

# Index

Page numbers in italics, e.g., *153* refer to figures. Page numbers in **bold**, e.g. **173**, signify entries in tables.

- apatite-fission track dating 39–42
- aperture variation in fractures 117–128, 265
- aquifers, confined 125
- arrest
  - lines 8, 153, *155–156*, 180, *247*
  - of fractures 117–128, 185, 246
  - see also* rib marks
- asperities 235
- indentation 318, 321
- axial splitting 43–45
  
- barriers to fluid flow 4
- basin
  - evolution 257
  - inversion 93, 243, 245, 252
  - subsidence 249, 250
- black shales, preferential jointing in 129–151
- blastesis 185
- Bohemian Massif 25–47, 103–116, *184*, 190, 194–206, 287, 293, 315–324
- border planes 153–155, 168, 248
- boundary conditions for mechanical analyses 269
- boundary-element models (BEASY) 118–124
- branching 103, *104*, 113
- breakdown 169, 171, 178–180, 248–249, 252
- breccias 235, 239
  - fault 233, *234*, 265
  - implosion 233, *234*, 237, 239
- Bristol Channel Basin 89–102, 118, *119*, *123*, 209–221, 243–255, 287
- brittle-ductile transition 224
- brittle failure 245–246
- brittle-plastic transition 224
- brittle subcritical fracture 20–21
- buoyancy pressure 145, 148
  
- C-fracture *155*
- canyons
  - box-shaped 52, 54, 55
  - slot-shaped 49–71
- cap rock 228–229, **229**
- cataclasis 233, 238
- cathodoluminescence 3, 3–5, 6
- Catskill Delta Complex, USA 129–151, 288–290, 293
- cement
  - bridges 1–8, 235
  - carbonate mineral 4, 231–240
  - fracturing of 5, 6
  - post-kinematic 4
  - precipitation history 1, 7
  - self-sealing of faults 238
  - sulphate mineral 4, 231–240
- cement-filled gaps 2, 6–8
- censoring 270
- ceramics, creep failure 11–12, 16–18
- chatter marks 321
- chemical reactions, impact on fracture strength 75–76
- chert spheroids 11–15
- coefficient of friction 98
- compaction 126, 144 *see also* disequilibrium compaction
- compass, Freiburger, calibration 286–288
- conchoidal ridge *155*
- confining pressure 206, 272
- Cook-Gordon debonding 126
- core, fracture logging of 223–242
- crack
  - extension 113
  - growth 18, 36, *44*
    - dynamic 285
    - subcritical 49, 73–87, 272, 285
  - see also* fringe cracks
  - propagation 44
  - velocity 36, 103–104, 108, 110, 112, 114–115, 246, 248
- crack-jump mechanism 92
- crack-seal textures 1–5, 7–8
- crack-tip *194*, 194, 245–246
  - process zones 49, 53, 66, 73–87
  - shielding 67
  - stress concentration 60, 69, 142, 184, 194
- cracks
  - cooling, in permafrost 67–68
  - fold-limb splay 49
  - secondary 110, 112
  - thermal-shock 68
  - wing 66, 155, 191
  - see also* microcracks
- creep failure
  - in alumina 16
  - in ceramics 11–12, 16, 18
- crenulation cleavage 218
- critical-point phenomena 299–314
- cross-fractures 153–155, 169–170, 174–176
- cross-joint 91, 93
- cubic flow law 300, 308, 310
  
- dating
  - <sup>14</sup>C, of lakebeds 232
  - of dykes 202
  - of fractures, K/Ar 25, **27**, 30, 36, 190, 246
  - see also* apatite fission track dating
- debris avalanche 224
- decoupling of beds 94, 100
- deformation
  - bands 19, 20, 153
  - dilational 301, *303*
    - jogs 301
    - see also* pull-aparts
  - localization of 299–314
- Devonian, Appalachian Basin, USA 129–151, 288–290, 293

- diagenetic history 211–212  
   of fractures 3  
   of reservoirs 126  
 diatomaceous mudstone, alteration of 11–12, 13  
 differential erosion 50, 57  
 differential geometry 153–182  
 diffusion creep 20–21  
 diffusion-mass transfer mechanism 321–323  
 diffusive-pore spheroidization 16–17  
 discontinuities 245  
   effects of 118  
   opening-displacement 155  
   shearing-displacement 155  
   tearing-displacement 155  
 disequilibrium compaction 143  
 dissolution, impact on fracture properties 90, 233  
 distinct-element modelling method (UDEC) 299–314  
 ductile failure 11–24  
 dyke 117–119, 122, 155, 179  
   basaltic 164  
   emplacement 49  
   impact on jointing 76  
   *see also* granite dykes
- earthquakes 265, 299, 316, 321–322  
 echelon fringes 103, 104, 105, 108–109, 185, 186,  
   190–206, 248, 252, 316  
 en echelon cracks *see* echelon fringes  
 energy release rate  
   critical 113  
   steady-state 114, 114–115  
 Euler's theorem 164  
 exhumation of granite 39–42  
 extension, regional 60, 62, 66, 68, 216
- F-joint 155  
 fault-slip analysis 315  
 faults 11, 153  
   breccia 234  
   gouge 316 *see also* breccia  
   initiation, Annulus model for 216  
   normal 213, 228, 229, 231, 239, 245, 263  
     Basin and Range style 49–71  
     reverse-reactivated 214, 218, 252, 292  
   oblique-slip 228, 229  
   relationship to veins and joints 212–213, 257–267  
   self-sealing by cementation 238  
   strike-slip 213, 218, 228, 229, 239, 245, 252,  
     259  
   termination zone 259, 262, 263  
 feather fractures 153, 154, 166, 180 *see also* plumose  
   structures
- fibres  
   crystal growth 315, 318, 320–322  
   veins 294  
 fine hackle 153, 169  
 finite-element analysis 99, 119  
   model (FRANC) of joint zones 58–69  
   *see also* boundary-element models
- flaw  
   critical 104  
   existing 110, 272  
   initial 104, 275  
   impact on fracture spacing and length 73–87
- fluid  
   flow 224–225, 229, 265, 285  
     localization of 308–314  
       regional 132  
   inclusions 3, 6, 27, 30–31, 37, 188, 190, 196, 232, 239  
   pressure 217–218, 226, 227, 233, 238, 240, 272,  
     299–314  
   release 224
- fold  
   description of 157  
   pericline 98–99  
   rollover 93, 252  
   tangential longitudinal strain 98  
 fold-limb splay cracks 49  
 folding  
   flexural-flow 93, 98, 213  
   relationship to fracturing 157  
 Fourier analysis 171
- fractal  
   distributions 269, 299  
   geometries 215, 217, 237  
   multifractal techniques 310–313  
   properties of fluid flow 299, 310–311
- fractionation  
   compaction-driven 237  
   convection-driven 238  
   diffusion-driven 237
- fractography 25, 40, 103–116, 153–182, 185, 191,  
   192–194, 245–251
- fracture  
   anisotropy 305, 308, 310, 312, 313  
   augen 191  
   brittle subcritical 20–21  
   cleavage formation 205  
   cluster growth mechanism 85  
   density 25, 231, 270, 279, 299, 305–308, 312, 313  
   apparent 270  
   front, cyclic propagation of 35, 40  
   growth  
     by pore growth and coalescence 11–14, 15  
     lateral 74  
     subcritical 73–87, 272  
   kinematics 226–231  
   lances 179  
   length 73–87, 299, 305, 306, 308, 312  
   logging 223–242  
   mechanics 153, 245–246  
     linear elastic 11, 155  
   mechanisms 25  
     map of 20–21  
   modelling of 44, 285  
   morphology 246  
   networks 218, 264, 265–266, 269–270  
     deformation and fluid flow in 299–314  
     geometry and orientation 89–102, 305–308  
   orientation 223, 226–231  
   prediction 89–102  
   propagation 43  
   roughness 109, 272  
   seal properties 223, 226  
   step over 126  
   strength 75–76, 272, 275  
   spacing 73–87, 217, 276  
   strike-slip 237

- swarms 73–87
- tensile 228, **229**, 231, 233, 235, 239
- timing 231–237, 257
- tips 11, *13*, 16, 118, 155, *156*
  - damage distribution at 18
  - diffusive-mass transfer at 20
- velocity 205
  - model 75–82
- fracture-opening 1, 8, 304
- fractures
  - around a major fold 89–102
  - diagenetic history 3
  - driving forces for formation of 204
  - extension 124
  - opening-mode 2–4, 7–8, 11–24, 75–76, 183, 248
  - shear (faults) 124
  - sheet 30, 32, *186*, *189*, 195
  - spheroidal 11–24
  - T-shaped 124–126
- fracturing
  - in cooling of igneous rock 25–47, *234*
  - of quartz crystals 1
  - relationship to folding 157
- frequency distributions *see* log-normal frequency distribution; negative exponential frequency distribution; power-law scaling; von Mises distribution
- frictional contact 316
  - in finite-element models *61*, *63*
- frictional wear 315
- fringe 153, 184, *191*, 204
- fringe cracks 33, 44, 45, 109–110, 183–208, 248
  - planes 183, 198
  - propagation 30, 32
  - subcritical 36, *44*
  - rotation 36
  - segments, tilted 155
  - twisted 35
  - see also* echelon fringes; hackle fringe; hackles; joint fringes
- geomechanical modelling of fracture pattern development 7–8
- geomechanical properties of fractures 313
- geothermal system, fracturing in 223–242
- glass, hackle formation in 110, 112
- grain coarsening by Ostwald ripening 14
- granite
  - brittle fracture in 21
  - dykes 30, 37, *44*
  - fractures 183–208, 248
  - joints in 25–47
  - melt inclusions 42–43, *44*
- gravity 273
  - body (load) model 57–60, 62, *64–65*, 66, 69
- hackle
  - flakes 110
  - fringe 103, 105, 108, 169, *179*
  - plumes 317
- hackles 103–116, 169–180
  - curved 156
  - cuspsate 103, **105**
  - formation in glass 110, 112
  - formation in polymers 112–113
  - formation in silicon single crystals 113–115
  - incipient 171–173
  - index of raggedness 104, 108, *111*
  - see also* fine hackle; inclusion hackles; twist hackles
- hanging-wall 321
  - buttress 291
  - ramp 290
- <sup>3</sup>He/<sup>4</sup>He ratios 225, 232, 239
- helicoids as idealized fractures 164–168, 177, 179
- Hertzian ring cracks 318, *319*, 321–322
- humidity, relative, impact on fracture strength 75–76
- hydraulic fracturing 35, 39–41, 43, 45, 117, 142–148, 228, 233, *234*, 237, 288, 290, 301 *see also* hydrofractures
- hydrocarbons
  - cracking of 147–148
  - exploration of 265
  - generation of 129–151, 288–290, 299
  - in situ* combustion of 11–12, *13*
  - migration of 126, 129, 238
  - see also* organic carbon
- hydrofractures 117–128, 204
- hydrothermal
  - fluids 39, 204
  - minerals 192, 195, 197, 231–240, 299
- igneous rock
  - fracturing during cooling of 25–47, *234*
  - sheet opening 305
- implosion breccias 233
- inclusion hackles 103, *155*, 247
- indentation
  - creep 321–322
  - pits 315–324
- inversion, Alpine 213, 252 *see also* basin inversion
- joint
  - bundle *186*
  - definition of 245
  - density *132*, 134
  - dip distribution analysis 53–57, 66
  - fringes 103–116, *154–155* *see also* twist hackle fringe
  - network 91, 281–282
  - spacing 73–87, *141*, 148
  - swarms 49
- joint-normal
  - loading 142
  - stretching 43, 142
  - tractions 62
- joint propagation 49, 245–246, 272
  - arrest of 183
  - barriers to 213, *214*
  - closely spaced 49–71
  - depth *201*
  - lateral 75
  - modelling of 75
  - timing of 144, 202
- joint sets 25, 49, 89–102, 183, 205, 245
  - bed-normal 269–284
  - cross-fold (Alleghanian) 138–144, 257
  - dispersion of 286
  - orientation distribution 285–297
  - saturated 73

- joint surface  
 morphology of 153–182, 243–255, 285  
 ornamentation 142
- joint zone development 49–71
- jointing, exfoliation 53, 59, 66, 69
- joints 245, 259  
 Alpine 93, 99, 245, 249, 252, 254  
 as stress release structures 217  
 bed-containment 271–272  
 burial 93, 245, 257–258  
 classification of 257  
 cooling 217  
 composite 197  
 differences from veins 209–221  
 driving forces for formation of 43–45, 129–151, 204, 249, 272  
 formation in granite 25–47  
 lager 184, 188, 195, 199  
 mineral-filling 245  
 penny-shaped 43–44  
 post-uplift 257  
 simulation of 269–284  
 successions 32–34  
 syntectonic 257, 263  
 T-shaped 138  
 T-intersection with bedding 271–273, 277, 279–281  
 uplift 257  
 X-intersection with bedding 271–273, 279–281
- kinks 183, 248
- layer thickness, impact on fracture spacing and length 73–87
- log normal frequency distribution 217, 307
- main joint *see* parent joint
- material behaviour for mechanical analyses of joint patterns 269
- matrix densification 14, 16
- maturation of source rocks 132, 143–144, 288–290
- mechanical analyses of fracture patterns 269
- mechanical interaction distance 73
- metamorphism 217
- microcracks 80, 109
- microveins 91–92, 96, 249
- migration *see* hydrocarbons
- mineralization, impact on fracture properties 90
- mirror  
 plane 103–105, 107, 110, 113  
 secondary 110
- mist 103, 104, 110, 112–113
- modelling *see* boundary-element models; distinct-element modelling method; fault initiation, Annulus model for; finite-element analysis; fracture modelling; frictional contact; geomechanical modelling; joint propagation, modelling of; probabilistic decision models of fracture patterns; vitrinite reflectance, kinetic model
- Mohr-Coulomb rheology 300
- Mohr failure envelope 123
- mudcracks 217, 294–295
- negative exponential frequency distribution 217
- nuclear waste repository 223
- Nyquist frequency 171
- <sup>18</sup>O isotope in water 225, 239
- opal-CT to quartz transformation 13, 16
- ore deposits 190, 224, 238, 299
- organic carbon 129, 132–134, 136, 142–143, 148
- orientation data 223, 226–231, 285–297
- Ostwald ripening, grain coarsening by 14
- overburden load 60
- overpressure 42–45, 91, 117, 120–127, 142, 204, 237  
 mechanisms for generating 143–144, 146–148
- palaeodepth, of granites 188, 190, 202–205
- palaeostress 243–255
- parent joint 33, 34, 45, 155, 169–170, 176–180, 186–187, 191, 193–194, 198, 202, 205, 247, 248, 253
- partial fractures 153, 166 *see also* hackles
- percolation threshold 117
- permafrost 67–68
- permeability 233, 239  
 by field pumping test 265  
 fracture 1, 90, 130 *see also* barriers to fluid flow  
 increase by hydraulic fracturing 117, 124–126  
 of hydrocarbon source rocks 129
- pipe formula 308, 310
- pit density 112
- plumose  
 axis 30, 153, 155, 247, 248, 249  
 barbs 317  
 markings 32, 75  
 structures 34, 35–36, 103, 104, 155, 156, 169, 171, 180, 186, 190–192, 197, 205, 245–254, 317, 321, 323
- Poisson probability distribution 269
- Poisson Ratio 58, 78, 120–123, 275
- pore growth and coalescence 11–21  
 by cavitation along crystal facets 16  
 by creep 17  
 by crystal-plastic deformation mechanisms 18  
 by diffusive-mass transfer 16–17, 21  
 in ceramics 19  
 in ductile metals 16  
 resulting from matrix densification 14, 16  
 resulting from solution-precipitation 14, 18
- porosity  
 fracture 1–2, 4, 126, 239  
 impact of fractures on 90
- power-law scaling 217–218, 307, 310–311
- pressure *see* buoyancy pressure; confining pressure; fluid pressure; overpressure
- pressure solution 126, 315  
 cleavage 218, 253  
 seams 216
- probabilistic decision models of fracture patterns 269, 272–276
- propagation exclusion zone 73, 79
- pull-apart 301  
 structures 92, 212, 216  
 voids 92
- relay ramp 216, 245
- reservoirs, fractured 89–90

- rest melts 204
- rheology, impact on fracture development 91–101
- rib marks 33, 153, 155–156, 168–180, 192, 197, 204, 317
- scanline sampling 93–96, 135–140
- scanner, fracture 170
- seals 126, 238
- segment traces, hook-shaped or sigmoidal 155
- segmentation, en echelon 103–109, 115, 153, 155, 164, 168, 179, 186–187, 192, 194, 198, 206, 214, 248  
*see also* border planes; echelon fringe; partial fractures; twist hackle
- shear 272  
  bands 233  
  conjugate 252  
  displacements 301–302  
  fractures 235, 245  
  loading 194  
  simple 216  
  zone 305
- shoulder 155
- side-lode damage 17–18, 21
- sills 117
- simulation  
  of fracture patterns 269  
  of joint patterns 269–284  
  *see also* modelling
- skewness 53–55, **56**
- slickensides 245, 315–316, 321
- slickolites 315
- sliding  
  along fractures 300, 305  
  frictional 305, 313  
  *see also* slip on joints
- slip on joints 315–324
- solution features 153, 155, 245
- solution-precipitation 14, 16  
  creep 16, 18, 20–21
- stability analysis of fractures 285
- statistics  
  cone of confidence 285–286, 288, 294–295  
  of orientation joint data 285–297  
  sampling error 288  
  use of kurtosis 55, **56**, 285–288, 295  
  use of skewness 53–55, **56**
- stepovers 276
- stick-slip mechanisms 316, 323
- stiffness *see* Young's modulus
- stockworks 217
- strain  
  analysis 73  
    centre-to-centre 294  
    from joints 215, 218  
    prediction of, in folds 157  
  indicators  
    anisotropy of magnetic susceptibility 294  
    remnant magnetization 294  
    *see also* mudcracks; veins  
  rate 272  
  remote 279
- stress 66, 73, 148, 155, 217, 228, 240, 246, 304  
  barriers 118, 126  
  bending 290  
  compressive 217, 229, 253  
  critical **275**, 299, 308, 310, 313  
  differential 272, 300, 304, **306**, **310**  
  driving 57, 272–273, 285, 299, 305–307, **310**, 313  
  far-field 98, 194, 223, 301  
  intensity factor 76, 82, 85, 112, 205  
  principal 252, 259, 263, 300, 304, 317  
  tensile 117, 120–122  
    concentration 53, 63, 64–65  
    rotation 173  
    sintering 16
- stress field 239, 257, 285, 290, 292  
  compartmentalisation of 213  
  crack-tip 184, 249, 272, 288  
  local 249, 252, 259, 263  
  regional 226, 265  
  remote 144, 183, 249, 253, 258–259, 260, 264, 273, 288 *see* stress, far field  
  rotation 245
- stress shadow 49, 66–67, 84, 85–86, 272–273, 275–276  
  edge-crack theory 68
- striae *see* plumose structures
- stylolites 216
- subcritical index, impact on fracture spacing and length 73–87
- surface roughness 112
- tail cracks 155
- tension, remote 66
- thermo-elastic contraction 43, 148
- tip curvature 272
- tip-lines 180, 193, 258, 263
- tool marks 315, 317, 321–322
- toughness, critical 76
- traces, bedding planes and fractures as 270
- transpression 216
- transension 216
- twist  
  angle 177  
  rate of 178–180
- twist hackle 103, 153, 155, 166, 176–178, 184–185, 188, 191, 193, 197–199, 204, 206  
  abrupt 248  
  face 155, 247, 253  
  fringe 153, 155, 187, 202, 245, 247–254  
  gradual 248 *see also* twist hackle fringes  
  second order 155  
  step 155, 247, 253
- undulations 33, 34–35, 43, 104, 172, 197, 204
- V or crescentic tool markings 321
- veins 155, 179, 204, **232**, 245, 253, 292, 294–295  
  arrested 119  
  crack-seal 211, 294  
  differences to joints 209–221  
  en-echelon 212, 218  
  fibres 294  
  high-density 211, 212  
  layer-normal extensional 92  
  mineral-filled 117, 122, 155, 214, 245  
  *see also* microveins; stockworks
- visualisation 245

- vitritine reflectance, kinetic model (EASY% $R_0$ ) 145–147
- volcano, fracture development in 223–242
- von Mises distribution 286
- Wallner Lines 104, 155 *see also* arrest lines
- wear
  - brittle 315, 320
  - ductile 315–316
  - see also* tool marks
- weathering 215, 248
- welded fracture contacts 99
- well logs
  - fracture logging from 223–242
  - orientation and distribution of joints in 285
- window sampling 93–96
- wing cracks 66, 155, 291
- Young's modulus 58, 78, 117–128, 272, **275**
- zig-zag arrays 20