

Index

Page numbers in *italics* refer to Figures. Page numbers in **bold** refer to Tables.

- accretion, final stage of planetary 339–340
- acid etching, Ar release by 83
- activation energy 83, 193, 194
- adularia, Klokken 99
- adularia breccia 288, 291
 - ⁴⁰Ar/³⁹Ar dating
 - methods
 - laboratory techniques 291
 - sampling 291
 - results **289**, 290, 291–292
 - results discussed 292–293
 - see also* K feldspar
- age equations
 - ⁴⁰Ar/³⁹Ar 11
 - K/Ar system 10
- age spectrum calculation by ⁴⁰Ar/³⁹Ar step-heating applications
 - chondrite meteorites 334
 - Dellen impact structure 351, 356, 358
 - exhumation studies 230, 231
 - Haifanggou Formation studies 280, 281
 - muscovite age standard 70
 - phengite muscovite diffusion study 117, 118–121
 - polyhalite studies 215, **216**, 217, 218–219
 - CO₂ laser testing 83–84
 - theory of 82–83, 91–92
- age standards, importance of 2–3
- albite spindles as domains 110
- Allende meteorite 183
- Alps
 - Central, Togni Quarry as source for age standard 69
 - Northern Calcareous Alps
 - orogenic history 208
 - palaeotemperature and age analysis
 - history of research 210, **210**
 - methods 210–211
 - results
 - ⁴⁰Ar/³⁹Ar dates 215, **216**, 217, 218–219
 - illite crystallinity 219
 - rock descriptions 211–212, 215
 - thin sections **213**, 214
 - vitrinite reflectance 219
 - results discussed 220–221
 - results fluid inclusion analysis 219–220
 - saltmines 208–209
 - setting 208, 209
- alteration
 - problems in dating 155
 - see also* sericitization
- Andean Cordillera, Pleistocene andesites ascent rate calculations 147
- andesite, Pleistocene, ascent rate calculations 147
- angiosperms
 - ⁴⁰Ar/³⁹Ar dating of first appearance
 - methods, sampling 279–280
 - methods laboratory procedure 280
 - results 281
 - results discussed 281–282
 - origins of 277–278
 - anorthosite, lunar, Ar source comparisons 176
 - apatite fission track (AFT) thermochronology 227
 - Apollo missions, dating lunar events 176
 - Appalachian Province, source of hornblende 247, **247**
 - Araguinha impact structure 349
 - argon
 - atmospheric
 - in comparisons 11
 - composition 15–16
 - contamination 14
 - palaeo-ratios 179–180
 - component release by non-thermal methods 83
 - component release by step-heating 82–83
 - retention age concept 54
 - solubility 138
 - various isotopes
 - Martian sources 300
 - atmospheric and interior components 307–309, **312**
 - spectrum due to cosmic rays 300
 - spectrum of sources 299
 - ³⁶Ar
 - ingress 138
 - problem in chondrites 335
 - production by cosmic rays 175
 - production of 13, 34
 - role of 14
 - ³⁶Ar_{atm} 34
 - ³⁶Ar/³⁸Ar, trapped in meteorites 302–303
 - ³⁷Ar
 - production of 13, 34
 - recoil 34
 - effects of 34–35
 - experiment to test
 - methods 35–36
 - results 36–40
 - results discussed
 - age correction 48–49
 - comparison with theory 47–48
 - Fish Canyon plagioclase 40, 43–46
 - hornblende Hb3gr 47
 - summary of implications 49–51
 - role of 4, 14
 - ³⁷Ar/³⁹Ar in recoil gas 54
 - ³⁷Ar_{Ca} 34
 - ³⁸Ar
 - cosmic ray induction 175–176
 - from ³⁷Cl 178–179
 - production by cosmic rays 175
 - production by neutron absorption 175
 - role of 4
 - spike calibration 53
 - terrestrial production 177–178
 - use as tracer 11

- argon (*Continued*)
- $^{38}\text{Ar}/^{37}\text{Ar}$
 - exposure ages 176–177
 - isochron 178
 - ^{39}Ar
 - as proxy for K concentration 53
 - recoil 33, 299
 - $^{39}\text{Ar}_K$ 34
 - $^{39}\text{Ar}_m$ 34
 - ^{40}Ar
 - concentration measurement, isotope dilution 53
 - diamond dating 180
 - problems of inherited 155
 - problems of non-radiogenic 297, **299**
 - $^{40}\text{Ar}^*$ 11, 34, 82
 - $^{40}\text{Ar}^*/^{40}\text{K}$, in mineral standards 63
 - $^{40}\text{Ar}/^{36}\text{Ar}$
 - atmospheric 13
 - palaeo-atmospheric 179–180
 - $^{40}\text{Ar}/^{39}\text{Ar}$ dating technique 1, 13
 - assumptions to be fulfilled 12–13
 - development of 11
 - measurement of isotopic ratios 13
 - overviews
 - methodological developments 2–4
 - technique applications 4–5
 - secondary standards 53
- Arrhenian non-linearity (ANL) plot 109, 110, 111, 113, 114
- Arrhenius parameters 83
- Arrhenius plot 265
- $^{40}\text{Ar}/^{39}\text{Ar}$ step-heating 91–92, 93–94, 93
 - point of inflection 193
 - use in phengite muscovite diffusion study
 - Arrhenius data 121–123
 - Arrhenius data inversion 126–130
- astronomical calibrations 18, 23–24
- astronomical tuning chronologies 21, 23–24, 63
- atomic absorption, for K concentration 53
- Australia, Pilbara greenstone, muscovite
 - thermochronology 100
- Bakersville (North Carolina), oligoclase samples 138
- basalt
 - ^3He monitoring 176
 - São Tomé sample dating 86, 87
 - Tristan da Cunha sample dating 88, 88, 182–183
- basaltic volcanic events, problems of dating 155
- biotite
 - mineral standard
 - recoil testing
 - method 55–56
 - results 56, **56**
 - results discussed 56–61
 - recoil-induced loss 34
- Bishop Tuff, age 26, 28–29
- blanks, furnace v. laser 84–86
- blocking temperature 91
- Bouillante geothermal system
 - adularia breccia 288, 291
 - $^{40}\text{Ar}/^{39}\text{Ar}$ dating
 - methods
 - laboratory techniques 291
 - sampling 291
 - results **289**, 290, 291–292
 - results discussed 292–293
 - tectonic setting 285–286, 287, 288
- Brione (Alps), source for age standard 69
- Brunhes-Matuyama Chron boundary age 18, 26, 28
- burn patterns, CO₂ laser testing 80–81
- cadmium (Cd) shielding 13–14, 335, 337
- calcium
 - ^{40}Ca neutron activation 176
 - Ca/K ratio in plagioclase 168–171
 - correction factor 13, 14
 - effects in nuclear reactor 13
 - interference by neutron fluence 177
- Caledonian Province, source of hornblende 247, **247**
- calibration, statistical optimization approach
 - future 29
 - misrepresentation 25–26
 - misuse 24–25
 - practicalities 21–22
 - use 22–23
- Canada, Heinrich events 245
- Central Atlantic Magmatic Province (CAMP) 159, 162
 - age of sericitization 171
 - handling sericitization problems 161–162, 163, 164
- Central China Orogen 189
- Central Dabie Complex 191
- chassignites 297, 311, 317, 318
- chemical abrasion-thermal ionization mass spectrometry (CA-TIMS) 22
- China, Central China Orogen 189
- chlorine (Cl)
 - concentrations and mineralization dating 179
 - correlation with ^{40}Ar in diamonds 180
 - problems in $^{40}\text{Ar}/^{39}\text{Ar}$ meteorite dating 301–302
 - various isotopes
 - ^{36}Cl
 - evidence in early solar system 183–184
 - half life 183
 - history of 175
 - interference by neutron fluence 177
 - in sodalite 177–178
 - ^{37}Cl neutron absorption 175, 178
- chondrite meteorites
 - $^{40}\text{Ar}/^{39}\text{Ar}$ dating
 - H type 339–341
 - L type 336–339
 - LL type 341–343
 - problems associated 334–336
 - summary of age data 343
 - classification 333
- Churchill Province, source of hornblende 247, **247**
- clay minerals
 - dating problems 33
 - recoil problems 53–54
 - special techniques for dating 54
- climate change, relation to Heinrich events 254–257
- closure temperature and closure theory 91
 - concept of 193
 - hornblende 245, 247
 - muscovite 123
 - plagioclase 137–138, 139
 - relation to staircase age spectrum of K feldspar 193

- CO₂ lasers
 initial development 79
 limitations 79
 new developments 80
 description 80, 81
 system performance 88–89
 system tests
 blanks 84–86
 burn patterns 80–81
 rastering 86–87
 step-heating 82–84
 noble gas extraction 3
- Colorado, San Juan volcanic field, as source of mineral standard 63
- Cone crater 176
- cooling ages, defined 193
- Cornubian batholith, mineralization dating 179
- cosmic rays
 exposure of meteorites 300
 CRE ages 4, 176–177, 317, 339
see also shergottites
 induction of noble gases in meteorites 175
 spallation 335
- Crete, astronomically tuned sections 18, 28
- crushing and Ar release by 83
- cryptocrystalline rocks, dating problems 33
- crystal defects
 density effect 54
 effect on dating 54
- crystallization degree in clays, effect on dating 54
- Curtis, Garniss, early work 9
- d*₀ value 34
- Dabie collisional complex 191
- Dabie Mountains 191
- Dabie Orogenic Belt 191
- Dabie-Sulu orogen 189
- Dakhleh impact event 349
- decay constants
 accuracy 3, 15–17
 for electron capture and beta decay of ⁴⁰K 22
 problems of uncertainties 21, 24
- Deccan traps, plagioclase dating problems 159, 160, 162
- deep pathway 137
- defects in crystal structure 137
 density effect 54
 effects on dating 54
 role in diffusion 265
- degassing and diffusion *see under* diffusion
- degassing curves, use in sericite detection 161–162
- Dellen impact crater, glass age study
 description 352
 geological setting 350, 351–352
 methods of study
⁴⁰Ar/³⁹Ar dating 354, 356
 electron microprobe 354
 FT-IR spectroscopy 354
 hydrogen isotope analysis 354
 optical microscopy 353
 Raman spectroscopy 354
 SEM 352, 354
 previous age research 351, 352
 petrography 356–357
- results
⁴⁰Ar/³⁹Ar date 358–359
 composition 355
 trapped water 357
- results discussed
 inherited argon 360–362
 perthitic texture 359–360
 water history 360
 significance of results 362–363
- Dellenite 352
- Denali Fault *see* Eastern Alaska Range
- depth-profiling, UV laser 137, 138, 266
 application to Ar diffusion and solubility measurement
 methods
 samples 138
 sample treatment 138, 143
 modelling 143–144
 results 140, 141, 142, 144–146
 results discussed
 diffusion 146–148
 solubility 148–152
- deuteric coarsening 107
- Devonian, atmospheric Ar ratios 179
- Dhofar shergottite (Dho378) 318, 319
- diagenetic minerals, special techniques for dating 54
- diamonds
 dating Zaire cubes 180
 micro-inclusion composition 175
- differential extraction and step-heating theory 82–83
- diffusion
 experimental techniques 2
 experiments *in vacuo* 112–114
 geological realities 111–112
 measurement of Ar in Itrongay feldspar 266
 methods of analysis
 laser ablation 267–268
 sample preparation 266–267
 results 268–270
 results discussed 270–272
 summary of model 272–273
- measurement of Ar in phengite muscovite 117–118
 Arrhenius data 121–123
 Arrhenius data inversion 126–130
 modelling mixing 123–126
 pressure effects 130–133
 step-heating observations 118–121
 summary 133–134
- measurement of Ar in labradorite and oligoclase
 methods
 sample preparation 138
 techniques 138, 143
 model 143–144
 results 144–146
 results discussed 146–148
- mechanisms 137, 266
- modelling 109
 consistency of 109–111
see also diffusion domains
- observations on 107–109
 rate relation to temperature 265
 role of Fick's Law 109
 role of phonons 108
 in solids, mathematical treatment 108
 use in technique development 2

- diffusion domains
 multi-diffusion domain (MDD)
 analysis 117
 model 266
 model future
 extra-terrestrial material 102
 K-Ar thermochronology 98–99
 K-Ca thermochronology 99–102
 model merits 95–96
 model shortcomings 96–98
 relation to cooling history 190, 193
 theory 92–95
 multi-path (MP) diffusion model 190, 193, 265
 diffusion *v.* fluid-mediated transport 107
 discrete domain theory 109–110
 checking for consistency 109–111
 geological realities 111–112
 double-vacuum resistance furnace 79
 doubly-pumped window 79, 80
- Eastern Alaska Range
 early research 226
 exhumation history
 methods of analysis
 laboratory techniques 228–230
 multi-domain diffusion model 230–231, 233
 sampling 227, 228
 results
 biotite ages 233–235
 feldspar age constraints 235
 feldspar MDD thermal models 232, 235–236
 results discussed 236–239
 geological setting 226, 227–228
 electron microprobe (EMP) analysis,
 muscovite B4M 70, 72–74
- Ethiopian traps, plagioclase dating problems 159, 162
- Evernden, Jack, early work 9
- exhumation rate 225
 Eastern Alaska Range
 early research 226
 exhumation history
 methods of analysis
 laboratory techniques 228–230
 multi-domain diffusion model 230–231, 233
 sampling 227, 228
 results
 biotite ages 233–235
 feldspar age constraints 235
 feldspar MDD thermal models 232,
 235–236
 results discussed 236–239
 geological setting 226, 227–228
- extraterrestrial materials 4, 102
see also meteorites
- Faneromeni section (Crete) 18, 28
- fast pathway diffusion 137
- fast-path diffusion 266
- fault gouge, recoil testing 54
- feldspar
 alkali *see* albite; K feldspar
 plagioclase *see under* plagioclase feldspar
- Fennoscandia *see* Dellen impact crater
- Fickian diffusion and Fick's Law 109, 112
- Fish Canyon plagioclase (FCp) 35
 experiment to test ³⁷Ar recoil
 methods 35–36
 results 36, 37, 38, 39
 results discussed 40, 43–46
- Fish Canyon sanidine (FCs)
 age 3, 16, 17–18, 21, 26
 correlation to orbital tuning 23
 as mineral standard 63
 experiment to test
 methods
⁴⁰Ar/³⁹Ar technique 65–66
 sampling 64
 separation 64–65
 results 65, 66
- Fish Canyon Tuff, exposure for standard mineral
 sampling 64, 64
- fission track annealing 107
- flame photometry, for K concentration 53
- flood basalts *see* large igneous provinces (LIP)
- fluence monitor
 defined 11
 Fish Canyon sanidine 17–18
- fluid inclusion analysis
 mineralization dating 180–183
 Northern Calcareous Alps, Haselgebirge Formation
 methods 211
 results 219–220
 Rhynie chert 179
- fluid-mediated transport *v.* diffusion 107
- French West Indies, Bouillante geothermal system
 adularia breccia 288, 291
⁴⁰Ar/³⁹Ar dating
 methods
 laboratory techniques 291
 sampling 291
 results 289, 290, 291–292
 results discussed 292–293
 tectonic setting 285–286, 287, 288
- Fuping Terrane 190
- Gangdisê feldspar 110–111
- geochronometers, controls on 107
- geomagnetic polarity timescale 26, 28
- geothermal activity timing in Bouillante
 adularia breccia 288, 291
⁴⁰Ar/³⁹Ar dating
 methods
 laboratory techniques 291
 sampling 291
 results 289, 290, 291–292
 results discussed 292–293
 tectonic setting 285–286, 287, 288
- glass-enveloped mass spectrometer 9
- gold-bearing mineral veins, fluid inclusion
 dating 180
- grain size
 effect on recoil 33, 53–54
 effect on standard mineral *see* muscovite B4M
 effect on thermochronology 98
 impact on Arrhenius diagrams 109
- Grande Découverte-Soufrière (GDS) volcanic system
 adularia breccia 288, 291
⁴⁰Ar/³⁹Ar dating

- methods
 - laboratory techniques 291
 - sampling 291
 - results **289**, 290, 291–292
 - results discussed 292–293
 - tectonic setting 285–286, 287, 288
 - greenschist facies, dating 157, 165–166
 - Grenville Province, source of hornblende 247, **247**
 - Guadeloupe, Bouillante geothermal system
 - adularia breccia 288, 291
 - $^{40}\text{Ar}/^{39}\text{Ar}$ dating
 - methods
 - laboratory techniques 291
 - sampling 291
 - results **289**, 290, 291–292
 - results discussed 292–293
 - tectonic setting 285–286, 287, 288
- Haifanggou Formation
 - $^{40}\text{Ar}/^{39}\text{Ar}$ dating
 - methods
 - laboratory procedure 280
 - sampling 279–280
 - results 281
 - results discussed 281–282
 - fossil content 278
 - lithological description 278–279, 279
 - halogen ratios, fluid inclusions 181, 182
- Haselgebirge Formation 208, 209
- Hawk Mine, Bakersville (North Carolina),
 - oligoclase samples 138
- HED meteorites 341
- Heinrich events 245
 - H3 characteristics 252
 - $^{40}\text{Ar}/^{39}\text{Ar}$ hornblende ages 253–254
 - detrital carbonate 252
 - magnetic susceptibility 252
 - oxygen isotopes 246, 253
 - radiogenic isotope provinces 252–253
 - terrigenous biomarkers 253
 - $^{230}\text{Th}_{\text{xs}}$ 253
 - H3 mechanism 257–260
 - relation to climate change 254–257
 - sedimentary evidence 246
- helium (He)
 - induction in iron meteorites 175
 - retention 107
 - ^3He
 - cosmic ray induction 175–176
 - Hawaiian basalts 176
- Hemerden tungsten (Cornwall), dating 178–179
- Higashi-akaishi peridotite, fluid inclusion
 - studies 181
- Himalaya, Main Central Thrust, muscovite
 - thermochronology 98
- hornblende
 - $^{40}\text{Ar}/^{39}\text{Ar}$ age and provenance 245, 253–254
 - sources in ice-rafted detritus 247–248
 - closure temperature 247
 - Lone Grove pluton 35
 - experiment to test ^{37}Ar recoil
 - method 36
 - results 39, 40, 40, 41, **42**
 - results discussed 47
 - mineral standard
 - recoil testing
 - method 55–56
 - results 56, **56**
 - results discussed 56–61
 - Huaiyang metamorphic belt 191
 - hydrogen, diffusion in silicon 108–109
 - hydrothermal systems
 - Bouillante geothermal system
 - adularia breccia 288, 291
 - $^{40}\text{Ar}/^{39}\text{Ar}$ dating
 - methods 291
 - results **289**, 290, 291–292
 - results discussed 292–293
 - tectonic setting 285–286, 287, 288
 - dating 157, 180–183
 - study and the role of $^{40}\text{Ar}/^{39}\text{Ar}$ 5
 - I-Xe dating 178
 - ice-rafted detritus, provenance studies 245
 - ideograms 335
 - igneous rocks, dating with K-Ar 10
 - illite crystallinity
 - Northern Calcareous Alps, Haselgebirge Formation
 - methods 211
 - results 219
 - illite-smectite, special techniques for dating 54
 - impact event studies
 - Dellen impact crater, glass age study
 - description 352
 - geological setting 350, 351–352
 - methods of study
 - $^{40}\text{Ar}/^{39}\text{Ar}$ dating 354, 356
 - electron microprobe 354
 - FT-IR spectroscopy 354
 - hydrogen isotope analysis 354
 - optical microscopy 353
 - Raman spectroscopy 354
 - SEM 352, 354
 - previous age research 351, 352
 - petrography 356–357
 - results
 - $^{40}\text{Ar}/^{39}\text{Ar}$ date 358–359
 - composition **355**
 - trapped water 357
 - results discussed
 - inherited argon 360–362
 - perthitic texture 359–360
 - water history 360
 - significance of results 362–363
 - impact crater record 333, 349
 - role of $^{40}\text{Ar}/^{39}\text{Ar}$ 4
 - Inter-Tropical Convergence Zone (ITCZ) 255
 - iodine, subducting slab release 181
 - island arc volcanism dating by Bouillante
 - geothermal system
 - adularia breccia 288, 291
 - $^{40}\text{Ar}/^{39}\text{Ar}$ dating
 - methods
 - laboratory techniques 291
 - sampling 291
 - results **289**, 290, 291–292
 - results discussed 292–293
 - tectonic setting 285–286, 287, 288

- isochron plots
 inverse 307
 regular 303–307
- Irongay feldspar (low sanidine/orthoclase)
 age 266
 description 266
 diffusion study
 methods of analysis
 laser ablation 267–268
 sample preparation 266–267
 results 268–270
 results discussed 270–272
 summary of model 272–273
 history of research 266
- J* parameter 54
- Japan, Sanbagawa metamorphic belt, fluid inclusion studies 181
- jet stream 254
- K (potassium)
 abundance 1
 concentration measurement 53
 effect of neutron activation 3
 K–Ar age, B4M muscovite 69
 K–Ar decay scheme, constants 16
 K–Ar thermochronology 98–99
 K–Ca thermochronology 99–102
 various isotopes
³⁹K, neutron bombardment 33
³⁹K/Ar dating technique 1
³⁹K/⁴⁰K ratio 11
³⁹K/⁴¹K ratio 10–11
⁴⁰K
 abundance 10, 15, 16
 atomic weight 10
 calculation of mineral content 167–168
 daughter isotopes 10, 10
 decay constant 10
 decay scheme 12
 half life 10
⁴⁰K/Ar*, mineral standards 63
⁴⁰K/³⁹Ar dating technique 1
 applications 9
 assumptions to be fulfilled 12–13
 igneous rocks 10
 primary standards 53
- K feldspar
 Ar retention compared with plagioclase 147
 diffusion styles 265
 Gangdisê feldspar 110–111
 laboratory degassing 108–109
 Madagascar sanidine 112
 microtextures and temperature 107
see also adularia; orthoclase; sanidine
- Karelian Province, source of hornblende 247, **247**
- Karin family 339
- Karoo Magmatic Province 159, 162, 163
 age of sericitization 171
- Kilimanjaro obsidian, dating 88, 88
- krypton (Kr)
 subducting slab release 181
 various isotopes
⁷⁸Kr, cosmic ray induction 175–176
⁸⁰Kr, cosmic ray induction 175–176
⁸¹Kr in cosmic ray dating 176
- La Garita Caldera (Colorado), as standard mineral source 64
- labradorite
 Ar diffusion and solubility measurement
 methods
 samples 138
 sample treatment 138, 143
 modelling 143–144
 results **140, 141, 142**, 144–146
 results discussed
 diffusion 146–148
 solubility 148–152
- Lanqi (Tiaojishan) Formation
⁴⁰Ar/³⁹Ar dating
 methods
 laboratory procedure 280
 sampling 279–280
 results 281
 results discussed 281–282
 fossil content 278
 lithological description 279, 279
- Lappajarvi impact 349
- large igneous provinces (LIP)
 problems of dating 155
 handling age reduction 159–160
 importance of filtering data for sericite 163–165
 study using ⁴⁰Ar/³⁹Ar 5
- laser heating/ablation
 benefits of technique 351
 history of use 79
 new developments 79–80
 scanning laser technology 80
 system performance 88–89
 system tests
 blanks 84–86
 burn patterns 80–81
 rastering 86–87
 step-heating 82–84
- laser depth-profiling 137, 138, 266
 application to Ar diffusion and solubility measurement
 methods
 samples 138
 sample treatment 138, 143
 modelling 143–144
 results **140, 141, 142**, 144–146
 results discussed
 diffusion 146–148
 solubility 148–152
- lasers
 application to noble gas extraction 3
 role in fusing crystals 14
- Late Heavy Bombardment (LHB) studies 102
- lattice diffusion 137, 265
- Laurentide Ice Sheet
 Heinrich events 245, 254, 257–260
- lavas, ascent rate calculations 147
- Lesotho lavas, dating 163
- Lesser Antilles magmatic arc *see* Bouillante geothermal field
- liquid scintillation counting (LSC) 16, 22

- Lona crater 349
 Lone Grove pluton hornblende 35
 experiment to test ^{37}Ar recoil
 method 36
 results 39, 40, 40, 41, 42
 results discussed 47
 Los Angeles basaltic shergottite
 experiment to test argon age 303, 304
 isochron plots 303–307
 nature of trapped argon 307–309
 lunar crater dating 176
 lunar maria, problems of dating 155
 lunar rock samples, dating 176–177

 McLean pluton, dating 24
 Madagascar
 gem feldspar (Itrongay) 193
 age 266
 description 266
 diffusion study
 methods of analysis
 laser ablation 267–268
 sample preparation 266–267
 results 268–270
 results discussed 270–272
 summary of model 272–273
 history of research 266
 sanidine 112
 Main Asteroid Belt 333
 Main Central Thrust (Himalaya), muscovite
 thermochronology 98
 mantle (upper), study of volatiles 175
 Mars
 application of $^{40}\text{Ar}/^{39}\text{Ar}$ 4
 argon sources 299–300
 resolution of components 300–303
 Los Angeles basaltic shergottite
 experiment to test argon age 303, 304
 isochron plots 303–307
 nature of trapped argon 307–309
 meteorites
 ages 297, 298, 312–313
 classification 297, 311
 exposure to cosmic rays 300
 monitoring 176
 shergottite NWA4797 shock melting study 318,
 318–319
 methods of analysis
 $^{40}\text{Ar}/^{39}\text{Ar}$ recording 321–323
 sample preparation 320–321
 microscope images 320
 petrography 319–320
 results
 calculated CRE age 325–327
 groundmass 323
 plagioclase grains 324–325
 vein 323–324
 results discussed 327–330
 mass spectrometer
 calibration 14–15
 pioneering design 9
 mathematical modelling *see* modelling
 Matuyama-Brunhes (MB) boundary,
 age 18, 26, 28
 Meliata Ocean 208
 melting and impact craters 333
 Meridional Overturning Circulation (MOC) 254
 Messadit section (Morocco) 18
 metamorphism, dating low grade 157, 165–166
 meteorites
 chondrites
 $^{40}\text{Ar}/^{39}\text{Ar}$ dating
 H type 339–341
 L type 336–339
 LL type 341–343
 problems associated 334–336
 summary of age data 343
 classification 333
 cosmic-ray induced noble gases 175
 cosmogenic exposure 4, 175
 dating by I-Xe 178
 ^3He concentration 176
 role of $^{40}\text{Ar}/^{39}\text{Ar}$ 4
 see also Mars
 metrological standard, defined 69
 Mianlue suture 190
 mica standards *see* biotite; muscovite
 microlites, problem of 351
 microtexture *see* texture
 mineral standards
 defined 63
 importance of 2–3
 for neutron flux determination 63
 testing
 see biotite; hornblende; muscovite; plagioclase;
 sanidine
 mineralization dating 178–179, 180–183
 Mississippi Valley Type (MVT) mineralization dating
 179, 180–181, 182
 model cooling history (MCH) method 194–195
 modelling
 diffusion 109
 diffusivity and solubility 143–144
 effect of sericitization 157–160
 mixing 123–126
 multi-diffusion domains *see under* multi-diffusion
 domain (MDD)
 multi-path (MP) diffusion *see* multi-path
 diffusion
 thermal history 272–273
 monazite age, Dabie Mountains 191
 moon rock dating 176–177
 Morocco, astronomically tuned sections 18
 multi-diffusion domain (MDD) *or* multi-domain
 diffusion (MDD)
 analysis 117
 modelling 266
 model future
 extra-terrestrial material 102
 K–Ar thermochronology 98–99
 K–Ca thermochronology 99–102
 model merits 95–96
 model shortcomings 96–98
 relation to cooling history 190, 193
 theory 92–95
 multi-path (MP) diffusion 190, 193, 265
 multibeam collection 14
 multiplier detectors 14

- muscovite
 age standard B4M and petrological suitability 69
 K–Ar age 69
 Rb–Sr age 69
 checks for petrological equilibrium
 methods of analysis
 $^{40}\text{Ar}/^{39}\text{Ar}$ step heating 70
 EMP 70
 Rb–Sr 70
 size separation 70
 XRD 70
 results
 Rb–Sr 70–71
 SMP 72–74, 73
 XRD 71–72, 72
 results discussed 74–77
 K–Ar thermochronology with MDD model 98–99
 K–Ca thermochronology with MDD model
 99–102
 phengite muscovite and Ar diffusion 117–118
 Arrhenius data 121–123
 Arrhenius data inversion 126–130
 modelling mixing 123–126
 pressure effects 130–133
 step-heating observations 118–121
 summary 133–134
- nakhilites 297, 311, 317
 ^{21}Ne , cosmic ray induction 175–176
 $^{21}\text{Ne}/^{22}\text{Ne}$ ratio, spectral hardness 176
 near-surface diffusion pathway 137
 neutron absorption, by halogens 178–179
 neutron activation 3, 178–179
 neutron capture 337
 neutron dose (J value) 2–3
 neutron fluence, interference from Ca and Cl 177
 neutron fluence monitor, FCs 63
 neutron flux, determination 63
 neutron induced ^{37}Ar recoil
 causes of 351
 effects of 34–35
 experiment to test
 methods 35–36
 results 36–40
 results discussed
 age correction 48–49
 comparison with theory 47–48
 Fish Canyon plagioclase 40, 43–46
 hornblende Hb3gr 47
 summary of implications 49–51
- neutron irradiation
 production of isotopes 3–4, 33, 53
 use of vacuum encapsulation 54
- New Mexico (USA)
 polyhalite studies 207–208
 labradorite samples 138
- New Zealand, gold-bearing veins and fluid inclusion
 dating 180
- Ningqiang meteorite 183
- noble gas yields by cosmic rays 175–176
- North Atlantic Deep Water (NADW) 254
- North Atlantic ice-rafting detritus (IRD)
 hornblende provenance study
 methods of analysis 248–250
 results 250–252
 results discussed 253–254
 hornblende provenances 247–248
- North Atlantic ice-rafting events 245
- North Carolina (USA), oligoclase samples 138
- North China Block 190, 190
- North Pennine orefield, mineralization
 dating 179
- Northern Calcareous Alps
 orogenic history 208
 palaeotemperature and age analysis
 history of research 210, 210
 methods 210–211
 results
 $^{40}\text{Ar}/^{39}\text{Ar}$ dates 215, 216, 217, 218–219
 illite crystallinity 219
 rock descriptions 211–212, 215
 thin sections 213, 214
 vitrinite reflectance 219
 results discussed 220–221
 results fluid inclusion analysis 219–220
 salt mines 208–209
 setting 208, 209
- obsidian, dating of Kilimanjaro sample 88, 88
- oceanic island basalts, problems of dating 155
- oligoclase
 Ar solubility and diffusion measurement 138
 methods
 samples 138
 sample treatment 138, 143
 modelling 143–144
 results 140, 141, 142, 144–146
 results discussed
 diffusion 146–148
 solubility 148–152
- optimization approach to calibration
 future 29
 misrepresentation 25–26
 misuse 24–25
 practicalities 21–22
 use 22–23
- optimization model 3
- orbital tuning 23–24
- ore deposits
 dating 157
 dating using saline fluids 175
- orogenesis, studies using $^{40}\text{Ar}/^{39}\text{Ar}$ 4
- orthoclase (Itrongay feldspar; low sanidine/orthoclase)
 age 266
 description 266
 diffusion study
 methods of analysis
 laser ablation 267–268
 sample preparation 266–267
 results 268–270
 results discussed 270–272
 summary of model 272–273
 history of research 266
- orthopyroxenite breccia, Martian 297, 311, 317
- outgassing rate, Earth 179
- oxygen isotope studies
 Heinrich events 246, 253, 254, 255
 Martian meteorites 297

- patch perthite, role in diffusion 265
- Pb/Pb dating, shergottites 318
- perthite style, effect on diffusion 265
- phengite muscovite and Ar diffusion 117–118
- Arrhenius data 121–123
 - Arrhenius data inversion 126–130
 - modelling mixing 123–126
 - pressure effects 130–133
 - step-heating observations 118–121
 - summary 133–134
- phonon
- defined 108
 - role in diffusion 108
- Pilbara greenstone (Australia), muscovite thermochronology 100
- plagioclase
- Ar retention compared with K feldspar 147
 - dating 137
 - in shock melted shergottite 318
 - handing alteration to sericite 155, 156, 157
 - calculating ^{40}K 168
 - detection, using degassing curves 161–162
 - determining time of 162–163
 - effects on mineral age
 - mathematical modelling 157–158
 - age reduction calculation 158–160
 - plagioclase composition 159
 - time factor 159 - petrology 157
 - solubility and diffusion in labradorite and oligoclase
 - methods
 - experimental techniques 138, 143
 - sample description 138
 - modelling 143–144
 - results 144–146
 - results discussed
 - diffusion 146–148
 - solubility 148–152
 - standard minerals
 - Fish Canyon plagioclase (FCp) 35
 - experiment to test ^{37}Ar recoil
 - methods 35–36
 - results 36, 37, 38, 39
 - results discussed 40, 43–46
 - see also* shergottites, NWA4797
 - plateau, defined 2
 - plateau plot 334
 - Pleistocene lava, ascent rate calculations 147
 - pollen analysis, relation to Heinrich events 255–257
 - polyhalite, Alpine 207
 - crystallization and recrystallization
 - methods of analysis 210–211
 - results
 - $^{40}\text{Ar}/^{39}\text{Ar}$ dates 215, 216, 217, 218–219
 - fluid inclusion analysis 219
 - illite crystallinity 219
 - rock descriptions 211–212, 215
 - thin sections 213, 214
 - vitrinite reflectance 219
 - results discussed 220–221
 - as geochronometer 207
 - history of dating research 207–208
 - rheology 207
- potassium (K)
- abundance 1
 - role in dating 1, 3
 - various isotopes *see under* K
- pressure impact on diffusion 130–133
- primary standards
- defined 53, 63
 - recoil testing
 - method 55–56
 - results 56, 56
 - results discussed 56–61
- production ratios 13
- provenance studies, role of $^{40}\text{Ar}/^{39}\text{Ar}$ 4–5
- hornblende age and provenance 245, 253–254
 - sources in ice-rafted detritus 247–248
- Pueblo Park, New Mexico, labradorite samples 138
- pumpellyite facies, dating 165–166
- pyroxene in Martian orthopyroxenite 297, 311, 317
- pyroxenite, deuteritic alteration age 179–180
- Qinling granitoids 191
- Qinling Mountains 190
- Qinling–Dabie Orogenic Belt 189
- geological setting 190–191
 - granitoid chronology
 - methods
 - model cooling history (MCH) 194–195
 - sampling 191, 192, 193
 - thermal model 193
 - results
 - geochronology 192, 195–197
 - thermochronology 198–200
 - significance of results 200–203
- Qinling–Tongbai orogen 189
- quality of samples, importance of 2
- R* value, defined 63–64
- Rajahmundry traps 160, 162
- raster tests, CO_2 laser method 86–87
- Rb–Sr isotopic age
- B4M muscovite 69, 70, 71
 - Dabie Mountains 191
 - shergottites 318
- recoil of ^{37}Ar
- causes of 351
 - effects of 34–35
 - experiment to test
 - methods 35–36
 - results 36–40
 - results discussed
 - age correction 48–49
 - comparison with theory 47–48
 - Fish Canyon plagioclase 40, 43–46
 - hornblende Hb3gr 47
 - summary of implications 49–51
 - explained 3
 - problems of 33, 53, 299
 - quantification 34
- recoil distance 54
- recoil testing with vacuum encapsulation 54
- method 55–56
 - results 56, 56
 - results discussed 56–61

- recrystallization
 role in geochronometers 107
 water-assisted 107
- Reichenhall Formation 208
- relative probability plots 335
- Reynolds, J. H., early work 9
- Rhynie chert, fluid inclusions 179
- Rochechouart impact 349
- Rutherford backscattering 137
- ³⁶S
 in meteorites 175
 in sodalite 183
- Salado Formation 207
- saline fluid and ore mineral dating 175, 178–179
- San Juan volcanic field, as source of mineral standard 63
- Sanbagawa metamorphic belt, fluid inclusion studies 181
- sanidine
 Fish Canyon (FCs)
 age 3, 16, 17–18, 21, 26
 correlation to orbital tuning 23
 as mineral standard 63
 experiments to test
⁴⁰Ar/³⁹Ar technique 65–66
 methods 64–65
 results 65, 66
 vacuum encapsulation technique 54
 recoil test method 55–56
 results 56, 56
 results discussed 56–61
- Madagascar 112
- mineral standards (FCT-3; TCR-2)
 recoil testing
 method 55–56
 results 56, 56
 results discussed 56–61
- recoil-induced loss 34
see also K feldspar; orthoclase
- São Tomé basalt 86, 87
- scanning laser technology
 initial development 79
 limitations 79
 new developments 80
 description 80, 81
 system performance 88–89
 system tests
 blanks 84–86
 burn patterns 80–81
 rastering 86–87
 step-heating 82–84
- Schmeisneria*
 as an early angiosperm 277–278
⁴⁰Ar/³⁹Ar dating of first appearance
 methods, sampling 279–280
 methods laboratory procedure 280
 results 281
 results discussed 281–282
- secondary standards
 defined 53, 63
 recoil testing
 method 55–56
 results 56, 56
 results discussed 56–61
- sericitization 155, 156, 157
 calculating ⁴⁰K 168
 detection, using degassing curves 161–162
 determining time of 162–163
 effects on mineral age
 mathematical modelling 157–158
 age reduction calculation 158–160
 plagioclase composition 159
 time factor 159
 petrology 157
- Shangdan suture 190
- shergottites 297, 311, 317, 318
 Los Angeles basaltic
 experiment to test argon age 303, 304
 isochron plots 303–307
 nature of trapped argon 307–309
 NWA4797 shock melting study 318, 318–319
 methods of analysis
⁴⁰Ar/³⁹Ar recording 321–323
 sample preparation 320–321
 microscope images 320
 petrography 319–320
 results
 calculated CRE age 325–327
 groundmass 323
 plagioclase grains 324–325
 vein 323–324
 results discussed 327–330
 problems of argon components 300–303
 problems of dating 297, 298, 299
 radioisotopic ages 318
 shock deformation and impact craters 318, 333
 problems in ⁴⁰Ar/³⁹Ar dating 334–335
 shock melting in shergottite 318
see shergottite, NWA4797
 shock metamorphism in meteorites 317
 induced melting 318
- Siberian traps, plagioclase dating problems
 159, 162
- silicon, diffusion in 108–109
- size of grain
 effect on recoil 33, 53–54
 effect on standard mineral *see* muscovite B4M
 effect on thermochronology 98
 impact on Arrhenius diagrams 109
- Skiddaw granite, dating 179
- Sm-Nd mineral dating
 Dabie Mountains 191
 Martian meteorites 297, 298, 312–313
 shergottites 318
- smectite, special techniques for dating 54
- sodalite
³⁶Cl study 177–178
³⁶S 183
- solar flare protons, role in Ar isotope production
 176, 177
- solubility
 measurement of Ar in labradorite and oligoclase 138
 methods
 sample preparation 138
 techniques 138, 143
 model 143–144
 results 144–146
 results discussed 148–152

- South China Block 190, 190
- Southern Alps, gold-bearing veins and fluid inclusion dating 180
- spectral hardness and $^{21}\text{Ne}/^{22}\text{Ne}$ 176
- Stac Fada ejecta blanket 349
- staircase age spectrum, K feldspar 190, 193, 194
- standard, defined 69
- for neutron flux determination 63
- primary v. secondary 53, 63
- standard minerals
- importance of accurate ages 21
- importance of 2–3
- recoil testing
- method 55–56
- results 56, **56**
- results discussed 56–61
- testing
- see* Fish Canyon sanidine; Fish Canyon plagioclase; hornblende; muscovite B4M
- statistical optimization approach to calibration 21
- future 29
- misrepresentation 25–26
- misuse 24–25
- practicalities 21–22
- use 22–23
- step-heating
- applications
- chondrite meteorites 334
- Dellen impact structure 351, 356, 358
- exhumation studies 230, 231
- Haifangou Formation studies 280, 281
- muscovite age standard 70
- phengite muscovite diffusion study 117, 118–121
- polyhalite studies 215, 217
- CO₂ laser testing 83–84
- theory of 82–83, 91–92
- subduction-related fluid inclusion analysis 181
- suevite 352
- Superior Province, source of hornblende 247, **247**
- Susong metamorphic complex 191
- Svecoffenian Province, source of hornblende 247, **247**
- Sveconorwegian Province, source of hornblende 247, **247**
- Sweden, Dellen impact crater, glass age study
- description 352
- geological setting 350, 351–352
- methods of study
- $^{40}\text{Ar}/^{39}\text{Ar}$ dating 354, 356
- electron microprobe 354
- FT-IR spectroscopy 354
- hydrogen isotope analysis 354
- optical microscopy 353
- Raman spectroscopy 354
- SEM 352, 354
- previous age research 351, 352
- petrography 356–357
- results
- $^{40}\text{Ar}/^{39}\text{Ar}$ date 358–359
- composition **355**
- trapped water 357
- results discussed
- inherited argon 360–362
- perthitic texture 359–360
- water history 360
- significance of results 362–363
- tectonic studies, role of $^{40}\text{Ar}/^{39}\text{Ar}$ 4
- tectonothermal history and thermochronology 225
- Eastern Alaska Range
- early research 226
- exhumation history
- methods of analysis
- laboratory techniques 228–230
- multi-domain diffusion model 230–231, 233
- sampling 227, 228
- results
- biotite ages 233–235
- feldspar age constraints 235
- feldspar MDD thermal models 232, 235–236
- results discussed 236–239
- geological setting 226, 227–228
- temperature
- relation to diffusion rate 265
- role in Ar component release 82–83
- role in Ar solubility in plagioclase 151
- role in geochronometers 107
- temperature-time history 91, 225
- role of $^{40}\text{Ar}/^{39}\text{Ar}$ 4
- terrestrial impact record 349
- texture and microtexture, temperature effects 107
- thermal history interpretation 91
- role of Fickian diffusion 109
- use of K/Ar 9
- thermal neutrons
- capture 335, 337
- fluence 13
- thermochronology 91
- Itrongay feldspar
- age 266
- description 266
- diffusion study
- methods of analysis
- laser ablation 267–268
- sample preparation 266–267
- results 268–270
- results discussed 270–272
- summary of model 272–273
- history of research 266
- muscovite
- K–Ar muscovite 98–99
- K–Ca muscovite 99–102
- muscovite B4M 69–70
- orogen studies 225
- Eastern Alaska Range 226, 227–228
- early research 226
- exhumation history
- methods of analysis
- laboratory techniques 228–230
- multi-domain diffusion model 230–231, 233
- sampling 227, 228
- results
- biotite ages 233–235
- feldspar age constraints 235
- feldspar MDD thermal models 232, 235–236
- results discussed 236–239
- Qinling Dabie Orogen 189, 190–191

- thermochronology (*Continued*)
 granitoid chronology
 methods
 model cooling history (MCH) 194–195
 sampling 191, **192**, 193
 thermal model 193
 results
 geochronology **192**, 195–197
 thermochronology 198–200
 significance of results 200–203
- thermochronometry, use of K/Ar 9
- Tiaojishan Formation *see* Lanqi Formation
- time-temperature history 91, 225
 role of $^{40}\text{Ar}/^{39}\text{Ar}$ 4
- Togni Quarry (Brione), source for age standard 69
- Tristan da Cunha basalt, dating 88, 88, 182–183
- tungsten, dating of mineralization 178–179
- tweed perthite, role in diffusion 265
- U–Pb methods 21
 age of shergottites 318
 paired with $^{40}\text{Ar}/^{39}\text{Ar}$ for statistical optimization 21
 zircon ages
 Bishop Tuff 26, 28
 comparisons 16
 Dabie Mountains 191
 Eastern Alaska Range 228
 McLean pluton 24
- U/Th–He 333, 337
- UV laser ablation 137
 Ar release by 83
- UV laser depth-profiling 137, 138, 266
 application to Ar diffusion and solubility measurement
 methods
 samples 138
 sample treatment 138, 143
 modelling 143–144
 results **140**, **141**, **142**, 144–146
 results discussed
 diffusion 146–148
 solubility 148–152
- UV laser microprobe spot analyses 319, 334
- vacuum encapsulation 54
 use in recoil testing
 method 55–56
 results 56, **56**
 results discussed 56–61
- Vesuvius eruption products in dating 16
- vitrinite reflectance
 Northern Calcareous Alps, Haselgebirge Formation
 methods 211
 results 219
- volcanic events and rocks
 $^{40}\text{Ar}/^{39}\text{Ar}$ dating 5, 137
 use of adularia breccia 288, 291
 methods 291
 results **289**, 290, 291–292
 results discussed 292–293
 ascent rate calculations 147
 basaltic, problems of dating 155
 Vesuvius AD79 16
- wadalite, S36 183
- water-assisted recrystallization 107
- water-rock reactions *see* hydrothermal systems
- x_0 value 34
- Xe, various isotopes 181
 cosmic ray induction 175–176
- Xingxueanthus*
 as an early angiosperm 277–278
 $^{40}\text{Ar}/^{39}\text{Ar}$ dating of first appearance
 methods, sampling 279–280
 methods laboratory procedure 280
 results 281
 results discussed 281–282
- XRD, muscovite B4M 70, 71–72
- Yakutat microplate 226, 226, 227
 impact on Eastern Alaska Range 238–239
- Yangtze blueschist belt 191
- Zagami meteorite 297, **299**
- Zaire cubes, dating 180
- zeolite facies, dating 165–166
- zinc windows for laser work 79, 80
- zircon age with U–Pb, comparisons 16
 Bishop Tuff 26, 28
 Dabie Mountains 191
 Eastern Alaska Range 228
 McLean pluton 24