

Contents

Preface	V
J. Didier	
List of Contributors	XI

INTRODUCTION

Chapter 1. Granites in the main plutonic series	3
J. Lameyre and B. Bonin	
Introduction	3
Why are granites so common?	4
An epitome of granite classifications	5
The main plutonic series	7
Summary and conclusions	15
Chapter 2. The different types of enclaves in granites — Nomenclature	19
J. Didier and B. Barbarin	
Enclave and inclusion	19
Proposed nomenclature — definitions	21
Chapter 3. The outstanding contribution of Alfred Lacroix to the study of enclaves in magmatic rocks	25
J. Didier and R.C. Maury	
Introduction	25
Definition of enclaves	27
Classification of enclaves	27
Thermal metamorphism, melting and chemical interactions between foreign enclaves and the host magmas	30
Origin of cognate “homœogènes” enclaves	31
Concluding remarks	31

CASE STUDIES OF ENCLAVES IN MAGMATIC ROCKS THROUGHOUT THE WORLD

Chapter 4. Enclaves of the Miocene Himalayan leucogranites	35
P. Le Fort	
Introduction	35
The Himalayan leucogranites	35
Enclaves of country rocks	37

Mica-rich enclaves and schlieren	39
Tourmaline nodules or "cocardes"	44
Conclusions	46
 Chapter 5. The various types of enclaves in the Hercynian granitoids of the Massif Central, France	47
J. Didier	
Introduction	47
Geological setting and granitoid types in the Massif Central	47
The main types of enclaves	49
Enclaves in leucogranites	50
Enclaves in monzogranites and granodiorites	51
Origin of mafic microgranular enclaves in the granitoids of the Massif Central	57
Enclaves of the Velay anatectic complex	58
Conclusions	60
 Chapter 6. Vaugnerites: Special lamprophyre-derived mafic enclaves in some Hercynian granites from Western and Central Europe	63
H. Sabatier	
Introduction	63
Distribution and geological setting of the vaugnerites	63
Petrography and mineralogy of the vaugnerite enclaves	65
Geochemistry of the vaugnerite enclaves	70
The lamprophyric affinities of vaugnerites	75
Acid-basic interaction—evidence for a granitic component	76
Acid-basic consanguinity: vaugnerites and magnesian host granites	79
Petrogenesis of vaugnerites: the mantle origin and crustal influences	80
Conclusions	81
 Chapter 7. Enclaves in the Hercynian granitoids of the Urals Mountains, U.S.S.R. ...	83
G.B. Fershtater and N.S. Borodina	
Introduction	83
Geological setting and granitoid types	83
Plutonic granites	84
Granitoids of the volcano-intrusive group (I-type) and their enclaves	85
Main features of the autolithic enclaves	89
Conclusions	93
 Chapter 8. A two-stage crust-mantle interaction model for mafic microgranular enclaves in the Daning granodiorite pluton, Guangxi, China	95
Sha Liankun and Yuan Kuirong	
Introduction	95
Geological setting of the Daning pluton	95
Petrography of the mafic microgranular enclaves	97
Major element chemistry of the mafic microgranular enclaves	98
Trace element chemistry of the mafic microgranular enclaves	101
Towards a genetic model	104
Conclusions	110

Chapter 9. Mafic enclaves of some I-type granites of the Palaeozoic Lachlan Fold Belt, southeastern Australia	113
Y. Chen, B.W. Chappell and A.J.R.White	
Introduction.....	113
Some mafic enclaves of the Lachlan Fold Belt	113
Some general features of the field occurrence of mafic enclaves	115
Modes and petrography of mafic enclaves	118
Chemistry of mafic enclaves.....	119
Isotopic data from mafic enclaves.....	121
Discussion: origin of mafic enclaves of the Glenbog Supersuite	122
Origin of other mafic enclaves in the Lachlan Fold Belt.....	123
 Chapter 10. Microdioritic enclaves within the Scottish Caledonian granitoids and their significance for crustal magmatism	125
W.E. Stephens, P. Holden and P.J. Henney	
Introduction.....	125
Enclave-host equilibration	126
The Strontian and Criffell plutons	127
Characteristics of Strontian and Criffell enclaves	129
Whole rock compositions of Strontian and Criffell enclaves	130
Strontian and Criffell enclaves: protoliths, autoliths or xenoliths?	132
Proposed origin of the Strontian and Criffell enclaves.....	133
 Chapter 11. Enclaves of the Mesozoic calc-alkaline granitoids of the Sierra Nevada batholith, California	135
B. Barbarin	
Introduction.....	135
The Sierra Nevada granitoids	135
Nature of the different enclaves	136
Abundance and distribution of enclaves	137
The mafic magmatic enclaves	142
Origin and evolution of enclaves	148
General model proposed for the origin and evolution of the various enclaves, associated mafic rocks, and granitoids of the Sierra Nevada Batholith	151
Conclusions.....	153
 Chapter 12. Enclaves in the Mesozoic and Cenozoic granitoids of the Peruvian Coastal Batholith	155
M.A. Bussell	
Introduction.....	155
The Peruvian Coastal Batholith	155
Enclaves of deeply eroded plutonic interiors.....	156
Enclaves at steep margins of plutons.....	159
Enclaves in the roof and ring dyke environment.....	160
Enclaves in the Coastal Batholith: a general model	165
 Chapter 13. Enclaves of the Late Miocene Monte Capanne granite, Elba Island, Italy ..	167
F. Bussy	
Introduction.....	167

Tectonic setting of the Elba Island	167
The Monte Capanne granite	169
The hornfels xenoliths	171
The xenoliths of crystalline schists	171
The mafic microgranular enclaves	173
The enclaves in the other magmatic occurrences of Elba Island and Tuscany	177
Conclusions	178
 Chapter 14. The enclaves of the alkaline anorogenic granites: an overview	179
B. Bonin	
Introduction	179
Nomenclature: alkaline igneous rocks and alkaline suites	179
Xenoliths and magmatic stoping	180
Mafic enclaves resulting from commingling of mafic and felsic magmas	182
Microgranular enclaves and autoliths	185
Rockallite and lindinosite	186
Summary and conclusions	188
 Chapter 15. Enclaves and mafic-felsic associations in the Permian alkaline province of Corsica, France: Physical and chemical interactions between coeval magmas	191
B. Platevoet and B. Bonin	
Introduction	191
Diversity of enclaves, mafic-felsic associations and reaction zones	191
Liquid-liquid interactions	194
Fluid transfers	197
Chemical interactions in commingled magmas	198
Chemical interactions by fluid transfers in reaction zones	201
Existence and limitation of hybridization and contamination processes	203
Conclusions	204
 Chapter 16. Enclaves in plagiogranites of the Guevgueli ophiolitic complex, Macedonia, Greece	205
J. Bébien	
Introduction	205
Plagiogranites of the western unit of the Guevgueli complex	206
Petrography of enclaves and their plagiogranite hosts	208
Geochemical relationships between enclaves and their plagiogranite hosts	214
Petrogenesis of enclaves and their plagiogranite hosts	216
Conclusions	218
 Chapter 17. Comagmatic enclaves in lavas from the Mont-Dore composite volcano, Massif Central, France	221
A. Gourgaud	
Introduction	221
Distribution of mixed lavas in the Mont-Dore composite volcano	221
Pillow-like enclaves in the Mont-Dore felsic lavas	223
Fragmentation of pillow-like enclaves and development of progressive mechanical mixing	224

Phenocryst transfers	227
Geochemical control	229
Petrogenetic implications	231
Conclusions: pillow-like enclaves and magma mixing	233

Chapter 18. Enclaves in volcanic rocks from Japan 235

T. Koyaguchi

Introduction	235
Enclaves from the volcanic Niiijima Island	235
Enclaves from the Abu monogenetic volcano group	241
Heterogeneous and disequilibrium features in other Japanese volcanic rocks	246
Conclusions	249

MAIN FEATURES OF MAFIC MICROGRANULAR ENCLAVES

Chapter 19. Macroscopic features of mafic microgranular enclaves 253

B. Barbarin and J. Didier

Introduction	253
Colour and grain size	253
Morphology	254
Size, abundance and distribution in the plutons	255
Contacts with the host	257
Mineral composition	261
Conclusions	261

Chapter 20. Relative rheology of coeval mafic and felsic magmas: Nature of resulting interaction processes. Shape and mineral fabrics of mafic microgranular enclaves 263

A.N. Fernandez and B. Barbarin

Introduction	263
Rheological evolution of granitoid magmas	264
Thermal evolution and rheological behaviour of coeval magmas	267
Relative rheology of coeval magmas and types of interactions	269
Rheological control of chemical exchanges between mingled magmas	271
Shape, strain and mineral fabric of enclaves	273
Conclusions	275

Chapter 21. Interpretation of microstructures of microgranitoid enclaves 277

R.H. Vernon

Introduction	277
Microstructures reflecting an igneous origin	277
Microstructural differences between microgranitoid enclaves and xenoliths	278
Microstructures reflecting crystallization history	281
Microstructures reflecting hybridism	283
Microstructures reflecting magmatic flow	286
Microstructures possibly indicating vesiculation and loss of interstitial melt	288
Conclusions	290

Chapter 22. Comparative major element chemistry in various "microgranular enclave-plutonic host" pairs	293
F. Debon	293
Introduction	295
Comparative bulk chemistry and mineralogy in enclave-host pairs	299
Comparative mineral phase compositions in enclave-host pairs	303
Discussion: origin of the enclave-host relationships	306
Interdiffusion hypothesis	310
Conclusions	310
Chapter 23. Trace element behaviour in microgranular enclaves from granitic rocks ..	313
A.G. Tindle	313
Introduction	314
Theoretical models for trace element behaviour in microgranular enclaves	318
Identification of trace element behaviour in microgranular enclaves	330
Summary	330
Chapter 24. Sr-Nd isotopic study of igneous and metasedimentary enclaves in some Hercynian granitoids from the Massif Central, France	333
C. Pin	333
Introduction	334
Enclaves of the Sidobre monzogranite-granodiorite	336
Enclaves of the Mayet-de-Montagne monzogranite	337
Enclaves of the Pouzol-Servant microgranite	340
Enclaves of the St. Julien-la-Vêtre monzogranite-granodiorite	341
Discussion: isotopic constraints on the origin and evolution of enclaves	343
Conclusions	343
Chapter 25. Sr-Nd-O isotopic features of mafic microgranular enclaves and host granitoids from the Pyrenees, France: Evidence for their hybrid nature and inference on their origin	345
S. Fourcade and M. Javoy	345
Introduction	346
The Hercynian plutonism of the Pyrenees	349
Isotopic investigations and results	355
Isotopic evidence against the restite model and the closed-system differentiation model ..	357
Evidence for isotopic and chemical exchange between enclaves and host granitoids	360
Mixing and origin of enclaves and host granitoids	364
Concluding remarks	364
 GENESIS AND EVOLUTION OF MAFIC MICROGRANULAR ENCLAVES	
Chapter 26. Review of the main hypotheses proposed for the genesis and evolution of mafic microgranular enclaves	367
B. Barbarin and J. Didier	367
Introduction	368
Mafic microgranular enclaves as "reworked xenoliths"	368
Mafic microgranular enclaves as "restites"	368

Mafic microgranular enclaves as "autoliths"	369
Mafic microgranular enclaves as "disrupted fine-grained borders"	370
Mafic microgranular enclaves as "blobs of mantle-derived magmas"	370
The role of magma mixing	371
Chapter 27. Restite enclaves and the restite model	375
B.W. Chappell and A.J.R. White	
Historical development of the restite model	375
The restite model	376
Restite enclaves in S-type granites	378
Restite enclaves in I-type granites	379
Some implications of the restite model	381
Chapter 28. Synplutonic dykes and mafic enclaves	383
W.S. Pitcher	
Introduction	383
The nature of the evidence	384
Alternative explanations and possibilities	389
Synplutonic dykes: mixing, mingling and hybridization	390
The importance of the geological environment	391
Chapter 29. Commingling of contrasted magmas and generation of mafic enclaves in granitic rocks	393
R.A. Wiebe	
Introduction	393
Geologic framework	394
Criteria for the recognition of commingled magmas	394
Structural controls of commingling in plutonic rocks	398
Generation of non-chilled mafic enclaves	401
Chapter 30. Insights on the magma mixing model from volcanic rocks	403
S. Blake and T. Koyaguchi	
Introduction	403
Nomenclature of rocks formed by magma mixing	403
Physical properties governing the behaviour of enclaves during magma mixing	405
Evolution of magma compositions during mixing	409
Conclusions and applications to plutonic rocks	412
Chapter 31. Origin of mafic enclaves: Constraints on the magma mixing model from fluid dynamic experiments	415
T. Koyaguchi and S. Blake	
Introduction	415
The similarity between laboratory tanks and the magma chambers	415
Replenishment of magma chambers	418
Overturn of magma layers	420
Forced convection during chamber evacuation and magma ascent through a conduit	420
Mixing in a rising magma batch	425
Discussion	427
Conclusions and final remarks	429

Chapter 32. Textural anatomy of twelve magma-mixed granitoid systems	431
M.J. Hibbard	
Introduction	431
The mixing textures	432
Mixing textures in hybrid batches of magma	442
Are host plutons magma-mixed hybrids?	443
 Chapter 33. Genesis of mafic microgranular enclaves through differentiation of basic magmas, mingling and chemical exchanges with their host granitoid mag- mas	445
J.B. Orsini, C. Cocirta and M.J. Zorpi	
Introduction	445
The Corsican-Sardinian Batholith	446
Main characteristics of the mafic microgranular enclaves and their host rocks	448
The different types of chemical transfers	451
Nature of the processes of chemical transfers between acid and basic magmas	457
Pre-mixing history of parental magmas of mafic microgranular enclaves	459
Comparison with petrogenesis of layered basic/ultrabasic complexes	461
Conclusions	463
 Chapter 34. Appinites, lamprophyres and mafic magmatic enclaves: Three related prod- ucts of interaction between acid and mafic magmas	465
S.N. Ayrton	
Introduction	465
Setting and petrographic features of appinites	466
Geochemical identity of appinites	468
Petrogenesis of appinites	471
Lamprophyres and appinites	472
Lamprophyres and mafic microgranular enclaves	474
Nature and origin of the mafic magmas	474
Conclusions	475
 MAIN FEATURES, GENESIS AND EVOLUTION OF THE OTHER TYPES OF ENCLAVES	
 Chapter 35. Restites in migmatites and autochthonous granites: Their main features and their genesis	479
P. Barbey	
Introduction	479
Textures of restites	481
Mineralogical composition of restites	482
Accessory minerals in restites	485
Chemical features of restites	488
Genesis of restites: their occurrence in rocks or as rock	490
Conclusions	491
 Chapter 36. Enclaves of S-type granites in the Lachlan Fold Belt, southeastern Australia	493
A.J.R. White, B.W. Chappell and D. Wyborn	
Introduction	493

Enclaves in the Cooma Granodiorite	494
Enclaves in the Bullenbalong Suite granites	495
Enclaves in the Ingebyrah Suite granites	498
Origin of the enclaves of S-type granites	502
Chapter 37. Origin of surmicaceous enclaves in intrusive granites	509
J.M. Montel, J. Didier and M. Pichavant	
Introduction	509
Surmicaceous enclaves of the post-anatectic granites of the Velay dome	509
Surmicaceous enclaves of the Sidobre granite	519
Surmicaceous enclaves in other granites	524
The two types of surmicaceous enclaves	526
The bearing of surmicaceous enclaves to the petrology of granitoids	527
Chapter 38. Xenoliths and the role of assimilation	529
R.C. Maury and J. Didier	
Introduction	529
Xenoliths and the debate on assimilation	530
Xenocrysts: the simplest case of assimilation	532
Magma-xenolith relations in natural systems	533
Discussion of the assimilation processes	538
Conclusions	542
 CONCLUSIONS	
Chapter 39. Enclaves and granite petrology	545
B. Barbarin and J. Didier	
Impact of the enclave study on the petrology of granitoids	545
Twenty years of enclave study	548
References	551
References Index	603
Subject Index	617