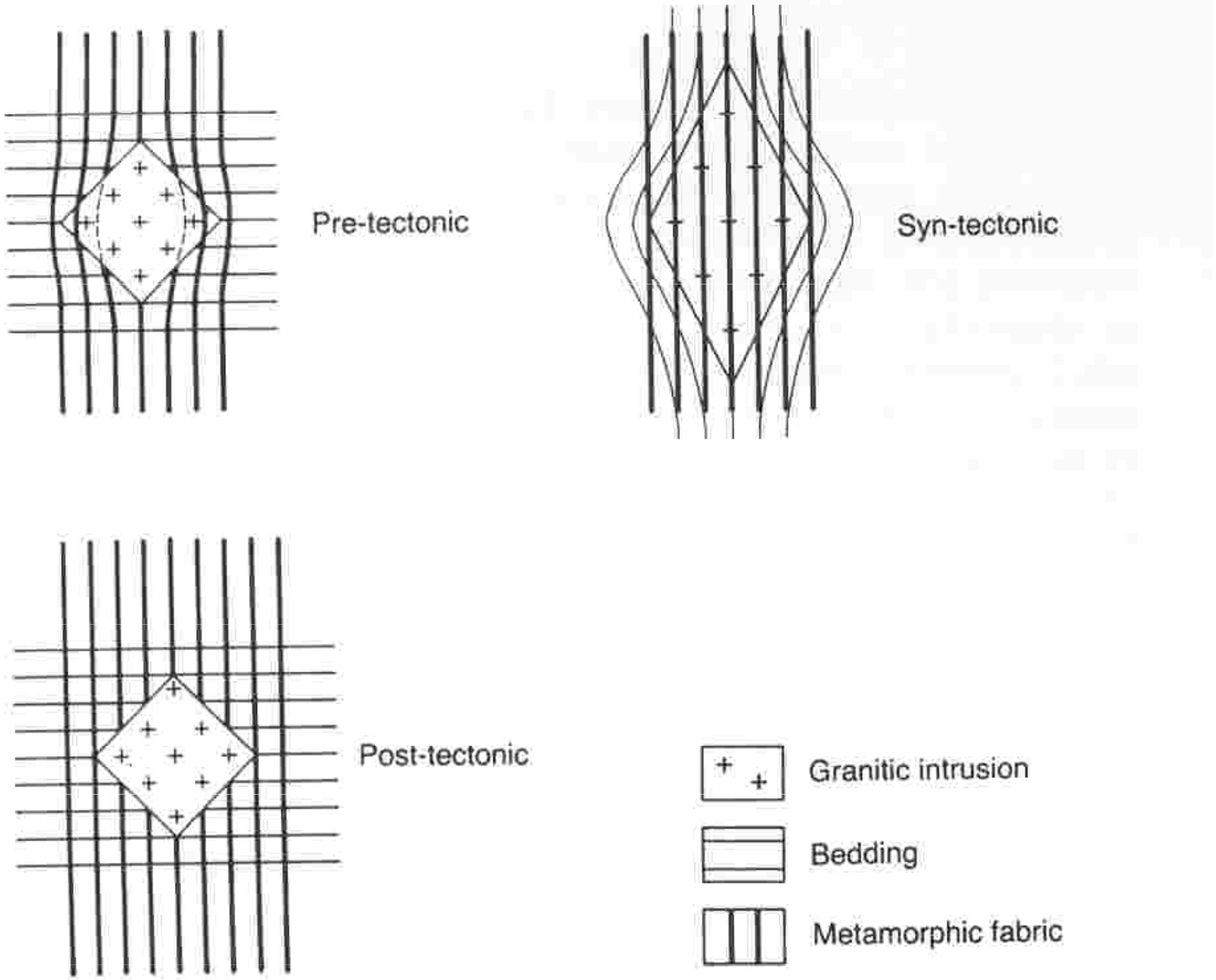
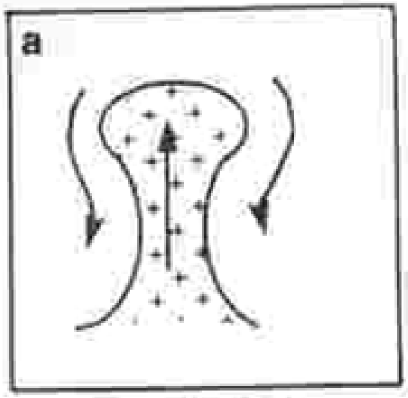


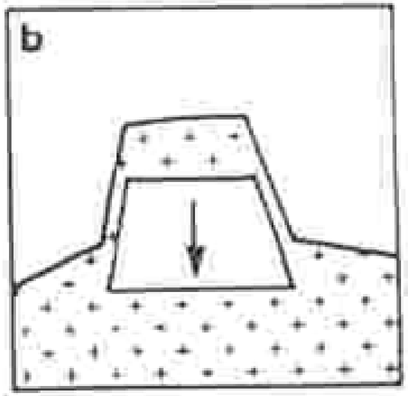
Fig. 2.3 Stylized relationship of granitic plutons to bedding and structure in country rocks. (The relationship between bedding and structure is arbitrary). A pre-tectonic pluton cuts bedding and deflects later metamorphic fabric, although marginal areas of the pluton may become deformed. A syn-tectonic pluton is conformable with bedding, and the metamorphic fabric penetrates the entire intrusive body. A post-tectonic pluton cuts both bedding and metamorphic fabric.

Table 2.2 Field characteristics relevant to the level of emplacement of granitoid intrusions. Plutons intruded at intermediate levels show transitional characteristics

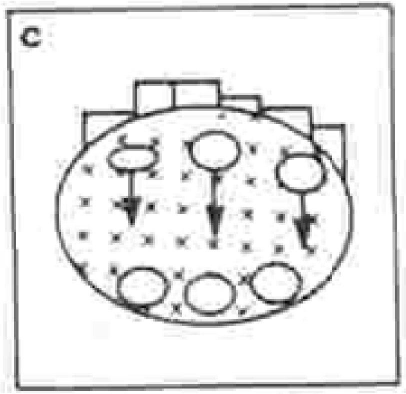
Feature	*Shallow intrusions*	*Deep-seated intrusions*
Contact relations with country rocks	predominantly sharp and discordant	predominantly diffuse and concordant
Pluton shapes	discrete isotropic to mildly anisotropic plutons	domes, conformable sheets
Contact facies of the granitoid	may be finer-grained	no chilled margins
Internal structures	internally controlled; structures unrelated to those in country rocks	externally imposed; structures similar to those in country rock
Textures	massive, may be porphyritic, granophyric	foliated, aphyric to augen gneisses
Regional metamorphic grade of country rocks	greenschist, lower amphibolite	upper amphibolite, granulite
Thermal aureole	prominent in rocks of suitable composition, e.g. pelites	obscure in most cases
Migmatites	local; restricted to contacts	regional (see Fig. 15-12 in Compton, 1985)
Other possible diagnostic (?) characteristics	miarolitic cavities; pegmatite dykes; hydrothermal alteration; granophyric textures; roof pendants; breccia dykes; cogenetic volcanic rocks nearby; abundant country rock xenoliths	



DIAPIRISM



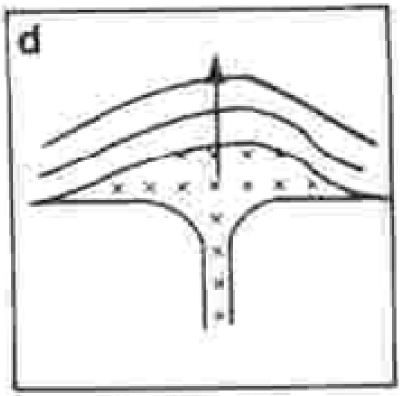
CAULDRON SUBSIDENCE



STOPING

COUNTRY ROCKS MOVE DOWN

(vertical cross-sections)



DOMING

COUNTRY ROCKS MOVE UP

(vertical cross-sections)

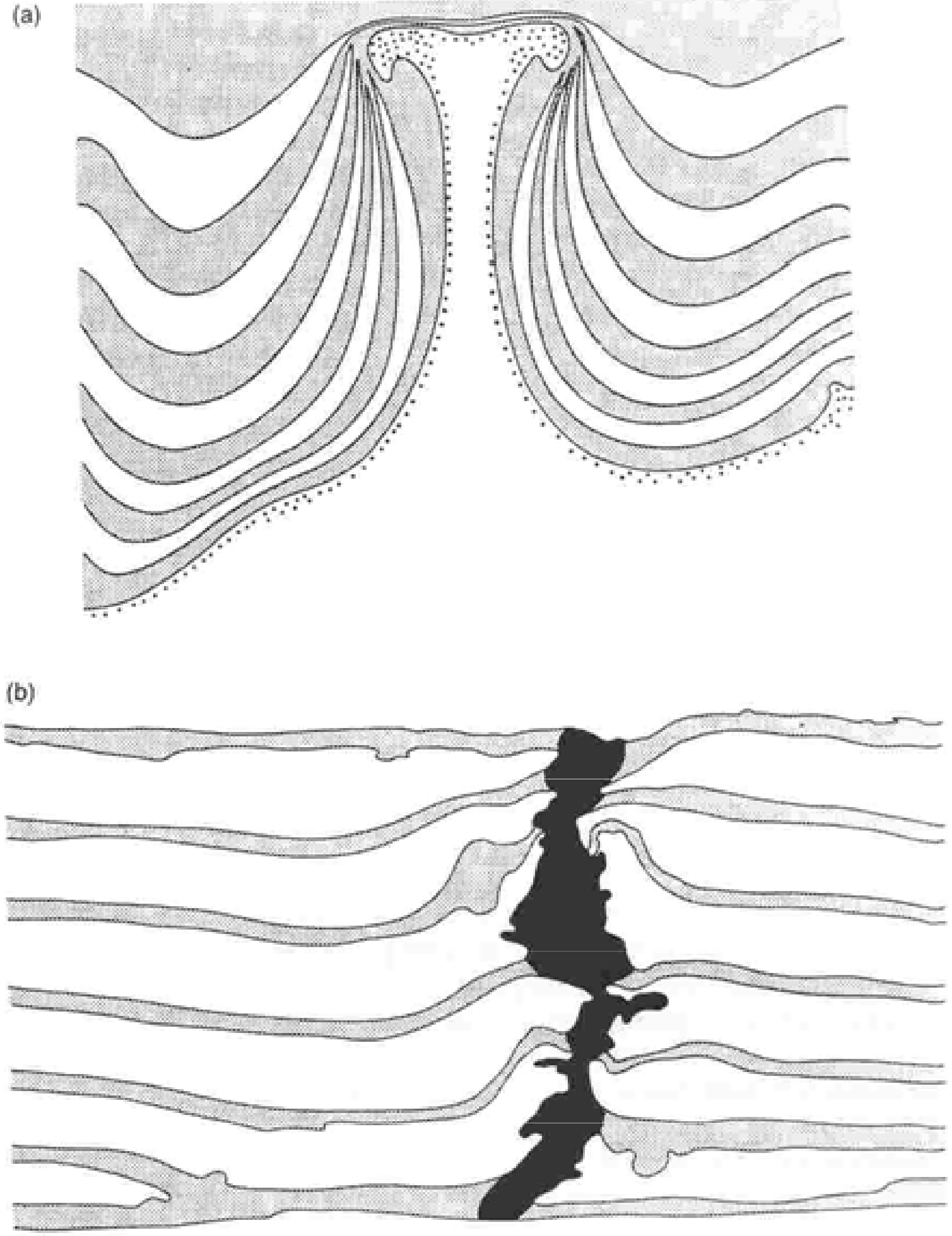
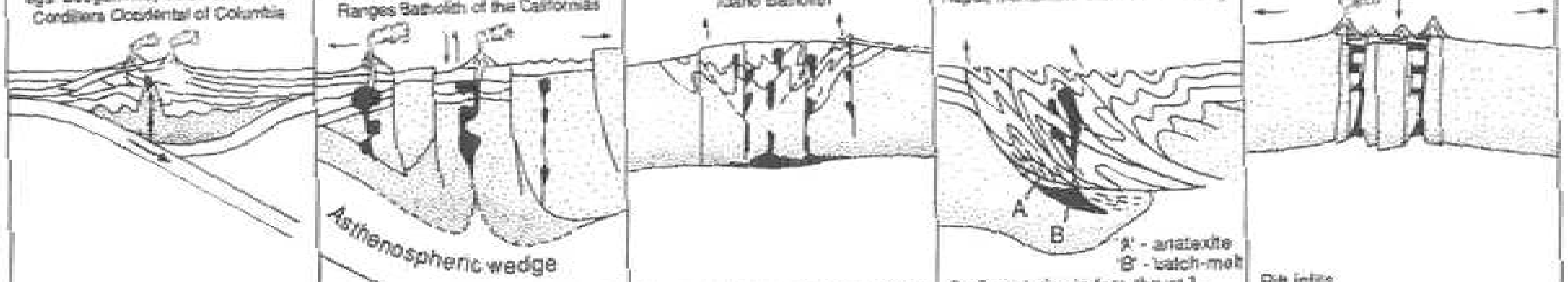


Fig. 2.14 Examples of experimentally modelled magma ascent (a) by diapirism and (b) by fracture exploitation (after Ramberg, 1981).

OROGENIC				ANOROGENIC
Oceanic island arc	Continent margin arc, liminal basin	Post-closure uplift	Oblique continental collision (Transpression)	Major rifting
egs. Bougainville, Solomon Islands, Cordillera Occidental of Columbia	Coastal Batholith of Peru, Peninsular Ranges Batholith of the Californias	Late Caledonian plutonism of Britain, Idaho Batholith	Lhotse and Manaslu Batholiths of Nepal, Mancellian Granites of Brittany	Ring complexes of Jos, Nigeria



Volcanic and volcaniclastic aprons	Sedimentation in fault-bounded marginal basins	Erosion: flanking molasse basins	Sedimentation in fore-thrust & pull-apart basins	Rift infills
Island arc basalts	Andesites & dacites in great volume	Plateau-type basaltic volcanicity	Often lacking volcanism esp. felsic	Alkali lavas, tuffs, as caldera infill
Burial metamorphism	Burial metamorphism	Strongly discordant aureoles	Regional, low-pressure metamorphism	
Gabbro, 'M'-type quartz diorite in mature arcs	'I'-type tonalite & granodiorite dominate, lesser granite & gabbro	'I' & 'S'-type granodiorite in contrasted association with diorite & gabbro	Migmatites, the Granite Series, largely 'S'-type granites	Biotite granite, alkali granite and syenite, A-type
Small zoned plutons	Discordant, linear batholiths feeding volcanoes	Dispersed plutons taking advantage of range of tectonic accidents	Concordant, 'diapir' batholiths & sheets in active shear zones	Resurgent subsidence cauldrons
Open folding	Spreading-minimal shortening	Strike-slip & normal faulting, uplift	Shortening & thrust thickening	Rifting
Au-bearing porphyry-Cu	Mo-bearing porphyry-Cu	Metals rarely concentrated	Sn & W skarn, vein & replacements	Sn, Nb, U, Th minerals in vugs and pegmatites
Ocean-ocean subduction	Ocean-continental subduction	Rapid, post-closure uplift	Inter-continental subduction	Encratonic or post-orogenic rifting
Short-lived, though sustained	Long-lived, episodic	Relatively short-lived 'bursts'	Episodic recycling over long periods	Relatively short-lived
Partial melting of mantle-derived, metamorphosed, mafic underplate	Partial melting of mantle-derived underplate: plus crustal contribution within continental lip	Partial melting of old, tonalitic lower crust plus mantle & mid-crustal contributions	Partial melting of recycled crustal material by ultrametamorphic anatexis: reworking as batch-melts	Partial melting of old mantle, or exhausted lower crust under anhydrous but F,B-rich conditions
Hot, 'dry', quartz-diorite magma rising high into new crust	'Hot, 'dry' tonalitic magma rising high into the new & old crust	Moderately hot and 'dry', evolved, crystal-bearing magma rising to various levels	Relatively warm, 'wet', granitic mush freezing at depth, with autometamorphic recrystallization	Relatively hot, fluidal magma, rising to near surface with sub-solidus crystallization
Subduction energy – transfer of heat by mafic magmas		Adiabatic decompression, plus heat transfer by mafic magmas	Blanketing by tectonic thickening of radiogenic crust, plus slab transfer of heat	Decompression on fast release from deep crustal trap

Figure 19.1 The granitic rocks in their contrasted tectonic niches. After Pitcher, W.S. (1987); see also Brew, D.A. (1992).