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ภาคผนวก

สิ่งสำคัญสิ่งหนึ่งของวิธีการแทรค-เอทช์ ก็คือการหาเงื่อนไขที่เหมาะสมในการกัดรอย ซึ่งจำเป็นต้องทำการทดลอง ในตารางข้างล่างได้รวบรวมเงื่อนไขที่เหมาะสมในการกัดรอยของพิชชันแฟรกเมนต์ ที่ปรากฏบนวัสดุบันทึกรอยชนิดต่างๆ ไว้ สำหรับการกัดรอยของอนุภาคมีประจุชนิดอื่น สามารถใช้เงื่อนไขในตารางเป็นแนวทางในการหาเงื่อนไขที่เหมาะสมได้

ตารางที่ 1 (11) Etching Conditions for Fission Fragments

Note: Because of chemical variations within most minerals, glasses, or plastics of a given type, optimum conditions may vary somewhat from those given. Only the preferred etchant is listed.

A. ETCHANTS FOR MINERALS

Mineral	Etching Conditions	Reference
allanite $[H_2O{\cdot}4(Ca,Fe)O{\cdot}3(Al,Fe)_2O_3{\cdot}6SiO_2]$	50N NaOH, 2-60 min, 140°C	Naeser and Dodge (1969)
apatite $[Ca_5(F,Cl)(PO_4)_3]$	0.25% HNO_3, ~1 min, 23°C, or olivine etch without oxalic acid	Bhandari et al. (1971b) Lal (unpub.)
aragonite ($CaCO_3$)	same as for calcite	
autunite $[Ca(UO_2)_2P_2O_8{\cdot}8H_2O]$	10% HCl, 10-30 sec, 23°C	Fleischer and Price (1964b)
barite ($BaSO_4$)	70% HNO_3, 3 h, 100°C	Fleischer and Price (1964b)
barysilite ($Pb_3Si_2O_7$)	glacial acetic acid, 5-70 sec, 23°C	Haack (1973)
bastnäsite ($CeFCO_3$)	20% HCl, 20-150 min, 155°C	Fleischer and Naeser (1972)
benitoite ($CaTiSi_3O_9$)	1 ml 40% HF:1 ml 65% HNO_3, 5 min, 230°C	Haack (1973)
beryl ($Be_3Al_2Si_6O_{18}$)	19N KOH, 9 h, 150°C	Fleischer and Price (1964b)
bismutite ($Bi_2O_3{\cdot}CO_2{\cdot}H_2O$)	1g NaOH:1g H_2O, 50 min, 140°C	Fleischer, Price and Woods (unpub.)
brewsterite $[(Sr,Ba,Ca)O{\cdot}Al_2O_3{\cdot}6SiO{\cdot}5H_2O]$	2 ml 48% HF:1 ml 95% H_2SO_4: 4 ml H_2O, 3 sec, 230°C	Haack (1973)
calcite ($CaCO_3$)	olivine etch with NaOH added for pH 12, 30 min, 23°C	Lal (unpub.)
celsian ($BaAl_2Si_2O_8$)	19N NaOH, 20 min, boiling	Haack (1973)
cerussite ($PbCO_3$)	glacial acetic acid, 10-30 min, 23°C	Fleischer et al. (1965a)
chlorite $[(Mg,Fe)_5(Al,Fe)_2Si_3O_{10}(OH)_8]$	48% HF, 10 min, 23°C	Debeauvais et al. (1964)
clinopyroxene [augite, $Ca(Mg,Fe,Al)(Al,Si)_2O_6$]	2 ml 48% HF: 1 ml 80% H_2SO_4: 4 ml H_2O, 5-20 min, 23°C	Crozaz et al. (1970)
	3 g NaOH: 2 g H_2O, 90 min, boiling	Lal et al. (1968)
clinopyroxene [diopside, $CaMgSi_2O_6$]	3 g NaOH: 2 g H_2O, 80 min, boiling	Lal et al. (1968)
clinopyroxene [pigeonite, $((Mg,Fe)SiO_3)_x$ $-(CaMg(SiO_3)_2)_{1-x}$]	3 g NaOH: 2 g H_2O, 80 min, boiling	Lal et al. (1968)
cryolite (Na_3AlF_6)	50% HI, 3 min, 23°C	Haack (1973)

ตารางที่ 1 (ต่อ)

Mineral	Etching Conditions	Reference
epidote [$Ca_2(Al,Fe)_3(SiO_4)_3OH$	50N NaOH, 0.5-2 h, 140°C	Naeser and Dodge (1969)
eulytite [$Bi_4(SiO_4)_3$]	5% HCl, 60 sec, 23°C 33% HNO_3, 15 min, 23°C	Fleischer, Price and Woods (unpub.) Haack (1973)
feldspar [albite, $NaAlSi_3O_8$]	3 g NaOH: 4 g H_2O, 85 min, boiling	Lal et al. (1968)
feldspar [anorthite, $CaAl_2Si_2O_8$]	3 g NaOH: 4 g H_2O, 14 min, boiling	Lal et al. (1968)
feldspar [bytownite, An_8Ab_2]	3 g NaOH: 4 g H_2O, 19 min, boiling	Lal et al. (1968)
feldspar [labradorite, An_6Ab_4]	3 g NaOH: 4 g H_2O, 40 min, boiling	Lal et al. (1968)
feldspar [microcline; orthoclase, $KAlSi_3O_8$]	5 g KOH: 1 g H_2O, 80 min, 190°C	Fleischer, Price and Woods (unpub.)
feldspar [oligoclase, An_2Ab_8]	3 g NaOH: 4 g H_2O, 75 min, boiling	Lal et al. (1968)
fluorite (CaF_2)	98% H_2SO_4, 10 min, 23°C	Fleischer and Price (1964b)
garnet [pyrope, $Mg_3Al_2(SiO_4)_3$]	50N NaOH, 0.5-2 hr, 140°C	Naeser and Dodge (1969)
garnet [almandine-pyrope, $(Fe_{1-x}Mg_x)_3 \cdot Al_2(SiO_4)_3$]	5 to 30 min 50N NaOH, boiling	Haack and Gramse (1972)
garnet [spessartine, $Mn_3Al_2(SiO_4)_3$]	10 min, 50N NaOH, boiling	Haack and Gramse (1972)
garnet [andradite-grossular; $Ca_3(Fe_{1-x}Al_x)_2 \cdot (SiO_4)_3$]	1 to 6 h, 75N NaOH, boiling	Haack and Gramse (1972)
gillespite ($FeO \cdot BaO \cdot 4SiO_2$)	19 N NaOH, 12 min, boiling	Haack (1973)
glass (see separate list of etchants for glasses)		
gypsum ($CaSO_4 \cdot 2H_2O$)	5% HF, 5-10 sec, 23°C	Fleischer and Price (1964b)
halite (NaCl)	1 g/ℓ $HgCl_2$ in ethanol, 30 sec, 23°C†	Komarov (unpub.)
harmotome [$Ba_5(NaK)Al_{11}Si_{29}O_{80} \cdot 25H_2O$]	2.4% HF, 30 sec, 23°C	Haack (1973)
hardystonite ($Ca_{1.99}Pb_{.01}ZnSi_2O_7$)	1 g NaOH: 1 g H_2O, 20-70 min, 140°C	Price et al. (1970b)
heulandite [a zeolite, $(Ca,Na_2)O \cdot Al_2O_3 \cdot 9SiO_2 \cdot 6H_2O$]	10 ml aqua regia: 1 ml 48% HF, 30 sec, 23°C	Fleischer (unpub.)
huebnerite ($MnWO_4$)	5 g NH_4Cl: 5 g $Na_4P_2O_7$: 5 ml H_3PO_4: 20 ml H_2O, 110 min, boiling	Haack (1973)
kleinite [$Hg_2N(Cl,SO_4) \cdot nH_2O$]	37% HCl, 7 min 23°C	Fleischer, Price and Woods (unpub.)
leuchtenbergite (low-iron clinochlore)	49% HF, 10 min, 23°C	Debeauvais et al. (1964)
lithium fluoride (LiF)	H_2O + .13 gm/liter LiF + 0.5 ppm Fe, ~1 min, 23°C†	Johnston (unpub.)
margarite [$CaAl_4Si_2O_{10}(OH)_2$]	48% HF, 2 min, 23°C	Fleischer and Price (1964b)
mica [biotite, $K(Mg,Fe)_3AlSi_3O_{10}(OH)_2$]	20% HF, 1-2 min, 23°C	Price and Walker (1962a)
mica [lepidolite; zinnwaldite, $K_2Li_3Al_4Si_7O_{21}(OH,F)_3$]	48% HF, 3-70 sec, 23°C	Fleischer and Price (1964b)
mica [muscovite, $KAl_3Si_3O_{10}(OH)_2$]	48% HF, 10-40 min, 23°C	Price and Walker (1962a)
mica (phlogopite; lepidomelane, $KMg_2Al_2Si_3O_{10}(OH)_2$]	48% HF, 1-5 min, 23°C	Price and Walker (1962a)
microlite ($Ca_2Ta_2O_7$)	1 ml 48% HF; 1 ml 65% HNO_3, 6 min, 23°C	Haack (1973)
mimetite [$Pb_5Cl(AsO_4)_3$]	33% HNO_3, 3 sec, 23°C (10$\bar{1}$0 planes)	Haack (1973)
monazite [$(Ce,La,Th)(PO_4, SiO_4)$]	98% H_2SO_4, 6-8 min, 23°C †	Muralli and Rajan (unpub.)

ตารางที่ 1 (ต่อ)

Mineral	Etching Conditions	Reference
mullite ($Al_6Si_2O_{13}$)	25N NaOH, 100°C, 4-5 h	Fleischer (unpub.)
nasonite [$Pb_4(PbOH)_2Ca_4(Si_2O_7)_3$]	1 g NaOH: 1 g H_2O, 10 min, 137°C	Fleischer, Price and Woods (unpub.)
nickel chloride; nickel bromide ($NiCl_2$, $NiBr_2$)	air (40% humidity), 10 min, 20°C (submicroscopic)	Caspar (1964)
olivine [$(Mg,Fe)_2SiO_4$]	1 ml H_3PO_4: 1 g oxalic acid: 40 g EDTA: 100 ml H_2O: ~4.5 g NaOH*, 2-3 h, 125°C (or 6 h, 95°C)	Krishnaswami et al. (1971)
orpiment (As_2S_3)	0.25N NaOH, 10-15 min, 23°C	Perelygin and Otgonsuren (unpub.)
orthopyroxene [bronzite, $Mg_{1-f}Fe_fSiO_3$, (.1<f<.2)]	3 g NaOH: 2 g H_2O, 40 min, boiling	Lal et al. (1968)
orthopyroxene [enstatite, $MgSiO_3$]	3 g NaOH: 2 g H_2O, 35 min, boiling	Lal et al. (1968)
orthopyroxene [ferrohypersthene, $Mg_{1-f}Fe_fSiO_3$, f>.5]	3 g NaOH: 2 g H_2O, 70 min, boiling	Lal et al. (1968)
orthopyroxene [hypersthene, $Mg_{1-f}Fe_fSiO_3$, (.2<f<.5)]	3 g NaOH: 2 g H_2O, 42 min, boiling	Lal et al. (1968)
pennine (a chlorite)	48% HF, 5 min, 23°C	Fleischer and Price (1964b)
pollucite ($H_2O{\cdot}2Cs_2O{\cdot}2Al_2O_3{\cdot}9SiO_2$)	5-8% HF, 55 sec, 23°C	Haack (1973)
pucherite ($BiVO_4$)	5% HCl, 90 sec, 23°C	Fleischer, Price and Woods (unpub.)
pyromorphite ($Pb_5Cl(PO_4)_3$)	33% HNO_3, 5 sec, 23°C, on $(10\bar{1}0)$ planes)	Haack (1973)
quartz (SiO_2)	KOH(aq), 3 h, 150°C, or 48% HF, 24 h, 23°C	Fleischer and Price (1964b)
raspite ($PbWO_4$)	6.25N NaOH, 4 min, 23°C	Fleischer, Price, and Woods (unpub.)
sanbornite ($BaSi_2O_5$)	19N NaOH, 60 min, boiling	Haack (1973)
scheelite ($CaWO_4$)	6.25N NaOH, 90 min, 95°C	Fleischer, Price, and Woods (unpub.)
sphene ($CaTiSiO_5$)	conc HCl, 0.5-1.5 h, 90°C 6N NaOH, 20-30 min, 130°C	Naeser and Faul (1969) Calk and Naeser (1973)
spodumene ($LiAlSi_2O_6$)	48% HF, 24 h, 23°C	Fleischer and Price (1964b)
stilbite [$(Ca,Na_2)O{\cdot}Al_2O_3{\cdot}6SiO_2{\cdot}6H_2O$), a zeolite]	1% HF, 60 sec, 23°C	Fleischer (unpub.)
stibiotantalite [$(SbO)_2(Ta,Nb)_2O_6$]	1 ml 48% HF: 1 ml 65% HNO_3, 6 min, 23°C	Haack (1970)
talc [$Mg_3Si_4O_{10}(OH)_2$]	48% HF, 15 min, 23°C	Walker (1963)
thorite ($ThSiO_4$)	H_3PO_4, 1 min, 250°C	Fleischer et al. (1965a; 1966b)
torbernite [$Cu(UO_2)_2P_2O_8{\cdot}12H_2O$]	10% HCl, 10 min, 23°C	Fleischer et al. (1965a)
tridymite (SiO_2)	10% HF, 1 h, 23°C	Fleischer et al. (1965a)
topaz [$Al_2SiO_4(F,OH)_2$]	KOH(aq), 100 min, 150°C	Fleischer and Price (1964b)
tourmaline (complex silicate)	KOH(aq), 20 min, 220°C	Fleischer and Price (1964b)
vanadinite [$Pb_5Cl(VO_4)_3$]	33% HNO_3; 1 sec, 23°C	Haack (1973)
vermiculite (biotite-derived)	48% HF, 5-10 sec, 23°C	Fleischer and Hart (unpub.)
whitlockite [$Ca_3(PO_4)_2$]	0.25% HNO_3, 10 sec to 2 min, 23°C, or olivine etch without oxalic acid	Fleischer et al. (1965a) Lal (unpub.)

ตารางที่ 1 (ต่อ)

Mineral	Etching Conditions	Reference
willemite (Zn_2SiO_4)	33% HNO_3, 10 sec, 23°C	Haack (1973)
zircon ($ZrSiO_4$)	H_3PO_4, few sec, 375-500°C, or NaOH(aq), .25 to 5 h, 220°C, or 2 ml 48% HF: 1 ml 80% H_2SO_4 at 180°C in a pressure bomb	Fleischer et al. (1964a) Naeser (1969) Krishnaswami et al. (1973)

*to adjust pH to 8.0; † shallow pits

B. ETCHANTS FOR GLASSES

Type	Etching Conditions (at 23°C if not otherwise noted)	Reference
alumino-silicate (Corning 1720)	5.7% HF, 6 min	Fleischer and Hart (1972c)
andesitic glass ($Ab_{60}An_{40}$)	5% HF, 3-5 min 29% HBF_4: 5% HNO_3: 0.5% acetic acid, 50 min	Fleischer et al. (1969a) Macdougall (1971)
basaltic glass	20% HF, 1 min 25% HBF_4; 5% HNO_3; 0.5% acetic acid, 10 min	Fleischer et al. (1968b) Macdougall (1971)
borate glass	H_2O, 1 min	Fleischer and Price (1963b)
flint (lead-silicate) glass	5.7% HF, 3 min	Fleischer et al. (1971a)
germania glass (GeO_2)	48% HF, 6 sec	Fleischer (unpub.)
lead phosphate glass	1 ml 70% HNO_3: 3 ml H_2O, 2-20 min	Lal (unpub.)
obsidian	48% HF, 30 sec	Fleischer and Price (1964c)
phosphate glass	48% HF, 5-20 min	Fleischer and Price (1963b)
pumice	5% HF, 500 sec	Fleischer et al. (1965e)
silica glass (fused quartz; Vycor; Libyan Desert Glass)	48% HF, 1 min	Fleischer and Price (1963b)
soda-lime (microscope slide; cover slip; window glass)	48% HF, 5 sec (better: 5% HF, 2 min) 24% HBF_4: 5% HNO_3: 0.5% acetic acid, 1 h	Fleischer and Price (1963b) Macdougall (1971)
tektite	48% HF, 30 sec 24% HBF_4: 5% HNO_3: 0.5% acetic acid, 90 min	Fleischer and Price (1964a) Macdougall (1971)
uranium-soda glass	48% HF, 5 sec	Brill et al. (1964)
uranium phosphate glass	50% HF, 30 min	Hart (unpub.)
$V_2O_5 \cdot (P_2O_5)_5$ (semiconducting)	48% HF, 10 sec	Fleischer et al. (1965d)

C. ETCHANTS FOR PLASTICS

Plastic (Trade Names)	Etching Conditions	Reference
amber	30 g $K_2Cr_2O_7$: 50 ml conc. H_2SO_4, 40 h, 28°C	Uzgiris and Fleischer (1971)
cellulose acetate (Kodacel; Triafol T; Cellit)†	1 ml 15% NaClO: 2 ml 6.25N NaOH, 1 h, 40°C	Price et al. (1971)
	25 g NaOH: 20 g KOH: 4.5 g $KMnO_4$: 90 g H_2O, 2-30 min, 50°C	Somogyi et al. (1968)
cellulose acetate butyrate†	6.25N NaOH, 12 min, 70°C	Fleischer et al. (1965d)
cellulose nitrate (Diacell; Nixon-Baldwin)†	6.25N NaOH, 2-4 h, 23°C	Fleischer et al. (1965b)

ตารางที่ 1 (ต่อ)

Plastic (Trade Names)	Etching Conditions	Reference
cellulose propionate (Cellidor)	28% KOH, 100 min, 60°C	Becker (1969)
cellulose triacetate (Kodacel TA401, unplasticized; Bayer TN)†	1 ml 15% NaClO: 2 ml 6.25N NaOH, 1 h, 40°C	Price et al. (1970a)
dimethyl siloxane (crosslinked)	25N NaOH, 3 min, 115°C	Fleischer and Bergeron (unpub.)
formophenol (ambrolithe, phenoplaste)	6N NaOH, 1 h, 40°C; 48% HF, 30 sec, 40°C, in sequence	Monnin et al. (1966)
HBpaIT (polyester, $C_{17}H_9O_2$)	6.25N NaOH, 8 min, 70°C	Fleischer et al. (1965a)
ionomeric polyethylene (Surlyn)†	10 g $K_2Cr_2O_7$: 35 ml 30% H_2SO_4, 1 h 50°C	Besson et al. (1967)
polyamide (H-Film)	$KMnO_4$ (25% aq), 1.5 h, 100°C	Besson et al. (1967)
	6N NaOH solution	Fleischer (unpub.)
polyimide	$KMnO_4$ in H_2O	Monnin and Isabelle (1970)
poly 1-4 butylene terephthalate	1 ml 6.25N NaOH: 1 ml ethanol, 24 h, 23°C	Fleischer (unpub.)
polycarbonate (Lexan; Makrofol; Merlon; Kimfol)†	6.25N NaOH, 20 min, 50°C	Fleischer and Price (1963a)
	6.25N NaOH + 0.4% Benax*, 20 min, 70°C	Price et al. (1968a)
polyethylene	10 g $K_2Cr_2O_7$: 35 ml 30% H_2SO_4, 30 min, 85°C	Monnin et al. (1967)
polyethylene terephthalate (Mylar; Chronar; Melinex; Terphane)	6.25N NaOH, 10 min, 70°C	Fleischer and Price (1963a)
	$KMnO_4$ (25%, aq), 1 h, 55°C	Monnin et al. (1967)
polymethyl methacralate (Plexiglas; Lucite)†	sat. $KMnO_4$, 8 min, 85°C	Monnin et al. (1966)
polyoxymethylene (Delrin)	5% $KMnO_4$, 10 h, 60°C	Monnin et al. (1966)
polyphenoxide	$KMnO_4$, (25% aq), 4 min, 100°C	Besson et al. (1967)
polyphenylene oxide (PPO)	$KMnO_4$ aq., sat., 24 h, 93°C	Fleischer (unpub.)
polypropylene (Cryovac-Y)†	35 ml 30% H_2SO_4: 10 g, $Cr_2K_2O_7$, 5 min, 94°C	Besson et al. (1967)
polystyrene	sat. $KMnO_4$, 2.5 h, 85°C	Monnin et al. (1966)
	10 g $K_2Cr_2O_7$: 35 ml, 30% H_2SO_4, 3 h, 85°C	Monnin et al. (1967)
polyvinyl acetate (Formvar)	6.25N NaOH, 200 h, 23°C	Fleischer (unpub.)
polyvinylaceto-chloride	$KMnO_4$ (25% aq.) 30 min, 100°C	Besson et al. (1967)
polyvinylchloride	sat. $KMnO_4$, 2.5 h, 85°C	Monnin et al. (1966)
polyvinylidene chloride (Saran)	$KMnO_4$ (25% aq.), 2 h, 55°C	Besson et al. (1967)
polyvinyl toluene	$KMnO_4$, sat., aq., 30 min, 100°C	Fleischer and Price (unpub.)
silicone-polycarbonate copolymer	6.25N NaOH 20 min, 50°C	Fleischer et al. (1972b)
siloxane-cellulose copolymer	8N NaOH + ~0.1% Dowfax, 3 h, 85°C	Fleischer, Viertl and Holub (unpub.)

*Dow surfactant 2A1, Dowfax, Dow Corning; presaturated with etch products (Peterson, 1970).
†Tracks of low-energy alpha particles can be revealed by etching this plastic.

ประวัติผู้เขียน

นาย นเรศร์ จันทน์ขาว เกิดเมื่อวันที่ 4 ธันวาคม พ.ศ.2497 ที่จังหวัดพังงา สำเร็จปริญญาวิทยาศาสตรบัณฑิต สาขาวิทยาศาสตร์ทั่วไป จากมหาวิทยาลัยเกษตร-ศาสตร์ เมื่อปี พ.ศ.2518 และได้รับประกาศนียบัตรชั้นสูง สาขาวิชานิวเคลียร์เทคโนโลยี่ จากบัณฑิตวิทยาลัย จุฬาลงกรณ์มหาวิทยาลัย เมื่อปี พ.ศ.2520 ระหว่างศึกษาระดับปริญญามหาบัณฑิต ได้รับทุนอุดหนุนการศึกษา "ผู้ช่วยสอน" จากบัณฑิตวิทยาลัย จุฬาลงกรณ์มหาวิทยาลัย เป็นเวลา 24 เดือน