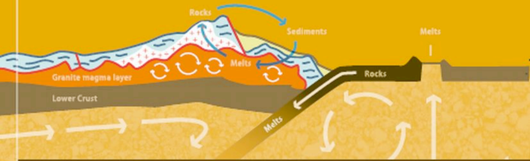
Guo-Neng Chen
Rodney Grapes



Granite Genesis: In-Situ Melting and Crustal Evolution

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by

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Cartoon illustrating a geodynamic interpretation for the cycling evolution of continent rock material, emphasising the relationship between the two major material (energy) cycling processes in the continental crust and the mantle and formation of an intercrustal convecting granite magma layer.

CONTENTS

PREFACE

"We are never devoid of some hope that we shall eventually know everything. It may often be salutary, nevertheless, to recognize the remoteness of that time and to take stock of our ignorance".

N.L. Bowen–

1947 Presidential address to the Geological Society of America

There is a vast amount of published research on granite and we cannot claim to be familiar with it all. However, we are aware of the recent developments with respect to attempts at reaching a consensus on the problem of granite origin. With the concept of granitisation apparently dormant, if not dead, a paradigm of granite magmatism, i.e. melting, segregation, ascent and emplacement, has strengthened over the last 15 years. The combined research presented in this book describes a viable alternative mechanism of granite formation to this widely accepted intrusion model, namely, in-situ melting–intracrustal convection.

The core idea of the in situ melting origin of granite was formulated by GC, who worked as a member of one of the geological teams engaged in mineral prospecting and regional mapping in SE China between 1971 and 1977. It started from being unable to obtain satisfactory answers to the questions; if ore-minerals of hydrothermal deposits are not derived from granite magma, why are they found in their host rocks? If the ore-minerals are from granite magma, why are large granite masses barren of ore deposits? During seven year's of study at Sun Yat-sen University since 1977, GC spent most of his spare time in the university library trying to find an acceptable solution, but failed. GC gradually realised that perhaps what was generally believed about the origin of granite needed revision. So began an intensive 20-year study from which GC came to the conclusion that granite is produced and remains within the region of crustal melting. Collaboration on this idea began with RG in 2002 who was then at Freiburg University, Germany, and has been at Sun Yat-sen University since October 2005.

In the following pages, we demonstrate that thermal convection within a mid-upper crustal partial melting zone is essential for the formation of granite magma and that without convection partial melting of crustal rocks generates migmatites, not granite batholiths. Granite is layer-like on a crustal scale and the shape and size of individual granite bodies merely reflects the geometric relationship between the irregular upper part of a granite layer and the erosion surface, rather than the volume of intruded magma. Chemical and isotopic compositions of granites are considered to reflect processes operating within the magma system rather than unknown deep sources. Formation and crystallisation of a crustal magma layer results in reorganization and redistribution of elements within the crust, to form both granite and their related hydrothermal mineral deposits. The in situ melting–intracrustal convection model of granite origin integrates the two-knowledge systems related to continental geology and plate tectonics and explains related geological, geochemical and geophysical observations. The geochemical fields of elements established on the basis of both the in situ melting–intracrustal convection model and periodic table illustrates the harmony and unity between the microcosm and macrocosm of the natural world.

While the views advanced in this book differ from a number of traditional ideas in geology, the same evidence used to support these ideas is also adopted to strengthen our hypothesis. Our main aim is to offer another way of not only looking at granite but the Earth in the hope that this will stimulate further thought and study. As such, we hope that the book will be of interest to both professional and student Earth scientists.

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CHAPTER 1

INTRODUCTION

1.1. ROCK GENESIS AND ITS RELATIONSHIP TO GEOSYSTEMS

Rocks that form the outer part of the Earth, the crust, provide a record of constant change in the Earth's environment with time in relation to the movement and/or reaction of rock material during their formation. Thus, understanding the genesis of rocks is the foundation of the geological knowledge system. The nature, size, shape, properties and arrangement of constituent minerals gives rise to the diversity of rocks and their origin so that the challenge of geology is in determining their material source and mechanism of formation. Among the three kinds of rocks, igneous, sedimentary and metamorphic, the material source of metamorphic rocks need not be considered because its predecessor is also rock. Igneous rocks derived by crystallisation of liquids can be divided into mafic and felsic end members represented by gabbro/basalt and granite/rhyolite, respectively, with different sources.

1.1.1. Sedimentary Rocks and Continental Geology

The genesis of sedimentary rocks that form the outermost part of the solid earth was early clarified by Lyell (between 1830 and 1833; 1868) in his *Principles of Geology* and by the geosynclinal hypothesis of Dana (1873), i.e. sediments in basins are derived from weathering and erosion of rocks in mountains or other uplifted areas, lithification of the sediments during burial, return of the new sedimentary rocks to the Earth's surface by tectonic processes, their subjection to renewed weathering and erosion, and so on as shown in Fig. 1.1. The relationship of endogenic/exogenic forces of the Earth, and the sedimentary rock cycle, demonstrate environmental variation and related material transportation in terms of two different tectonic settings, areas of uplift and subsidence. Without knowledge of this relationship, most theories of continental geology would not exist, and it is the main reason why the geosynclinal hypothesis remained fundamental in geology for over a century.

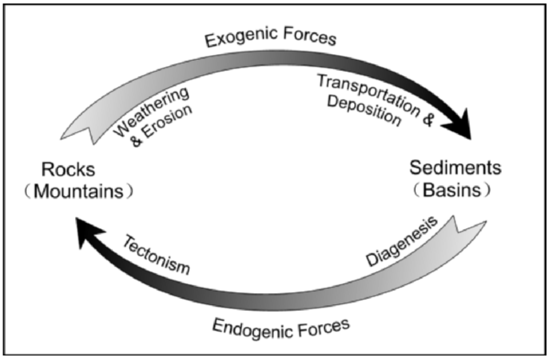

Figure 1.1. Genetic model of sedimentary rock formation and associated material cycle.

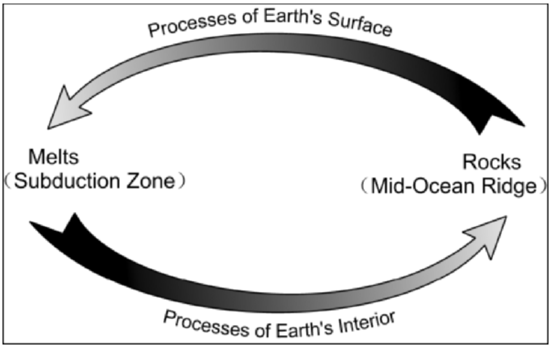

Figure 1.2. Genetic model of basalt and material cycling of the mantle.

1.1.2. Basaltic Rocks and Plate Tectonics

Basaltic rocks constitute the oceanic crust, and probably a significant part of the lower continental crust (Sima). From the work of Holmes who put forward the mantle convection hypothesis in the 1920's to that of Dietz (1961) and Hess (1962) who advanced the idea of ocean-floor spreading, the genesis of oceanic basalt and the corresponding material cycling of the mantle were successfully explained by geology, i.e. mafic magma from the mantle erupts from mid-ocean ridges to form the basaltic rocks of the ocean crust which moves away from the ridge axes, and is returned to the mantle by subduction (Fig. 1.2). Without this model, the plate tectonics hypothesis would not exist and it was probably the main reason why Wegener's hypothesis of continental drift was eventually accepted because it provided a mechanism for large-scale crustal movement.

1.1.3. 'Whence the Granites'

The genetic models of sedimentary and basaltic rocks explain environmental variables and material transport of the continents in relation to endo–exogenic forces, and energy/material flow in the Earth's interior in relation to tectonic plate

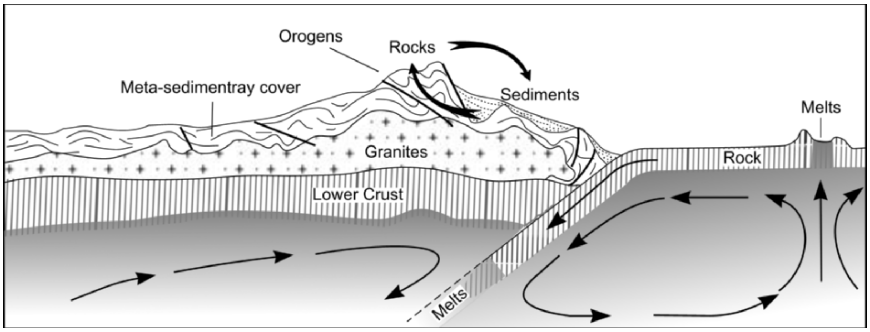

Figure 1.3. Cartoon showing spatial distribution of granite in the continental crust and relationship of the two material cycling processes known from geology.

movement. These models form the core theories of the two knowledge systems, i.e. *Continental Geology* and *Plate Tectonics*. However, as shown in Fig. 1.3, neither the formation process of sedimentary rock nor that of basalt produces granite that is considered to be distributed between the shallow crustal metasedimentary rocks and the lower continental crust.

Granite that belongs to the continent composes the fundamental part of the upper crust and is closely related to tectonism, metamorphism and mineralisation of the continental crust. The origin of granite, however, has been the subject of much debate since the eighteenth century when the science of geology was in its infancy. Accounts of the 'granite controversy' and the origin of granite can be found in Gilluly (1948), Pitcher (1993) and Young (2003) and will not be addressed here except to say that since the advent of plate tectonics in the 1960's, a framework has been provided in which the different interpretations of granite genesis can be re-explored and in many cases reconciled, although debate still continues. A misleading idea related to the basalt magma fractional crystallisation-differentiation scheme of Bowen (1914, 1922, 1948) is to combine the order of mineral crystallisation to the formation of basic to acid series igneous rocks. Only a small amount of residual granite liquid is generated by this process and this experimental evidence is clearly at odds with field evidence for the abundance of granite (Holmes 1926; Read 1957). While the mineral reaction series can be applied to the crystallisation of different magma compositions as recorded by their mineral textures, the first rocks formed are not necessarily mafic, and the last are not always felsic, because the rock crystallised from a melt depends on the composition of the melt and not the order of mineral crystallisation (Kennedy 1933). In this respect, the comment on Bowen's idea by Walton (1960) is relevant,

"Not that there was anything wrong with Bowen's chemistry or his application of it to the fractionation of basaltic magma; it was and will still remain a keystone of petrology. But there was a crucial tacit assumption involved in tying igneous theory so rigidly to a single model in which the evolution of most igneous rocks is dependent on the upward intrusion of basaltic magma into a level of the crust where it cools, crystallizes, and fractionates. The same chemistry can be applied to other models".

The granite controversy that raged between *granitisers* such as H.H. Read and *magmatists* such as N.L. Bowen in the late 1940's (Gilluly 1948) has effectively ended and most earth scientists would now agree that granites are of magmatic origin. In answering the question, *how does granite form?* or in Bowen's words 'Whence the granites?' the overwhelming opinion of most earth scientists is that granite is derived by partial melting of crustal rocks of various compositions. This idea essentially brings together the earlier competing explanations of granite genesis; magmatic (granites are igneous rocks resulting from the crystallisation of magma) and metamorphic (granites are the result of a dry or wet granitisation process that transformed sialic sedimentary rocks into granite), because granites are the result of ultra-metamorphism involving melting (anatexis) of crustal rocks. This explanation has important implications for the origin and chemical differentiation of the Earth's crust in relation to the source and evolution of thermal regimes, protolith composition, how much granite can be produced, over what time and at what temperature, the amount and source of available water needed, tectonic processes and plate tectonic settings—a truly holistic association.

1.2. GRANITES, MIGMATITES AND GRANITE PROBLEMS

1.2.1. Definitions

1.2.1.1. Granite

The maxim 'there are granites and granites' originally coined by H. H. Read remains just as true today as it did in 1933. In fact the number of 'granite types' has proliferated from at least 20 schemes that have been proposed to classify them (see Barbarin 1990, 1999 for summary, and Frost et al. 2001 for an appraisal of the more commonly used classification schemes). The most widely used classification schemes are geochemical and/or generic-alphabetical, i.e. S-, I-, M-, A-, and C-type granites (S = sedimentary source; I = igneous source; M = mantle source; A = anorogenic; C = charnockitic); calc-alkaline, alkaline, peralkaline, peraluminous, metaluminous granites; or are related to tectonic setting: 'orogenic' (oceanic and continental volcanic arc; continental collision), 'transitional' (post-orogenic uplift/collapse), and 'anorogenic' (continental rifting, hot spot, mid-ocean ridge, oceanic island) granites.

In this book the broad terms 'granitoid', 'granitic rocks' or simply 'granite' are used to mean quartz-bearing (>60 wt % SiO_2) plutonic igneous rocks in general. We adopt (or return to) where necessary a non-genetic classification of granitic rocks based on field and petrographic observation in that we use well-established rock names, e.g. granite, adamellite, granodiorite, tonalite, monzonite, diorite,