

# Contents

|          |   |           |
|----------|---|-----------|
| <b>1</b> | <b>Introduction . . . . .</b>   | <b>1</b>  |
| 1.1      | Tectonic Evolution . . . . .  | 1         |
| 1.2      | Mineralization of Mafic-ultramafic Rocks . . . . .                        | 3         |
| 1.3      | Controversies on Mafic-ultramafic Complexes<br>in Southern CAOB . . . . . | 4         |
| 1.4      | Mantle Plume. . . . .   | 5         |
|          | References . . . . .  | 6         |
| <b>2</b> | <b>Regional Geology . . . . .</b>   | <b>13</b> |
| 2.1      | Geological Background . . . . .   | 13        |
| 2.2      | Eastern Tianshan and Mafic-ultramafic Intrusions . . . . .                | 13        |
| 2.3      | Beishan Terrane and Mafic-ultramafic Intrusions . . . . .                 | 16        |
| 2.4      | Kalatongke Intrusion in Southern Altay. . . . .                           | 16        |
|          | References . . . . .  | 17        |
| <b>3</b> | <b>Analytical Methods . . . . .</b>                                       | <b>21</b> |
| 3.1      | Mineral Chemistry . . . . .   | 21        |
| 3.2      | Geochemistry . . . . .  | 21        |
| 3.2.1    | Major and Trace Elements . . . . .  | 21        |
| 3.2.2    | Rb–Sr–Sm–Nd Isotopes . . . . .  | 22        |
| 3.2.3    | Sulfur Isotopes. . . . .  | 23        |
| 3.3      | U–Pb Dating and Hf–O Isotopes of Zircons. . . . .                         | 23        |
|          | References . . . . .  | 24        |
| <b>4</b> | <b>Petrology and Mineralogy . . . . .</b>                                 | <b>25</b> |
| 4.1      | Hongshishan Mafic-ultramafic Intrusion . . . . .                          | 25        |
| 4.2      | Poshi Intrusion . . . . .   | 35        |
| 4.3      | Xuanwoling Intrusion . . . . .  | 37        |
| 4.4      | Bijiaoshan Intrusion . . . . .  | 48        |
| 4.5      | Luodong Intrusion . . . . .   | 57        |
| 4.6      | Other Intrusions Mentioned in the Thesis . . . . .                        | 59        |
|          | References . . . . .  | 66        |

|  |            |
|--|------------|
| <b>5 Zircon U–Pb Geochronology and Hf–O Isotopes . . . . .</b>     | <b>69</b>  |
| 5.1 Samples . . . . .  | 69         |
| 5.2 Zircon Morphology . . . . .                                    | 69         |
| 5.2.1 Bogeda–Haerlike Belt . . . . .                               | 69         |
| 5.2.2 Jueluotage Belt . . . . .                                    | 71         |
| 5.2.3 Middle Tianshan Terrane . . . . .                            | 71         |
| 5.2.4 Beishan Terrane . . . . .                                    | 71         |
| 5.3 U–Pb Ages . . . . .  | 72         |
| 5.3.1 Bogeda–Haerlike Belt . . . . .                               | 72         |
| 5.3.2 Jueluotage Belt . . . . .                                    | 73         |
| 5.3.3 Middle Tianshan Terrane . . . . .                            | 87         |
| 5.3.4 Beishan Terrane . . . . .                                    | 87         |
| 5.4 Hf–O Isotopes . . . . .  | 88         |
| 5.4.1 Bogeda–Haerlike Belt . . . . .                               | 88         |
| 5.4.2 Jueluotage Belt . . . . .                                    | 88         |
| 5.4.3 Middle Tianshan Terrane . . . . .                            | 104        |
| 5.4.4 Beishan Terrane . . . . .                                    | 104        |
| References . . . . .   | 106        |
| <b>6 Geochemistry . . . . .</b>                                    | <b>107</b> |
| 6.1 Hongshishan Intrusion . . . . .                                | 107        |
| 6.1.1 Major Elements . . . . .                                     | 107        |
| 6.1.2 Trace Elements . . . . .                                     | 113        |
| 6.1.3 Sr–Nd Isotopes . . . . .                                     | 116        |
| 6.2 Xuanwolong Intrusion . . . . .                                 | 116        |
| 6.2.1 Major Elements . . . . .                                     | 116        |
| 6.2.2 Trace Elements . . . . .                                     | 124        |
| 6.2.3 Sr–Nd Isotopes . . . . .                                     | 124        |
| 6.3 Bijashan Intrusion . . . . .                                   | 127        |
| 6.3.1 Major Elements . . . . .                                     | 127        |
| 6.3.2 Trace Elements . . . . .                                     | 128        |
| 6.3.3 Sr–Nd Isotopes . . . . .                                     | 128        |
| 6.4 Luodong Intrusion . . . . .                                    | 130        |
| 6.4.1 Major Elements . . . . .                                     | 130        |
| 6.4.2 Trace Elements . . . . .                                     | 132        |
| 6.4.3 Sr–Nd Isotopes . . . . .                                     | 132        |
| References . . . . .   | 133        |
| <b>7 Petrogenesis . . . . .</b>                                    | <b>135</b> |
| 7.1 Sr–Nd–Hf–O Isotopic Mapping . . . . .                          | 136        |
| 7.2 Fractional Crystallization and Crustal Contamination . . . . . | 138        |
| 7.3 Compositional Heterogeneity of the Mantle Sources . . . . .    | 143        |
| 7.4 Subduction Modification in the Mantle Sources . . . . .        | 145        |

|            |   |     |
|------------|---|-----|
| <b>7.5</b> | <b>Mechanism of Generation of Mafic-ultramafic Magmas . . . . .</b>                               | 147 |
| 7.5.1      | Arc-Related Alaskan-Type? . . . . .   | 147 |
| 7.5.2      | Post-orogenic Extension . . . . .   | 149 |
| 7.5.3      | Early Permian Mantle Plume . . . . .  | 149 |
| <b>7.6</b> | <b>Summary . . . . .</b>  | 150 |
|            | <b>References . . . . .</b>   | 151 |
| <b>8</b>   | <b>Mineralization . . . . .</b>   | 157 |
| 8.1        | Magmatic Ni–Cu Sulfide Exploration Progresses<br>in the Beishan Terrane . . . . .                 | 157 |
| 8.2        | Theoretical, Petrological, Mineralogical<br>and Geochemical Comparisons . . . . .                 | 158 |
| 8.2.1      | Theoretical Analysis . . . . .  | 160 |
| 8.2.2      | Petrological Comparison . . . . .   | 160 |
| 8.2.3      | Mineralogical Comparison . . . . .  | 163 |
| 8.2.4      | Geochemical Comparison . . . . .  | 165 |
| 8.3        | Controlling Factors for Contrasting Mineralization<br>and Implications . . . . .                  | 169 |
| 8.3.1      | Evaluation of Mineralization Potential<br>in the Beishan Mafic-ultramafic Intrusions . . . . .    | 169 |
| 8.3.2      | Crustal Assimilation . . . . .  | 172 |
| 8.3.3      | Mantle Sources . . . . .  | 174 |
| 8.4        | Implications for Mineralization of Mafic-ultramafic<br>Intrusions within Orogenic Belts . . . . . | 175 |
| 8.5        | Summary . . . . .   | 177 |
|            | References . . . . .  | 177 |
| <b>9</b>   | <b>Permian Mantle Plume and Paleozoic Tectonic Evolution . . . . .</b>                            | 183 |
| 9.1        | Subduction Events and Their Time . . . . .  | 183 |
| 9.2        | Crustal Accretion . . . . .   | 186 |
| 9.3        | Mantle Plume . . . . .  | 186 |
| 9.3.1      | Geochronology and Zircon Hf–O Isotopes . . . . .  | 188 |
| 9.3.2      | Geochemistry . . . . .  | 194 |
| 9.3.3      | A Mantle Plume Model . . . . .  | 197 |
| 9.4        | Model of Paleozoic Tectonic Evolution of Eastern<br>Tianshan and Beishan . . . . .                | 199 |
| 9.5        | Summary . . . . .   | 200 |
|            | References . . . . .  | 201 |
| <b>10</b>  | <b>Concluding Remarks . . . . .</b>   | 209 |