

Figure 2-11 (a) Densities of some common igneous compositions in the liquid state as functions of temperature. (b) Variations of density (above) and viscosity (below) of the three main types of magmas as they evolve toward more felsic compositions. The differences result mainly from their differing rates

of enrichment of silica, iron, and alkalis. The curves for tholeiites are based on lavas of Hawaii and the Galapagos Islands. The calc-alkaline curves are for rocks of the Cascade Range, and the alkaline ones are for the phonolitic series of Tahiti.

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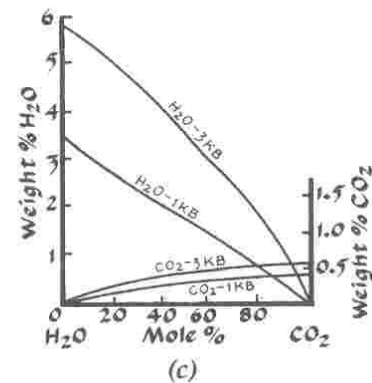
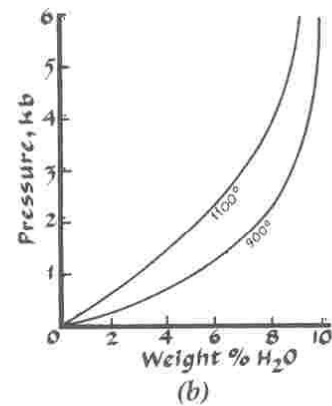
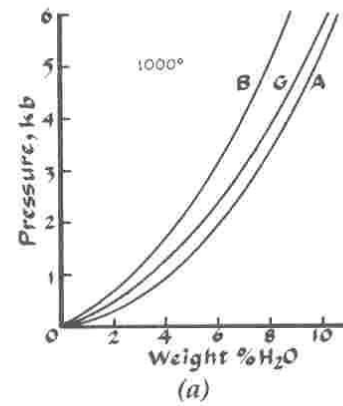


Figure 2-5 The solubility of volatiles in magmas is a function of pressure, temperature, and the compositions of the liquids and gases. (a) shows the solubility of H_2O in basalt (B), granite (G), and andesite (A), all at $1,100^\circ C$, as a function of pressure of H_2O . Note that although the three compositions have about the same solubilities at the same temperature, the three types of magmas are liquid at very different temperatures, and their solubilities under natural conditions will differ accordingly. As shown in (b), the solubility in granite increases with falling temperature; basalt and andesite show similar effects. Hence natural basalts have the lowest solubility as natural liquids and granites the highest. The pressure of another gas, such as CO_2 , decreases the solubility of H_2O . (c) shows solubilities in a basaltic melt at $1,200^\circ C$ and two different total pressures, one and three kilobars. [Data from Hamilton and Anderson, 1967, *Basalts* 1:445-482; Goranson, 1931, *Amer. J. Sci.*, 22:481-502; and Kadik et al., 1972, *Geoch. Internat.*, 9:1041-1050.]

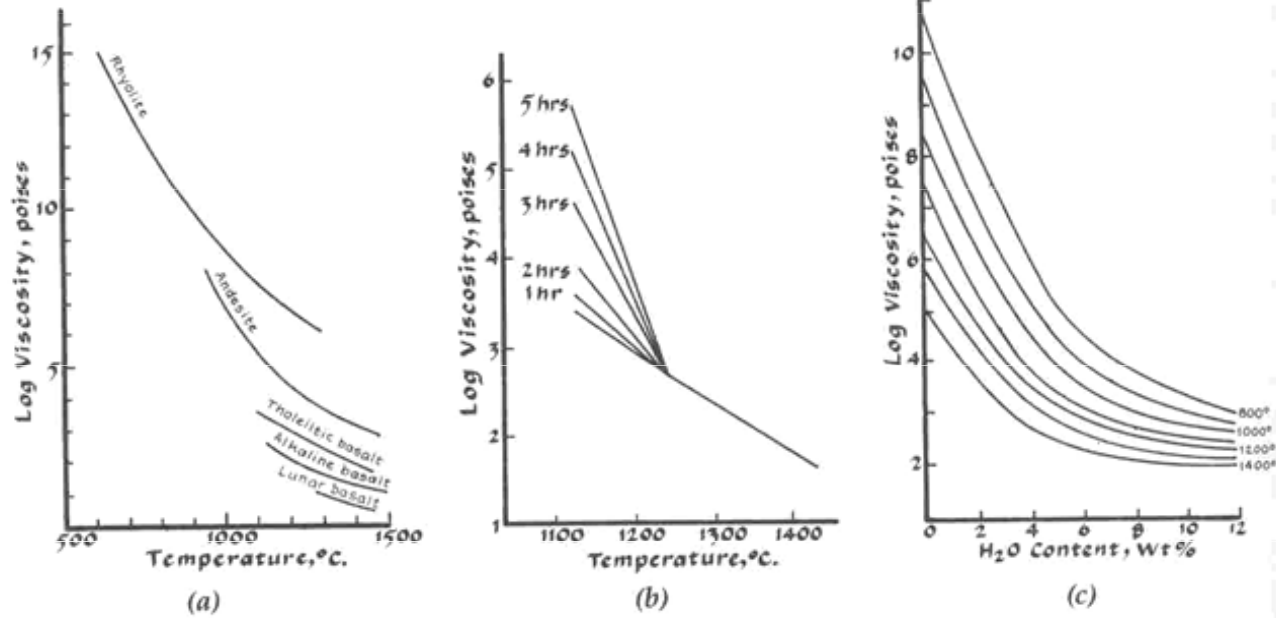
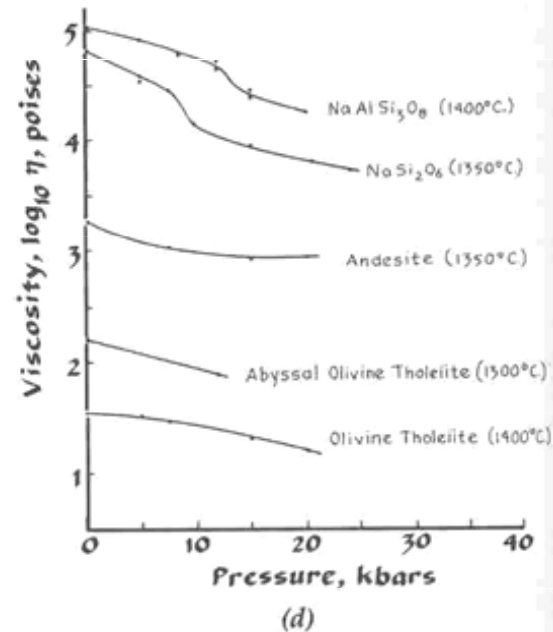
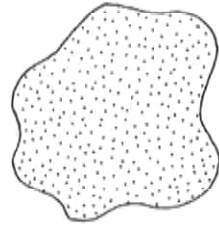
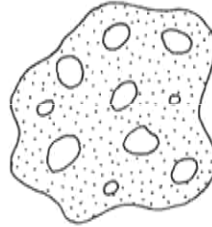


Figure 2-10 Viscosities of some common igneous melts (a) as functions of temperature in and above the melting range. (b) shows the increase in viscosity of a basalt after cooling for different periods of time. The inflection point is close to the temperature at which the basalt begins to crystallize. The effect of water on viscosity is illustrated by the example of a granitic liquid shown in (c). The effect of pressure is to reduce the viscosity of most silicate melts (d). [a, b, and c are from Murase and McBirney, 1973, *Geol. Soc. Amer. Bull.*, 84:3563-3592. d is from Scarfe, Mysen, and Virgo, 1987, *Geoch. Soc. Spec. Publ. No. 1*, 59-67.]

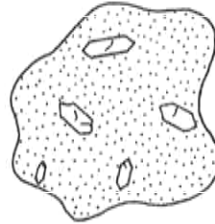




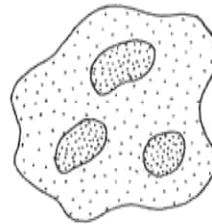
Single-phase system
Melt only that
generally contains
dissolved volatiles



Two-phase system
Melt plus bubbles
of volatile fluid



Two-phase system
Melt plus crystals
of olivine

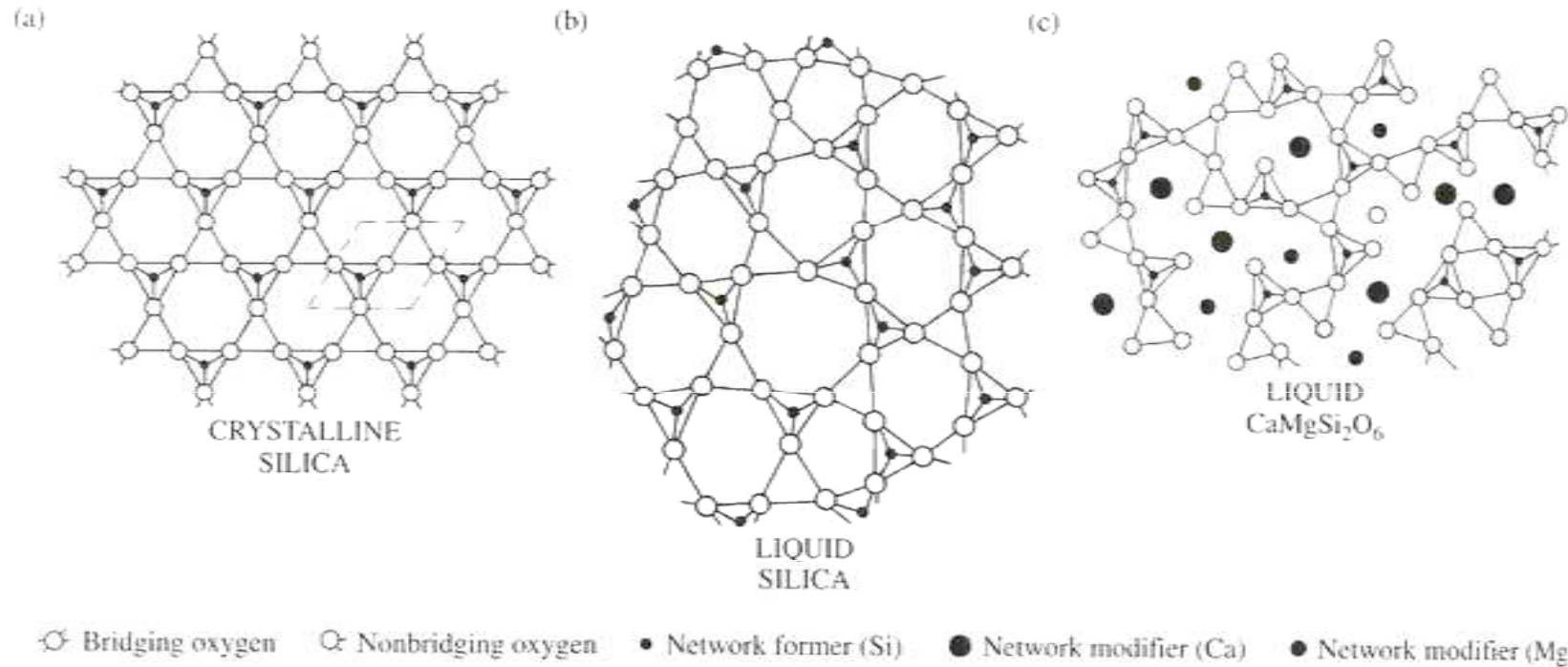


Two-phase system
Two immiscible
melts of different
composition

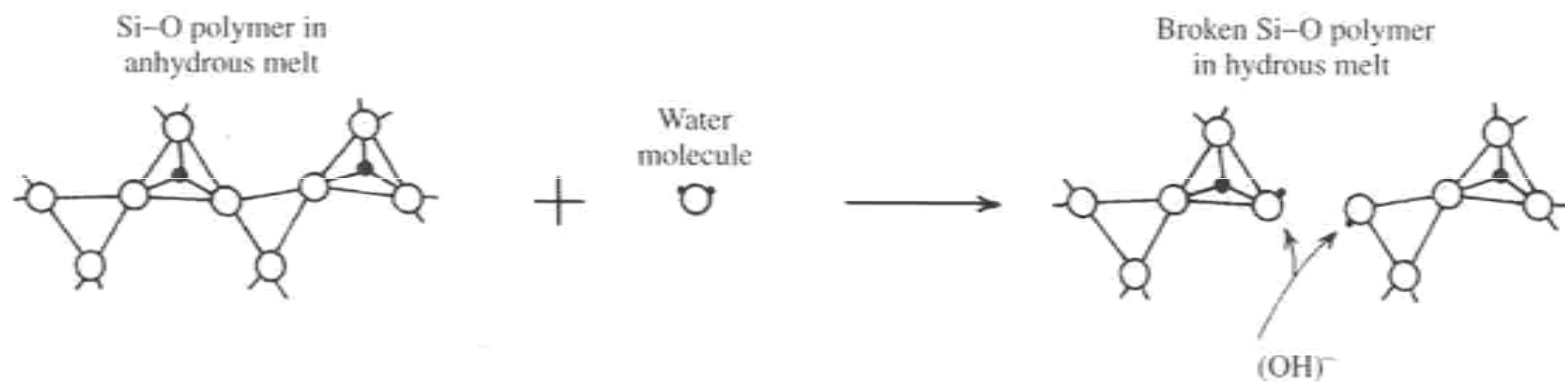


Four-phase system
Melt plus bubbles
of volatile fluid and
crystals of olivine
and plagioclase

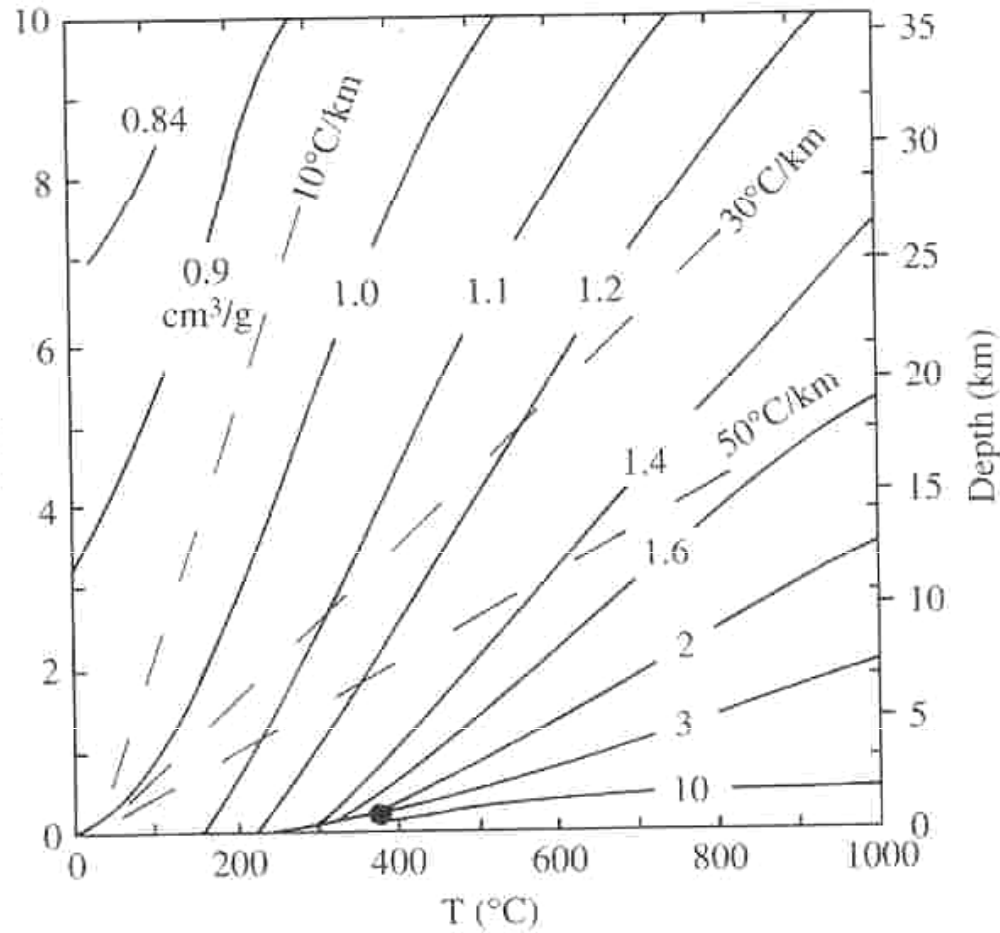
4.1 Schematic possible magmas.



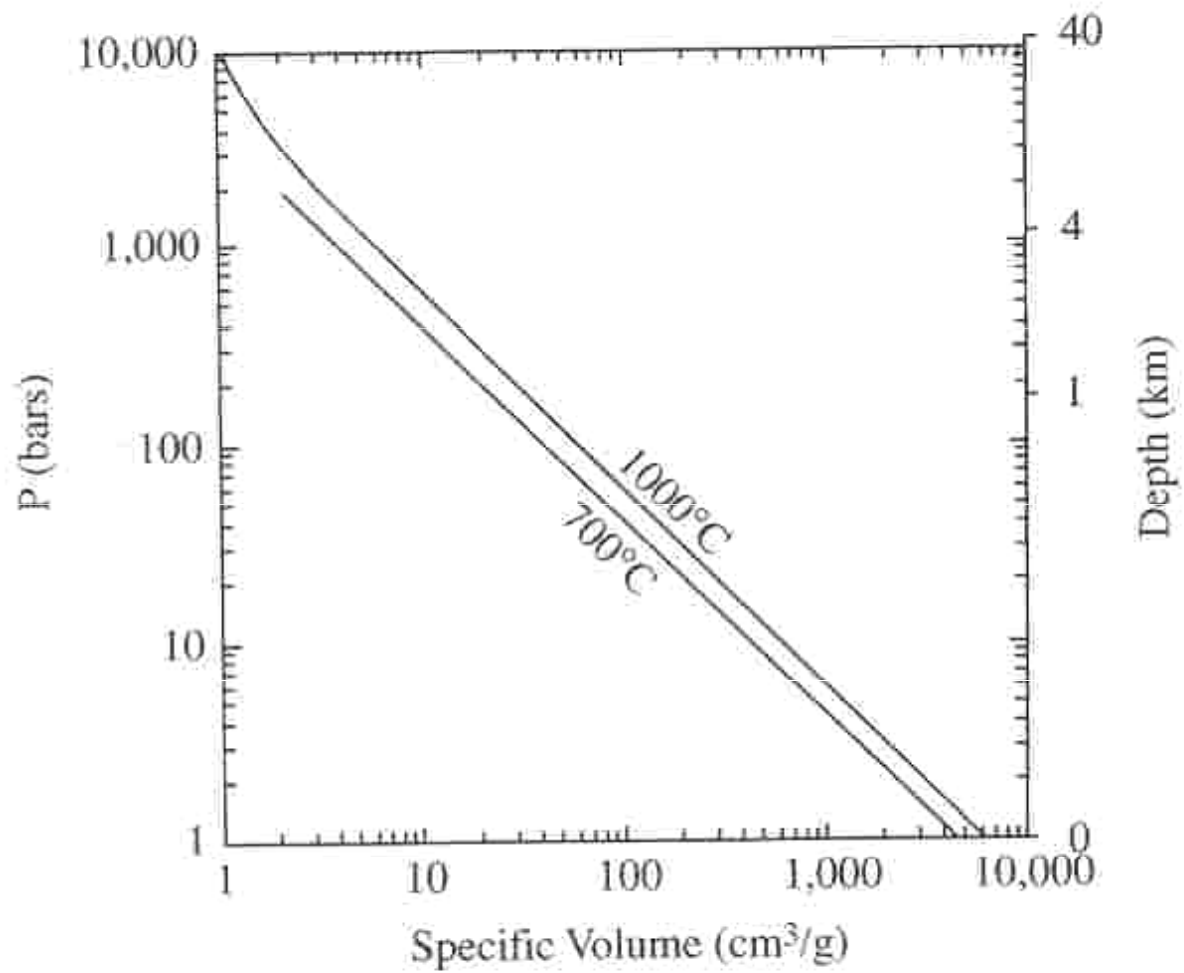
- 4.2 Conceptual models of atomic structures of silicate melts compared with the symmetric lattice of a crystalline solid. (a) Crystalline silica (high tridymite). Layers of hexagonal rings of Si-O tetrahedra with alternating apices pointing up and down are stacked on top of one another, creating a three-dimensional structure in which each oxygen is shared by two silicons. Tetrahedra with apices pointing up have the upper apical oxygen left out of the drawing so as to reveal underlying silicon. Dashed line indicates outline of one unit cell in the lattice. (b) Model of liquid silica. Si-O tetrahedra are slightly distorted relative to the crystalline lattice. Long-range order is absent. Structure is highly polymerized because all tetrahedra are interconnected by bridging oxygen anions. (c) Model of liquid $\text{CaMgSi}_2\text{O}_6$ showing less polymerization than that of liquid silica. Note presence of network-modifying cations (Ca and Mg) and nonbridging oxygen, neither of which occurs in the silica melt. (Redrawn from Carmichael et al., 1974, p. 133.)



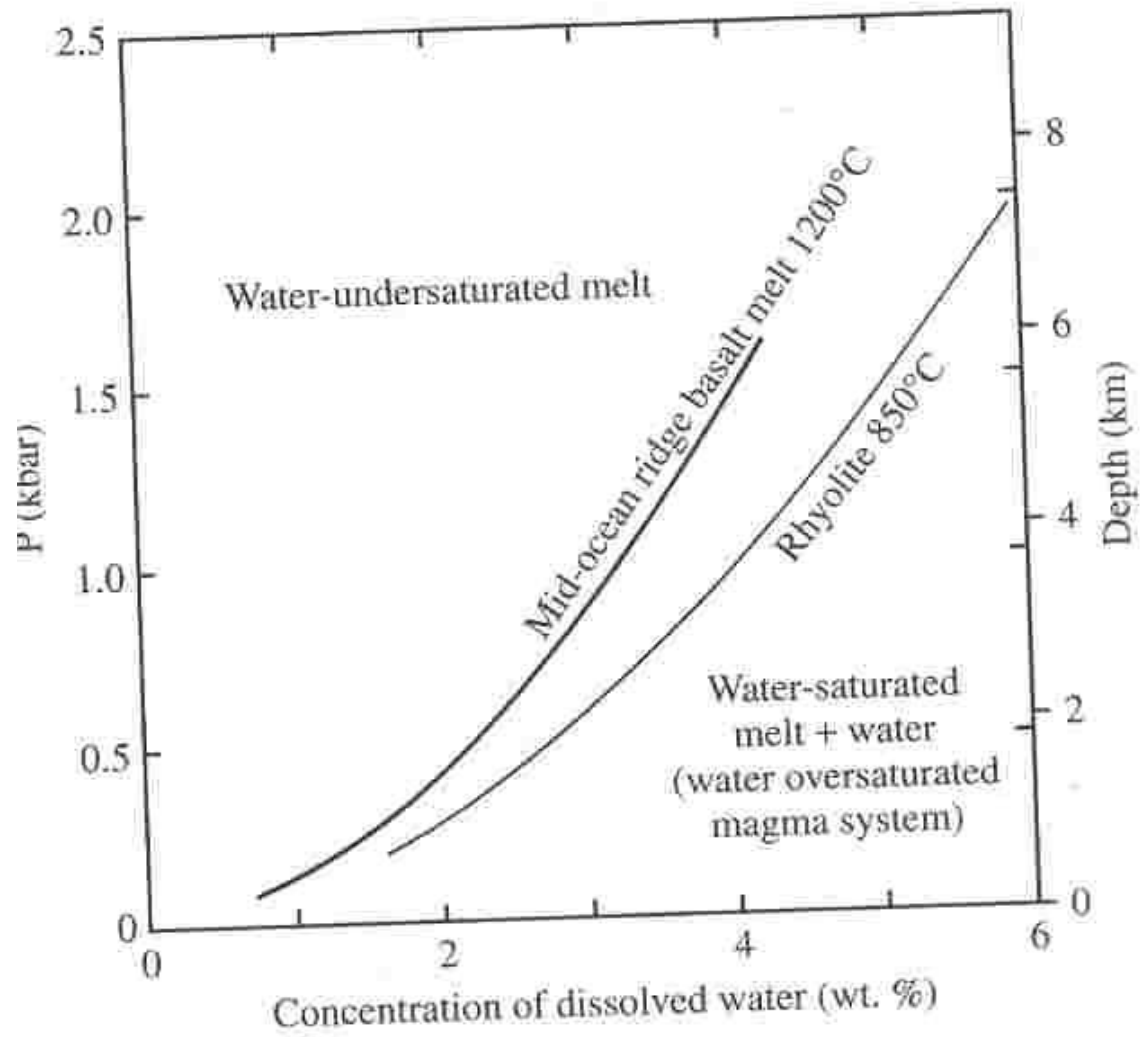
4.8 Some dissolved water in silicate melts forms hydroxyl ions, $(OH)^-$, which break O-Si-O polymers, reducing the degree of polymerization.



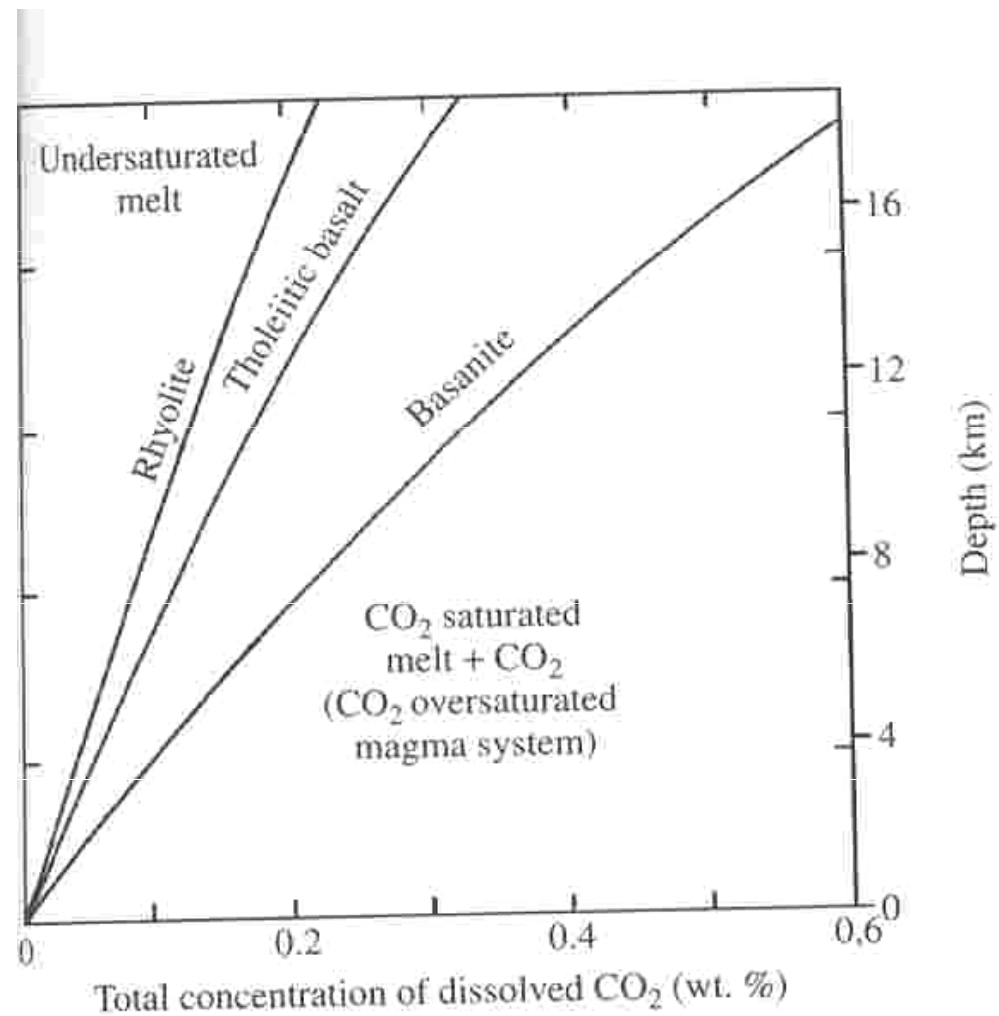
- 3 Specific volume (cubic centimeters per gram) of pure water as a function of P and T . For reference, geothermal gradients of 10°C , 30°C , and $50^{\circ}\text{C}/\text{km}$ are shown as dashed lines. Filled circle is the critical point of pure water. (Data from Burnham et al., 1969.)



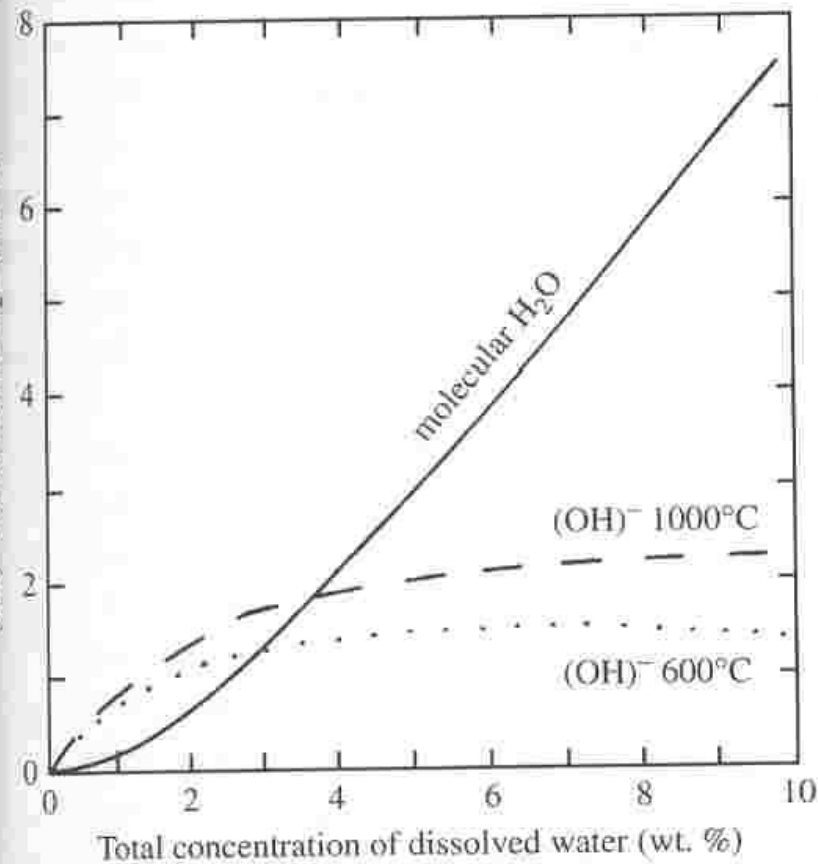
- 4.4 Specific volume of pure water as a function of P (and depth) for two temperatures.



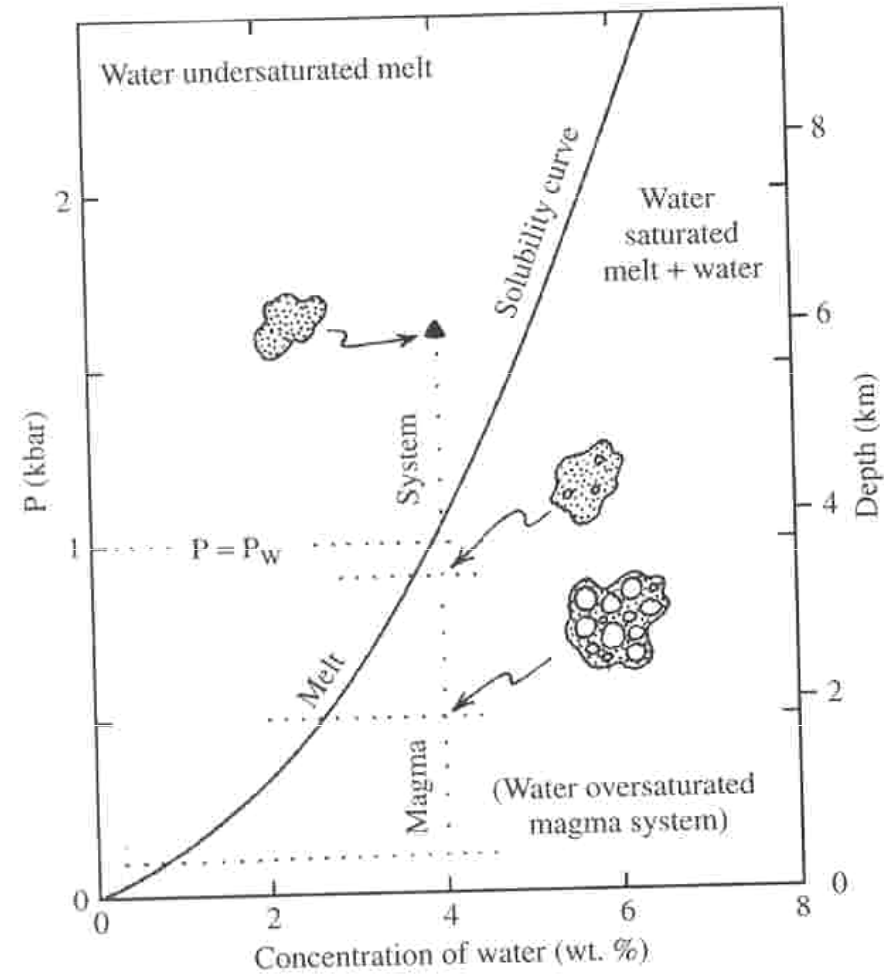
4.7 Solubility of water in silicate melts. (Redrawn from Moore et al., 1998.)



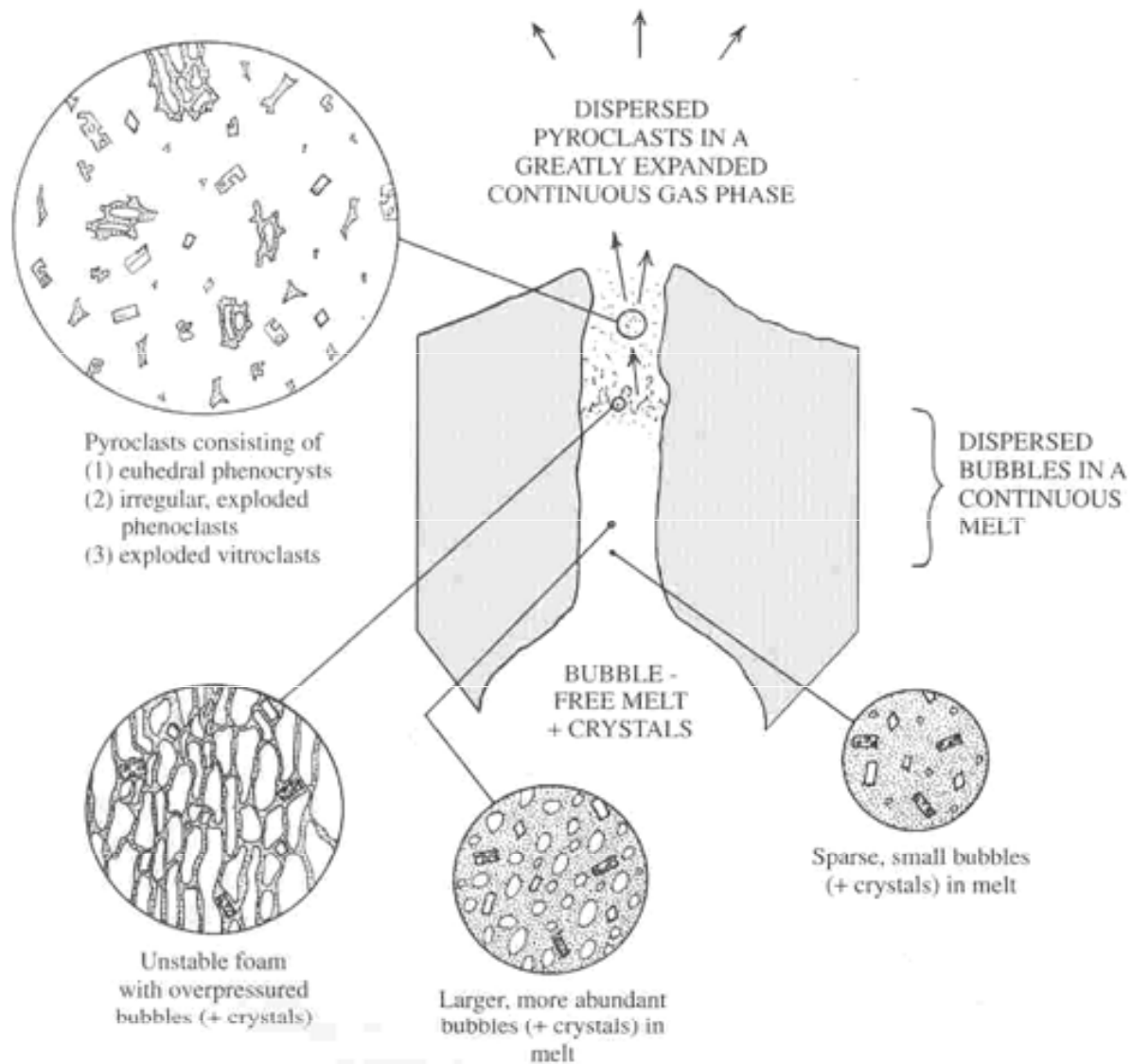
Solubility of carbon dioxide in some silicate melts. Note that more CO₂ can dissolve in less polymerized mafic and especially silica-undersaturated melts. (From Holloway and Blank, 1994.)



Dissolved water in rhyolitic melts exists in ionic, $(\text{OH})^-$, and molecular, H_2O form. The concentration of $(\text{OH})^-$ is dependent upon T but molecular H_2O concentration is independent of T . For example, in a melt at 1000°C that contains 4 wt.% total water, about half is dissolved as $(\text{OH})^-$ ions and half as molecular H_2O . For a 1000°C melt containing 2 wt.% total water, about 1.5 wt.% is dissolved as $(\text{OH})^-$ and 0.5 wt.% as molecular H_2O . (From Silver et al., 1990.)



4.11 Evolution of a hypothetical closed magma system during decompression from an initially water-undersaturated state. The initial magma is a crystal- and bubble-free melt at 1.6 kbar, corresponding to a depth of 6 km, and contains 4 wt.% dissolved water and no other volatiles.



Schematic cross section through the volcanic conduit of an exploding magma system. Circular diagrams are "snapshots" of the state of the expanding magma as a function of depth and P in the conduit. Because of limitations of the diagram area, the hundreds-fold expansion of the volatile fluid phase cannot be accurately represented.

Table 2-2 Average Chemical and Mineral Compositions of Selected Plutonic Rocks

	Chemical composition									
	Granite	Syenite	Granodiorite	Quartz Diorite	Diorite	Gabbro	Olivine Diabase	Diabase	Dunite	Lherzolite (Peridotite)
SiO ₂	70.18	60.19	65.01	61.59	56.77	48.24	48.54	50.48	40.49	43.95
TiO ₂	0.39	0.67	0.57	0.66	0.84	0.97	1.31	1.45	0.02	0.10
Al ₂ O ₃	14.47	16.28	15.94	16.21	16.67	17.88	15.24	15.34	0.86	4.82
Fe ₂ O ₃	1.57	2.74	1.74	2.54	3.26	3.16	3.06	3.84	2.84	2.20
FeO	1.78	3.28	2.65	3.77	4.40	5.95	8.88	7.78	5.54	6.34
MnO	0.12	0.14	0.07	0.10	0.13	0.13	0.21	0.20	0.16	0.19
MgO	0.88	2.49	1.91	2.80	4.17	7.51	8.08	5.79	46.32	36.81
CaO	1.99	4.30	4.42	5.38	6.74	10.99	9.38	8.94	0.70	3.57
Na ₂ O	3.48	3.98	3.70	3.37	3.39	2.55	2.69	3.07	0.10	6.63
K ₂ O	4.11	4.49	2.75	2.10	2.12	0.89	0.98	0.97	0.04	0.21
H ₂ O	0.84	1.16	1.04	1.22	1.36	1.45	1.35	1.89	2.88	1.08
P ₂ O ₅	0.19	0.28	0.20	0.26	0.25	0.28	0.28	0.25	0.05	0.10
Density	2.667	2.757	2.716	2.806	2.839	2.976	2.970	2.965	3.289	3.330
	Mineral composition									
Quartz	25	—	21	20	2	—	—	—	—	—
K Feldspar	40	72	15	6	3	—	—	—	—	—
Oligoclase	26	12	—	—	—	—	—	—	—	—
Andesine	—	—	46	56	64	—	—	—	—	—
Labradorite	—	—	—	—	—	65	63	62	—	—
Biotite	5	2	3	4	5	1	—	1	—	—
Amphibole	1	7	13	8	12	3	—	1	—	—
Orthopyroxene	—	—	—	1	3	6	—	—	2	15
Clinopyroxene	—	4	—	3	8	14	21	29	—	10
Olivine	—	—	—	—	—	7	12	3	95	71
Magnetite	2	2	1	2	2	2	2	2	2	1
Ilmenite	1	1	—	—	—	2	2	2	—	—
Apatite	tr	tr	tr	tr	tr	—	—	—	—	—
Sphene	tr	tr	1	tr	tr	—	—	—	—	—
Spinel	—	—	—	—	—	—	—	—	1	3

Source: After Daly and Larsen, *Geol. Soc. Am. Special Paper 36*, 1942 with modifications and reduced to 100%.

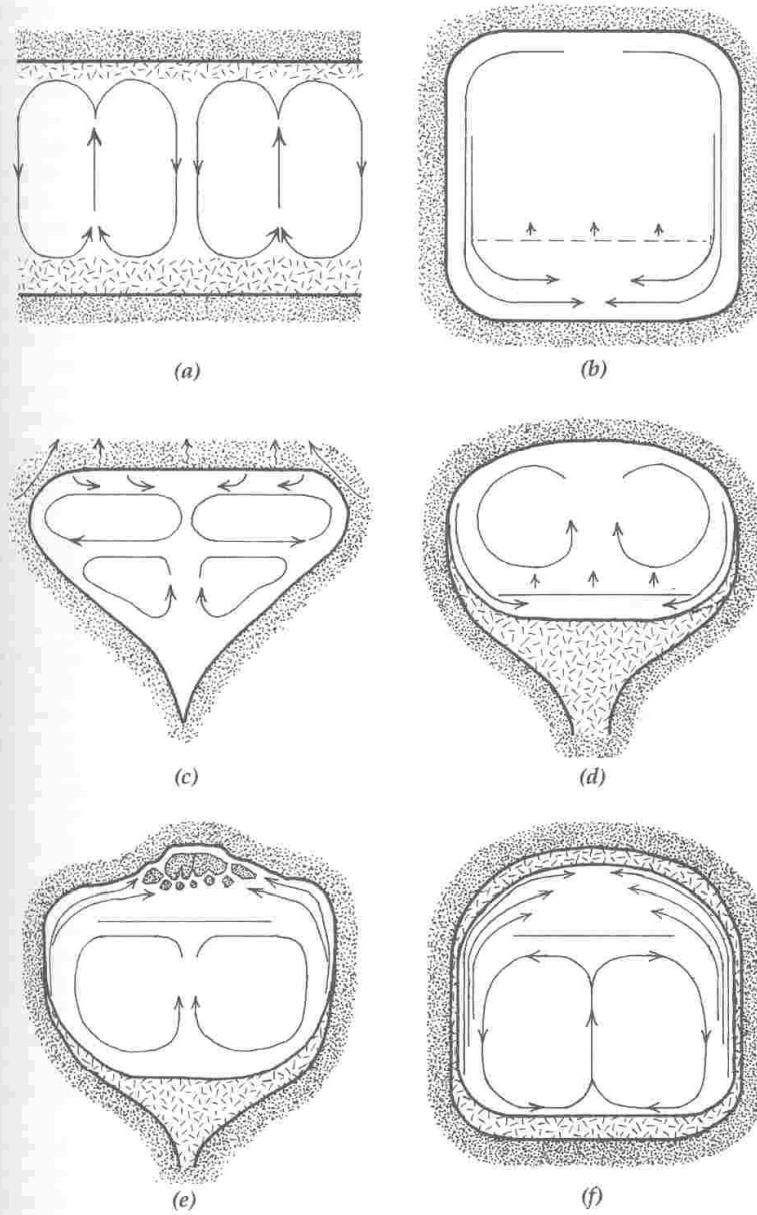


Figure 2-16 Different types of magmatic convection discussed in the text.

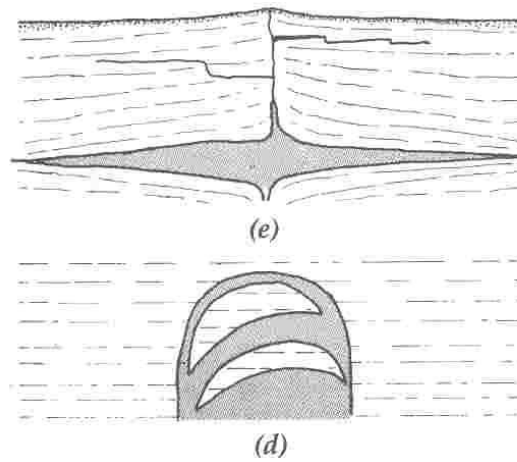


Figure 2-14 Magma generated in the mantle (a) is thought to rise when the buoyant mass of crystal-liquid mush becomes gravitationally unstable. It moves as plume-shaped diapirs through the plastic mantle (b) but on reaching more brittle rocks of the lithosphere, it may stope its way upward, either by dislodging blocks in a piecemeal fashion (c) or wedging its way upward in "bell-jar" shaped intrusions (d). At some stage in this sequence, the fluid part of the magma may separate from its crystalline residue. In the uppermost levels of the crust, magmas rise through dilational fractures that tend to become cylindrical conduits as they become established vents for surface eruptions (e).

