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THE ESCAPE OF PEGMATITE DIKES FROM GRANITIC PLUTONS: CONSTRAINTS FROM NEW MODELS OF VISCOSITY AND DIKE PROPAGATION

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ABSTRACT

The generation of pegmatite dikes during the cooling and crystallization of granitic plutons has been calculated using new models for the prediction of granitic melt viscosities and the propagation of dikes. These new models suggest that early in the cooling history of a modeled 10 × 10 × 10 km pluton, dikes cannot propagate, or will be short (on the order of 1 km), because the surrounding country-rocks have not yet been significantly heated. However, dikes formed tens to hundreds of thousands of years after intrusion can propagate up to approximately 10 km. Because the far-propagating dikes form late in the magmatic history of the pluton, they will be composed of chemically more evolved magmas than the bulk of the pluton and will crystallize as pegmatites. The model predicts that pegmatites should only rarely be found more than *ca.* 10 km from their host pluton, that more-evolved pegmatites should be found at greater distances from their host pluton than less-evolved ones, and that pegmatites should not be associated with small plutons. All of these model results are consistent with field observations, and support the petrogenetic relationship between granitic plutons and the evolved pegmatites surrounding them.

Keywords: granitic pegmatite, viscosity, silicate melt, thermal modeling, melt transport, dike propagation, granite pluton.

SOMMAIRE

La formation de filons de pegmatite granitique pendant le refroidissement et la cristallisation de plutons granitiques a fait l'objet de calculs fondés sur des modèles nouveaux permettant de prédire la viscosité d'un magma granitique et la propagation des filons. Ces modèles montrent qu'à un stade précoce du refroidissement d'un pluton typique mesurant 10 × 10 × 10 km, il est quasiment impossible pour des filons de se propager; s'ils sont développés, ils seront très courts, de l'ordre du kilomètre, parce que les roches encaissantes n'ont pas encore été suffisamment réchauffées. En revanche, les filons formés des dizaines ou des centaines de milliers d'années après la mise en place du pluton peuvent se propager jusqu'à environ 10 km de distance. On peut s'attendre qu'à cause de leur formation tardive, ce sont des magmas dont la composition est géochimiquement évoluée qui formeront ces filons, pour cristalliser sous forme de pegmatite. Selon le modèle, on ne devrait trouver que très rarement des filons de pegmatites au delà d'environ 10 km du pluton. De plus, les pegmatites géochimiquement plus évoluées devraient être plus distales que les pegmatites plus primitives. Enfin, on ne devrait pas trouver de tels filons autour d'un petit pluton. Toutes ces prédictions du modèle concordent avec les observations de terrain, et étayent la relation pétrogénétique entre plutons granitiques et le cortège de pegmatites évoluées qui les entoure.

(Traduit par la Rédaction)

Mots-clés: pegmatite granitique, viscosité, magma granitique, modèle thermique, transfert magmatique, propagation de filon, pluton granitique.

INTRODUCTION

Pegmatites associated with granitic plutons typically display regional zonation from less-evolved compositions near the parental pluton to more evolved (*e.g.*, F-, B-, Li-, Cs-, Rb-, P-rich) compositions further from the plutons (*e.g.*, Cameron et al. 1949, Heinrich 1953, Černý 1982a, b, 1992). The plutons commonly are assumed to be parental to the pegmatites; however, the low temperatures, 450–700°C (London 1992, 1996), and high viscosities expected of pegmatite-forming melts (Shaw 1972) makes their extraction from a granitic pluton near its solidus difficult, if not impossible. Although explanations of the regional zonation of pegmatite compositions have been advanced (*e.g.*, Černý 1992), they do not quantitatively account for the observed patterns.

Recently, several new models for the prediction of the viscosity of granitic melts have been created which better replicate measured viscosities at low H_2O

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contents, ≤ 4 wt%; these models demonstrate that the model of Shaw (1972) overestimates the viscosity of a granitic melt by up to a factor of 100 (Baker 1996, Hess & Dingwell 1996, Scaillet *et al.* 1996, Schulze *et al.* 1996), as shown using the model of Baker (1996, in press) in Figure 1. This revised model of melt viscosity is combined with a recent model for dike initiation and magma transport (Rubin 1995) to constrain the conditions under which batches of pegmatite-forming melts in dike-like bodies can escape their (presumably) parental plutons, and the distance they can travel into the country rocks. As will be demonstrated, these models can be used to semiquantitatively predict (order-of-magnitude estimates) the distance of pegmatite-dike propagation away from a cooling pluton. The models also account for the formation of the observed regional zonation of pegmatite dikes as a consequence of the compositional evolution of the granitic magma during crystallization of the pluton and the concurrent heating of the country rocks by the pluton.

THE DIKE PROPAGATION MODEL OF RUBIN (1995)

Rubin (1995) described a detailed model for dike propagation out of partially molten source-regions; his model considers both the physical aspects of fracture formation for dikes and the thermal aspects of intruding hot melts into cooler country-rocks. Only a brief introduction to his model is presented here. Rubin (1995) identified the following variables as important in controlling dike propagation: melt viscosity, η, latent heat of melting, L, thermal diffusivity, κ, heat capacity, c, elastic stiffness, G, excess source pressure driving the melt, ΔP, the host-rock temperature gradient, dT/dx, and the temperature of the magma above its rheological solidus (superheat), $\Delta T = T_l - T_{es}$ (where T_l is the liquidus temperature of the magma, and T_{es} is the temperature at which the magma will no longer be transported and will behave as a solid, *i.e.*, the effective solidus).

Rubin (1995) found that for dikes to propagate significantly into cooler country-rocks, there must exist a minimum distance into the country rocks where the temperature of the country rocks is above T_{es} of the magma, l_o^{min}

$$l_o^{min} = \frac{1}{0.27}\sqrt{\frac{c\Delta T/(L+c\Delta T)}{1+\sqrt{(L+c\Delta T)/c\Delta T}}\,\frac{\sqrt{3\eta\kappa}}{(\Delta P/G)^2\sqrt{\Delta P}}} \qquad (1)$$

Unless there is a sufficient distance over which country-rocks with temperatures above the effective solidus exist, the propagation of dikes is not expected to occur because magmas cool and crystallize more rapidly than dikes propagate. In this work, the value of l_o^{min} is used to evaluate the probability of pegmatite-dike propagation away from a parental granitic pluton.

Rubin's solution to the propagation equations in the absence of superheat, $\Delta T = 0$, produced a dimensionless freezing parameter, β, which is defined by:

$$\beta = \frac{2}{\sqrt{\pi}}\frac{c|dt/dx|\sqrt{3\eta\kappa}}{L(\Delta P/G)^2\sqrt{\Delta P}} \qquad (2)$$

For rocks with no superheat, there is a critical value of β, β^{crit}, for transport of magmas in dikes. β^{crit} is weakly dependent upon the ratio of the dike-tip suction to ΔP, but can be reasonably approximated as 0.15. If β exceeds β^{crit}, then the calculated velocity of dike propagation drops to 0, and the dike cannot propagate. If a magma is at a temperature above its effective solidus, then ΔT is greater than 0, and β becomes modified to $\beta_{\Delta T}$:

$$\beta_{\Delta T} = \beta\frac{L}{L+(4/\pi)c\Delta T} \qquad (3)$$

Rubin numerically solved his equations for this case when a magma's ΔT exceeds 0, and found that the propagation distance of the dike is a function of the fixed-length scale, l_o, which equals $\Delta T/|dT/dx|$, and $\beta_{\Delta T}/\beta^{crit}$ (Rubin 1995, Fig. 3). These solutions of Rubin are used in the present work to predict the propagation lengths of dikes.

In order to calculate propagation distances of pegmatite dikes away from a parental granitic pluton, it is necessary to numerically specify all values used in the above equations. Viscosity is calculated from the model of Baker (1996), as modified by Baker (in press); the latent heat of melting, 200 kJ kg^{-1}, thermal diffusivity, 6×10^{-7} m^2s^{-1}, heat capacity, 1.3 kJ $kg^{-1}K^{-1}$, elastic stiffness, 10^{10} Pa, and a typical excess pressure at the source, $10^{6.5}$ Pa, are all taken from Rubin (1995). The only variables remaining are the thermal gradient, dT/dx, and the temperature of the magma above its effective solidus, ΔT. In order to determine these values, a cooling model must be constructed for the pluton.

COOLING MODEL FOR THE PLUTON

In order to determine dT/dx through the lifetime of a cooling pluton, a thermal model has been constructed following Jaeger (1968). The intrusion is modeled as a 10 × 10 × 10 km cube which instantaneously intrudes the country rocks. The intrusion dimensions were based upon the Harney Peak granite, South Dakota, whose outcrop dimensions are similar (~12 × 12 km). Cooling of the pluton is considered to occur by conduction only, and the effects of latent heat of crystallization are ignored. Intrusion temperature of the pluton is 800°C, and country rocks are modeled with two initial temperatures, 500° and 300°C. The pluton temperature was chosen as a reasonable near-liquidus temperature

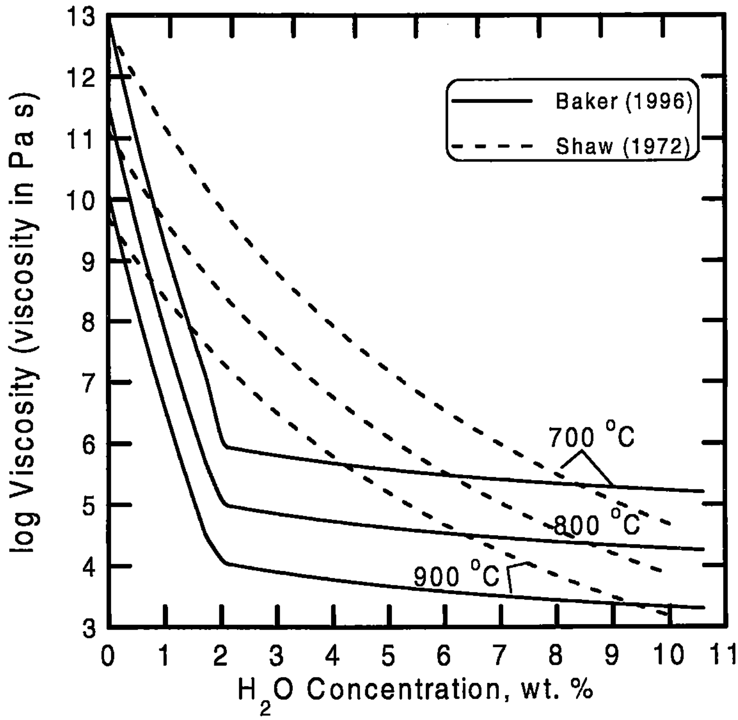

FIG. 1. Calculated viscosities of an evolved granitic composition (LCO; see Baker 1996) as a function of H_2O concentration. Dashed lines are calculated following Shaw (1972). Viscosities calculated following Baker (1996, in press) at low concentrations of H_2O (solid lines) are orders of magnitude below viscosities calculated by the method of Shaw (1972, dashed lines).

for a granitic melt (*cf.* London 1992), and the country-rock temperatures are based on the observation that the Harney Peak granite was intruded into rocks metamorphosed to the first sillimanite isograd (Shearer *et al.* 1992). An assumption that the country rocks were still at the first sillimanite isograd yields the high-temperature estimate, whereas an assumption that the country rocks had isobarically cooled to a temperature given by a typical geothermal gradient of 25 K/km produces the low-temperature estimate. A schematic diagram with calculated temperatures from the center of the pluton through the center of one face and into the country rocks is given in Figure 2.

This generalized model is of necessity a simplification of any real granitic pluton. One of the simplifications is that the heat effects of convection and crystallization are not considered. Nevertheless, this model captures the essentials of the pluton's and the host rocks' thermal history (*cf.* Jaeger 1968), and provides the order-of-magnitude estimates of the thermal gradients through the "magmatic lifetime" of the pluton necessary for the calculation of dike propagation. A significantly more complex model that includes the latent heat of crystallization and convection could be constructed, but the only significant effect it would have on the present study is to change the time at which the thermal gradient at the contact between the pluton and the country rocks reached any specific value. As discussed in their review of thermal modeling of plutons and country rocks, Furlong *et al.* (1991) compared simple analytical solutions and more complex models involving latent heat, hydrothermal effects, and realistic geometries of intrusive bodies, and concluded that simple analytical solutions, such as the one used in this study, provide adequate estimate of the rates of heat flux out of a generalized pluton and temperatures in the surrounding country-rocks.

Another simplification of the model is the treatment of the pluton as a single body instantaneously emplaced into the country rocks. Such is certainly not the case for the Harney Peak granite, which is composed of hundreds of sills and dikes (Shearer *et al.* 1992). However, if these sills and dikes were injected within a short span of time, 10,000 years or less, the assumption of instantaneous

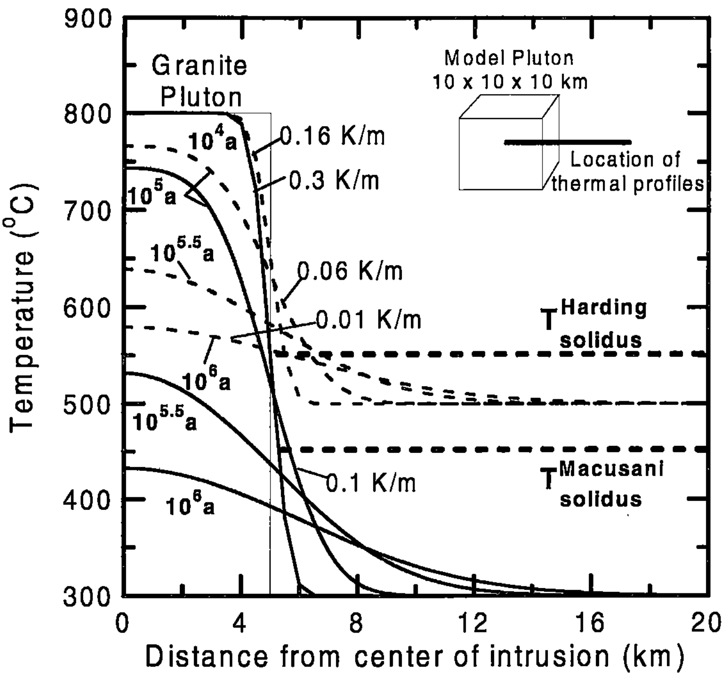

FIG. 2. Conductive cooling model for an instantaneously intruded 10 × 10 × 10 km pluton. Temperature profiles are calculated for various times, 10^4, 10^5, $10^{5.5}$, and 10^6 a, after intrusion using two initial temperatures of the country rock, 500° (thin dashed lines) and 300°C (solid lines). The thick dashed horizontal lines are the solidus temperatures of the Harding pegmatite composition (Chakoumakos & Lumpkin 1990) and of the Macusani rhyolite (London 1992). Note that at equivalent times, thermal gradients near the contact between the pluton and the country rocks (5 km) are nearly independent of the initial temperature of the country rock.

emplacement is still valid. The shape of the modeled body will affect its cooling rate, as demonstrated by Jaeger (1968). However, differences between the cooling profiles and rates of cooling of spherical and cubic bodies of the same volume are minor and will not significantly change the conclusions of the thermal modeling (Jaeger 1968).

Results of thermal modeling indicate that near the contact of the intrusion and the country rocks, the thermal gradient decreases from approximately 0.3 K/m at 10^4 a to 0.01 K/m at 10^6 a. The thermal gradient is very weakly dependent upon the initial temperature of the country rocks. For example, after 10^5 a, the thermal gradient is 0.06 K/m if the country rocks were initially at 500°C, but 0.1 K/m if country rocks started at 300°C. By $10^{5.5}$ a after intrusion, thermal gradients near the contact are down to 0.02 and 0.03 K/m for country rocks initially at 500°C and 300°C, respectively.

Thermal modeling of other sizes and shapes of plutons demonstrate that they follow similar temperature–time trajectories, such that thermal gradients are high early in the lifetime of the pluton and decay with time. For example, the thermal gradient at the contact of a 1 × 1 × 1 km pluton with country rocks at 500°C falls from 1.2 K/m after 100 a (800°C at the pluton center), to 0.5 K/m at 1000 a (770°C at center), and finally to 0.07 K/m after 10,000 a, by which time the center of the pluton is at subsolidus conditions (575°C). Comparison of the 10 × 10 × 10 km pluton with this smaller 1 × 1 × 1 km one demonstrates that as the pluton's size increases, thermal gradients of equal-aged plutons decrease. Modeling the thermal history of a tabular pluton can be performed by assuming a sheet of a given thickness and infinite lateral dimensions; the effects of non-infinite geometry only influence the thermal modeling at distances approximately equal to the sheet thickness (Jaeger 1968). Thermal modeling near the center of a sheet with a thickness of 5 km and lateral dimensions greater than 10 × 10 km demonstrates similar temperature profiles to those modeled for the 10 × 10 × 10 km pluton, but with more rapid cooling near the edges early in the pluton's history and slower cooling later. Thinner sheets cool significantly more rapidly, and sheets with a thickness equal to, or greater than, 10 km have longer cooling histories than those of the modeled 10 × 10 × 10 km pluton.

Superimposed upon the thermal model of the 10 × 10 × 10 km pluton (Fig. 2) are the solidus temperatures of the Harding pegmatite (Chakoumakos & Lumpkin 1990) and the Macusani rhyolite (London 1992, London *et al.* 1989). The thermal models indicate that if the country rocks were initially at 300°C, then after $10^{5.5}$ a the temperature at the center of the pluton has fallen below the solidus of the Harding pegmatite, and after 10^6 a, below the Macusani solidus. In the case of initially hotter country-rocks, 500°C, after 10^6 a the temperature at the center of the pluton is still greater than the solidus of the Harding pegmatite, but reaches the solidus temperature at the contact between the pluton and the country rocks.

These thermal models provide the thermal gradient and the ΔT necessary for calculations of dike propagation. For these calculations, the solidus temperatures will be considered as T_{es}, the point at which the magmas will stop moving. In reality, T_{es} is the temperature at which the melt becomes so choked with crystals that the magma can no longer flow (*cf.* Rubin 1995); T_{es} lies at some unknown temperature above the solidus for both compositions considered. However, the dependence of dike-propagation length and l_o^{min} on ΔT is weak, and a difference in 50°C results in a factor of at most 2 difference in dike-propagation length and l_o^{min}. It is expected that T_{es} is no greater than 50°C above the solidus; thus equating the two temperatures probably introduces less than a factor of 2 error in the calculations herein.

The Propagation of Pegmatite Dikes

Calculations for dike-propagation distances and l_o^{min} used a melt viscosity of 10^6 Pa s, as calculated by the updated model of Baker (1996, in press). This viscosity is typical of a granitic melt with a total H_2O content of 8 wt. %. Such a large H_2O content may be unrealistic, inasmuch as London (1992) provided evidence of the H_2O-undersaturated nature of pegmatite-forming magmas during most of their magmatic history. However, a viscosity of 10^6 Pa s is considered a reasonable estimate of the viscosity of the pegmatite-forming melt at 600°C; here the viscosity-reducing effects of fluorine (Baker & Vaillancourt 1995) and boron (addition of 1 wt.% B_2O_3 to an anhydrous melt reduces its viscosity by two orders of magnitude: Dingwell *et al.* 1992) added to a granitic melt with 4 to 5 wt.% H_2O are considered. For comparison, a viscosity of 10^7 Pa s, equivalent to 2.2 wt % H_2O at 600°C, decreases dike-propagation distances by a factor of 0.7 only, but increases l_o^{min} by a factor of 3.

TABLE 1. DIKE-PROPAGATION DISTANCES AND l_0^{min}

Time (a)	ΔT (°C)	dT/dx (K/m)	l_o^{min} (km)	Length (km)
Harding Pegmatite composition				
	Initial country-rock T = 500 °C			
10^4	250	0.16	7.6	4.4
10^5	210	0.06	7.0	13.0
$10^{5.5}$	90	0.02	3.9	20.8
10^6	25	0.01	1.1	13.0
	Initial country-rock T = 300 °C			
10^4	250	0.3	7.6	1.8
10^5	190	0.1	6.6	5.8
$10^{5.5}$	Below solidus			
10^6	Below solidus			
Macusani Rhyolite composition				
	Initial country-rock T = 500 °C			
10^4	350	0.16	8.9	6.6
10^5	310	0.06	8.4	21.0
$10^{5.5}$	190	0.02	6.6	50.4
10^6	125	0.01	5.0	76.8
	Initial country-rock T = 300 °C			
10^4	350	0.3	8.9	2.8
10^5	290	0.1	8.2	9.8
$10^{5.5}$	75	0.03	3.3	9.8
10^6	Below solidus			

See text for methods of calculation. l_o^{min} is the minimum distance into the country-rocks where the temperature of the country-rocks is higher than the solidus temperature of the magma.

Dike-propagation distances and l_o^{min} were calculated at 10^4 a, 10^5 a, $10^{5.5}$ a, and 10^6 a after intrusion (Table 1). In each case, the necessary thermal parameters are given in Figure 2; ΔT was calculated for both the Harding pegmatite and the Macusani rhyolite solidi, and is considered to be the difference in temperature between the center of the intrusion and the solidus temperatures shown in Figure 2. All other values used were as stated above. Distances were calculated from $\beta_{\Delta T}/\beta^{crit}$, where $\beta_{\Delta T}$ was calculated from equations 2 and 3, and β^{crit} was considered to be 0.15 (*cf.* Rubin 1995). Using Rubin's Figure 3, a diagram that displays propagation distance divided by $2l_o$, not l_o as in the original publication (Rubin 1996, pers. commun.), as a function of $\beta_{\Delta T}/\beta^{crit}$, the distance of dike travel can be calculated. The value of l_o^{min} was calculated using equation 1 and the results of the thermal modeling.

Results of the modeling demonstrate that early in the life history of the pluton, 10^4 a or less, dikes cannot propagate from the pluton (Table 1, Figs. 3, 4). However, near the final stages of the magmatic history of the pluton, 10^5 a and greater, the country rocks have warmed enough that dikes can propagate to approximately 10 km.

Consider first l_o^{min}, the minimum distance the dike must travel before it encounters country rocks with a

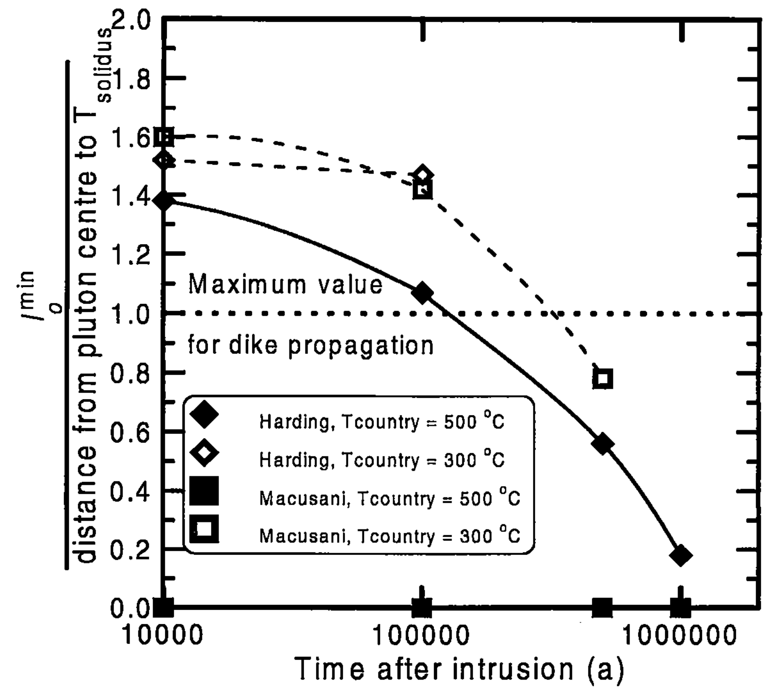

FIG. 3. Probability of dike propagation from a 10 × 10 × 10 km pluton initially intruded at 800°C for melts having the composition of the Harding pegmatite and Macusani rhyolite.

temperature below T_{es}. All of the calculated thermal profiles cross the solidus of the Harding pegmatite composition 6.5 km or less from the center of the intrusion (1.5 km or less away from the contact). Comparing these calculated thermal profiles with l_o^{min} for the Harding demonstrates that is it is probably impossible to extract a melt of the Harding composition from a pluton if the country rocks' initial temperature was 300°C before intrusion because l_o^{min} is greater than 6.5 km (Table 1). Even if the initial temperature of the country rocks was 500°C, the model indicates that more than 10^5 a of cooling must occur before dikes can propagate away from the pluton. For the Macusani composition, it is possible to have transport of the melt in dikes into the country rocks if the latter's initial temperatures was 300°C, but only for a short time period between $10^{5.5}$ and 10^6 a. Because country rocks with an initial temperature of 500°C are above the solidus temperature of Macusani melts, intrusion of dikes of this composition into the country rocks is possible at any time during the pluton's history.

Calculated dike-propagation distances demonstrate that for the composition of the Harding pegmatite, there appears to be a window of opportunity between 10^5 and 10^6 a after intrusion, when the maximum dike-propagation distance is possible as the pluton's center cools from 760° to 580°C. The maximum modeled dike-length is on the order of 20 km (from the center of the pluton) for the Harding pegmatite composition and crustal rocks initially at 500°C. For similarly hot country-rocks, the calculated lengths of dikes of Macusani composition reach a maximum calculated value of 78 km at 10^6 a, but with cooler country-rocks, say 300°C, dike-propagation distance is only 10 km. As Rubin (1995) repeatedly warned, these dike-propagation distances are maximum estimates, and cannot be relied upon to provide exact lengths. In addition, application of the thermal gradient at the contact of the pluton and country rocks to the calculation of dikes 70 km long almost certainly yields an overestimated dike-length. Nevertheless, results of this modeling indicate that pegmatite dikes can propagate on the order of 10 km away from their source plutons.

Modeling of dike propagation from plutons of different sizes demonstrates that the decreasing thermal gradients associated with larger plutons result in the easier formation and greater propagation-distances of pegmatite dikes. Conversely, in the case of small

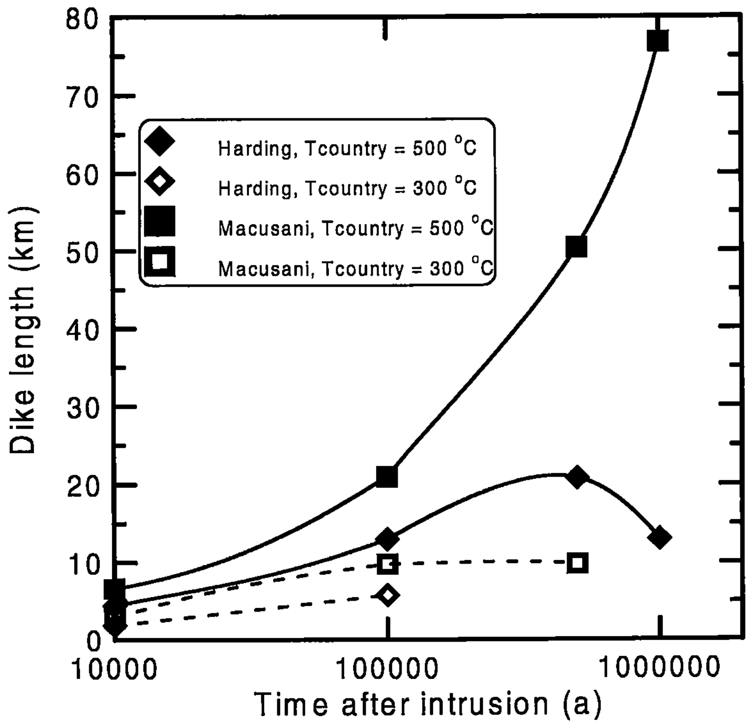

FIG. 4. Calculated dike-propagation distances for melts having the composition of the Harding pegmatite and Macusani rhyolite.

plutons, such as the 1 × 1 × 1 km pluton discussed above or a tabular pluton with a thickness less than 5 km and lateral dimensions greater than 10 × 10 km, melt does not seem able to propagate in dikes beyond the pluton because they do not provide enough heat to warm the country rocks. Therefore, pegmatite dikes are not predicted to be found in the country rocks around small plutons.

COMPARISON OF THE MODELED PROPAGATION OF PEGMATITE DIKES WITH OBSERVATIONS

A number of interesting results arise from the dike-propagation model. The first result discussed above is the estimated maximum distance of pegmatite-dike propagation, on the order of 10 km. This order-of-magnitude distance between the parental pluton and the most distal pegmatites is commonly observed in pegmatites emplaced within the middle to upper crust (*e.g.*, Cameron *et al.* 1949, Černý 1982b, 1992, Breaks & Moore 1992, Shearer *et al.* 1992). In some regions, pegmatites are found further than 10 km from exposed granite plutons. For the example of the Harney Peak pegmatite field, other authors (Shearer *et al.* 1992) have presumed that the pegmatites far from the exposed pluton are associated with a subsurface extension of the Harney Peak granite. This interpretation by Shearer *et al.* (1992) is consistent with, and also supports, the maximum distance of pegmatite dike propagation modeled in this study.

The model also predicts that dikes formed early in the pluton's history should be relatively short, or close to the pluton. The rocks in early-formed dikes should have compositions less evolved than those in later-formed dikes found further away from the pluton's margins, because the earlier-formed dikes are filled with higher-temperature magmas than the later-formed ones. This zonation of pegmatitic dikes from relatively primitive ones near the pluton to evolved ones far from the pluton has been observed in many studies (*e.g.*, Cameron *et al.* 1949, Heinrich 1953, Černý 1982b, 1992, Shearer *et al.* 1992, Mulja *et al.* 1995, Roda *et al.* 1995). Thus it appears that the frequently observed compositional zonation in pegmatite fields is due to a combination of magmatic evolution of the pluton producing increasingly evolved pegmatite-forming melts while the heat lost from the pluton warms the country rocks sufficiently to lower the nearby thermal gradient to the point where dikes can propagate significant distances away from the host pluton.

Comparison of the modeled results for the Macusani and Harding pegmatites demonstrate that melt composition can exert a significant control on dike propagation because of the effect of composition on solidus temperatures and the physical properties of the melts, as discussed by Černý (1992) in his study of pegmatite-dike zonation. The lower-solidus-temperature Macusani composition appears to have the ability to propagate further into the country rocks than the Harding composition, and also appears to be able to form dikes in cooler country-rocks than is possible for the Harding composition. These model observations suggest that only pegmatite-forming magmas with low solidus temperatures (*i.e.*, relatively evolved) should form from plutons emplaced in the cool upper crust, whereas pegmatites having a higher solidus temperature (*i.e.*, less evolved) can form in the middle to lower crust. This is not to say that less-evolved pegmatites are not found in the upper crust, but that their pluton of origin was probably emplaced into the middle to lower crust, and the pegmatite dikes propagated vertically into the upper crust.

Model results also indicate that small plutons, less than approximately 5 × 5 × 5 km, are unlikely to produce pegmatite dikes because of their rapid cooling and the high thermal gradients at their contacts with country rocks. This prediction of the model is consistent with many studies of pegmatite occurrences (*e.g.*, Cameron *et al.* 1949, Heinrich 1953, Černý 1982a, b, Breaks & Moore 1992, Shearer *et al.* 1992). However, it is recognized that if dikes passively fill fractures created in the country rocks, instead of being forcefully injected, then small plutons may be able to generate pegmatites.

In conclusion, the dike-propagation model for the formation of pegmatites from parental granitic plutons is successful in explaining some of the conundrums of pegmatite genesis. The observation that distal pegmatites are on the order of 10 km from their parental plutons, the compositional zonation of pegmatite fields, from less evolved compositions near the pluton to more evolved compositions far from the pluton, and the rare association of pegmatites with small plutons, all are consequences of the evolution of the residual melt and the process of dike intrusion from a cooling pluton into surrounding country-rocks.

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