THE Q-ANOR DIAGRAM: A TOOL FOR THE PETROGNETIC AND TECTONOMAGMATIC CHARACTERIZATION OF GRANITIC SUITES

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ABSTRACT

The Q-ANOR diagram is an empirically derived CIPW normative based equivalent to the modal IUGS classification scheme for granitoids. It employs the parameters Q= 100*(Qtz/(Qtz+Ab+Or+An)) and ANOR= (100*An/(An+Or)). In contrast to results obtained from normative triangular classification diagrams, plutonic rock type names derived from the Q-ANOR diagram closely approximate modal-derived results. Trends have been added to this diagram based on published datasets from the Peninsular Ranges (calcic: C), Tuolumne (calc-alkalic: CA), Sherman (alkali-calcic: AC), and Bjerkreim (alkalic: A) batholiths. These same major element datasets were employed to constrain the positions of the C-CA, CA-AC and AC-A suite boundaries on the widely employed SiO2 versus Na2O+K2O-CaO (or modified alkali-lime index, MALI) granitic classification diagram (Frost et al., 2001: J. Petrol. 42, 2033-2048). The modified Q-ANOR plot compliments the MALI diagram by identifying rock types comprising a suite and their relative abundances.

Previous workers have employed the Q-ANOR diagram to compare Proterozoic granitic suites of 'unknown' tectonic context to published datasets from Paleozoic suites or batholiths formed within 'known' tectonic settings, thus demonstrating its value in distinguishing between a subduction zone versus nonsubduction-zone related petrogenesis. Combining this empirical comparison approach with the Frost et al. granitic classification scheme, the modified Q-ANOR diagram can help constrain the petrogenesis and tectonic environments of plutonic suites that frequently represent voluminous map units within Archean through to Paleozoic orogenic belts. Advantages of this major element based approach over trace element based tectonomagmatic classification schemes include not being mainly controlled by melt source composition

Introduction

Two methods are generally employed to determine the topology of granitoid rocks. The 'classical' method is modal employing the IUGS alkali feldspar-quartz-plagioclase classification diagram of Streckeisen (1976) (Fig. 1a). Unfortunately obtaining modal data by point counting is time consuming and, depending on grain size, can be both difficult to do and fairly inaccurate. For these reasons this method is much less frequently employed than the second method, which is based on major element analyses. There are various of these approaches or schemes including the CIPW normative based Ab-Ab-Or triangular diagram of Barker (1979), plotting mesonorm, a modification of the Niggli molecular or catanorm, data on the Q-Ab-Or diagram of Streckeisen (1976) (often incorrectly attributed to LeMaitre (1989)) and the Q (Si/3-(K+Na+2Ca/3)-P (K-(Na+Ca)) cation diagram of Debon and LeFort (1982). Much less frequently used is the CIPW normative Q-ANOR diagram of Streckeisen and LeMaitre (1979) (Fig.1b).

Herein, we will show that: (1) of the various chemistry based classification schemes, this diagram provides the closest approximation to plutonic rock names obtained from the modal IUGS Qtz-Plag-Kfd diagram; (2) the Q-ANOR diagram provides remarkably good separation of granitoid suites with contrasting MALI (Na_2O+K_2O-CaO) (modified alkali-lime index)(Frost et al., 2001) character; and (3) a Q-ANOR diagram that includes trends for alkalic, alkali-calcic, calc-alkalic, and calcic rock series provides a tool that can help constrain the petrogenesis and tectonic environments of plutonic suites formed in 'unknown' tectonic settings.

Figure 1

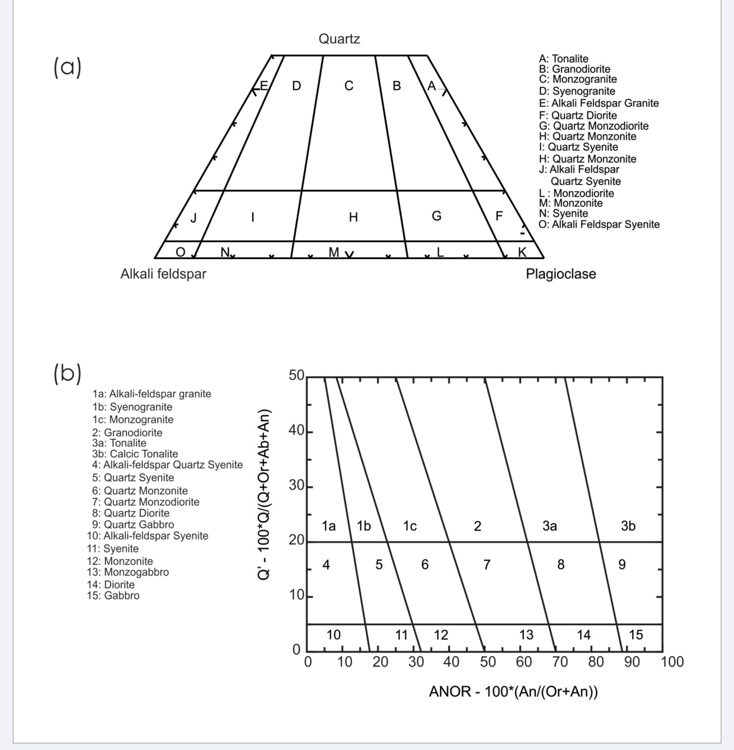
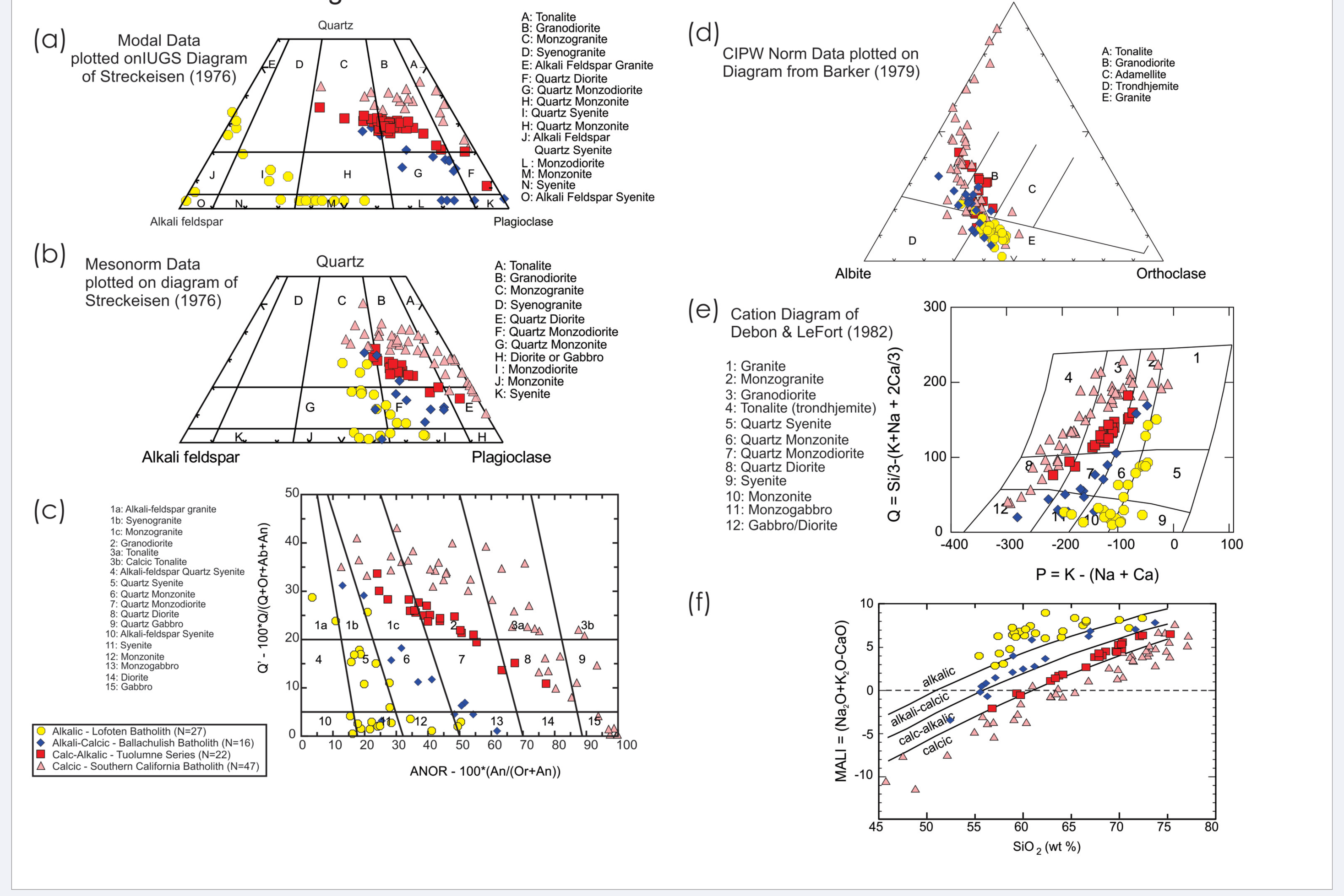


Figure 2



Comparison of Classification Schemes

In a paper concerning a new geochemical classification for feldspathic igneous rocks, Frost and Frost (2008) utilized four type plutonic suites: alkalic (Lofoten)(Malm and Ormaasen, 1973), alkali-calcic (Ballachulish)(Weiss and Troll, 1989), calc-alkalic (Tuolumne)(Bateman and Chappell, 1979) and calcic (Southern California)(Larsen, 1948). In Figure 2, these datasets are plotted on five frequently employed granitoid classification diagrams: (a) the modal IUGS alkali feldspar-quartz-plagioclase diagram of Streckeisen (1976); (b) mesonorm data plotted on this same diagram (often incorrectly attributed to LeMaitre (1989); (c) the Q-ANOR diagram of Streckeisen and LeMaitre (1979); (d) the CIPW normative Ab-An-Or diagram of Barker (1979); and (e) the Q-P cation diagram of Debon and LeFort (1982). These dataset are also plotted on the SiO2-MALI (modified alkali-lime index) diagram of Frost et al. (2001) (Fig. 2f). Comparison of these five lithological classification diagrams indicates that the Q-ANOR diagram yields a very close correspondence with the modal diagram. The second best correspondence is obtained from the Q-P cation diagram. The poorest results are those obtained from the Ab-An-Or diagram for all suites plot on top of each other mainly within the tonalite, granodiorite and granite fields. Plotting of mesonorm values on the Streckeisen (1976) diagram yielded reasonable results for the calcic, calc-alkalic and alkali-calcic suites but very poor results for the alkalic suite due to albite contained in alkali feldspar being included in plagioclase in the norm values. As regards degree of separation on these various lithological classification diagrams between different 'type' MALI suites (Fig. 2f), the Q-ANOR diagram yields the best separation and the Ab-An-Or diagram the poorest.

Background on the Q-ANOR Diagram

The Q-ANOR diagram (Fig. 1b) was derived empirically by Streckeisen and LeMaitre (1979) as a CIPW normative equivalent to the IUGS classification of Streckeisen (1976) (Fig. 1a). It is based on two parameters representing silica saturation (Q = normative (Q/Q+Ab+Or+An)x100)) and An/Or ratios (ANOR = normative (An/An+Or)x100)). Rock type boundaries in the diagram were constrained by employing a geochemical database of 2500 analyses that included many plutonic rocks with reliable modal data. Unfortunately, the diagram appears to have not received much acceptance or use, possibly because it was published in a German journal, Neus Jahrbuch fur Mineralogie, with a restricted circulation and profile.

There have been a number of workers, however, who have made fruitful use of the Q-ANOR diagram. Kerr (1989) employed this diagram to compare the voluminous Proterozoic Trans-Labrador granitoid belt (TLGB) of unknown tectonic affinity with Phanerozoic continental margin arc batholiths (Southern California, Peru). He concluded that a continental arc setting was inappropriate for the TLGB and that a post-orogenic setting dominated by crustal thickening, uplift and transcurrent faults was more appropriate. Similarly Chacko et al. (2000) employed the diagram to compare 1.9-2.0 Ga Talson magmatic zone granitoid rocks with Phanerozoic granitoid suites formed in various tectonic environments. These comparisons revealed that the Talson magmatic zone, which had previously been ascribed to active subduction, resembled Cordilleran interior granitoids that formed in the distant hinterland of a convergent plate

Figure 3

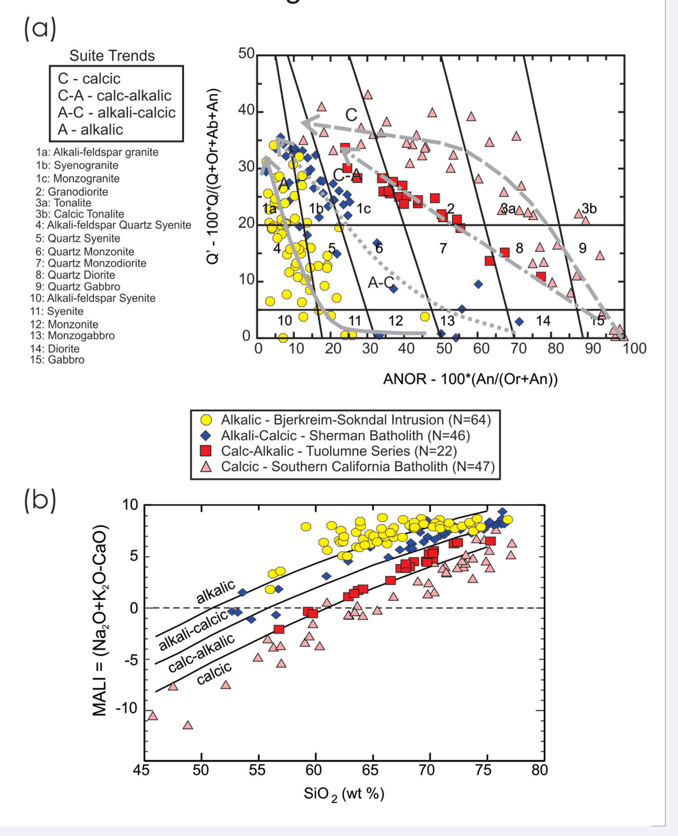


Figure 4

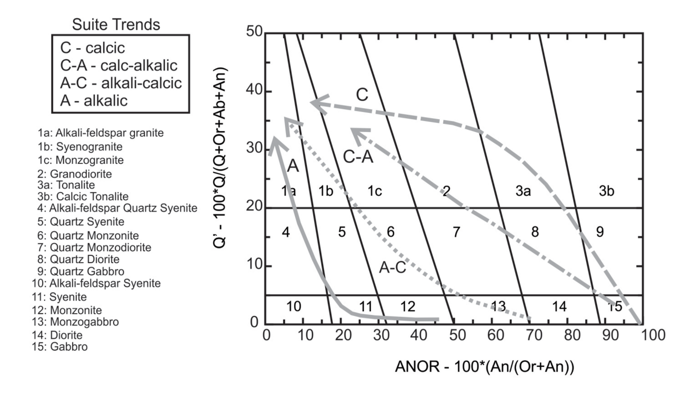
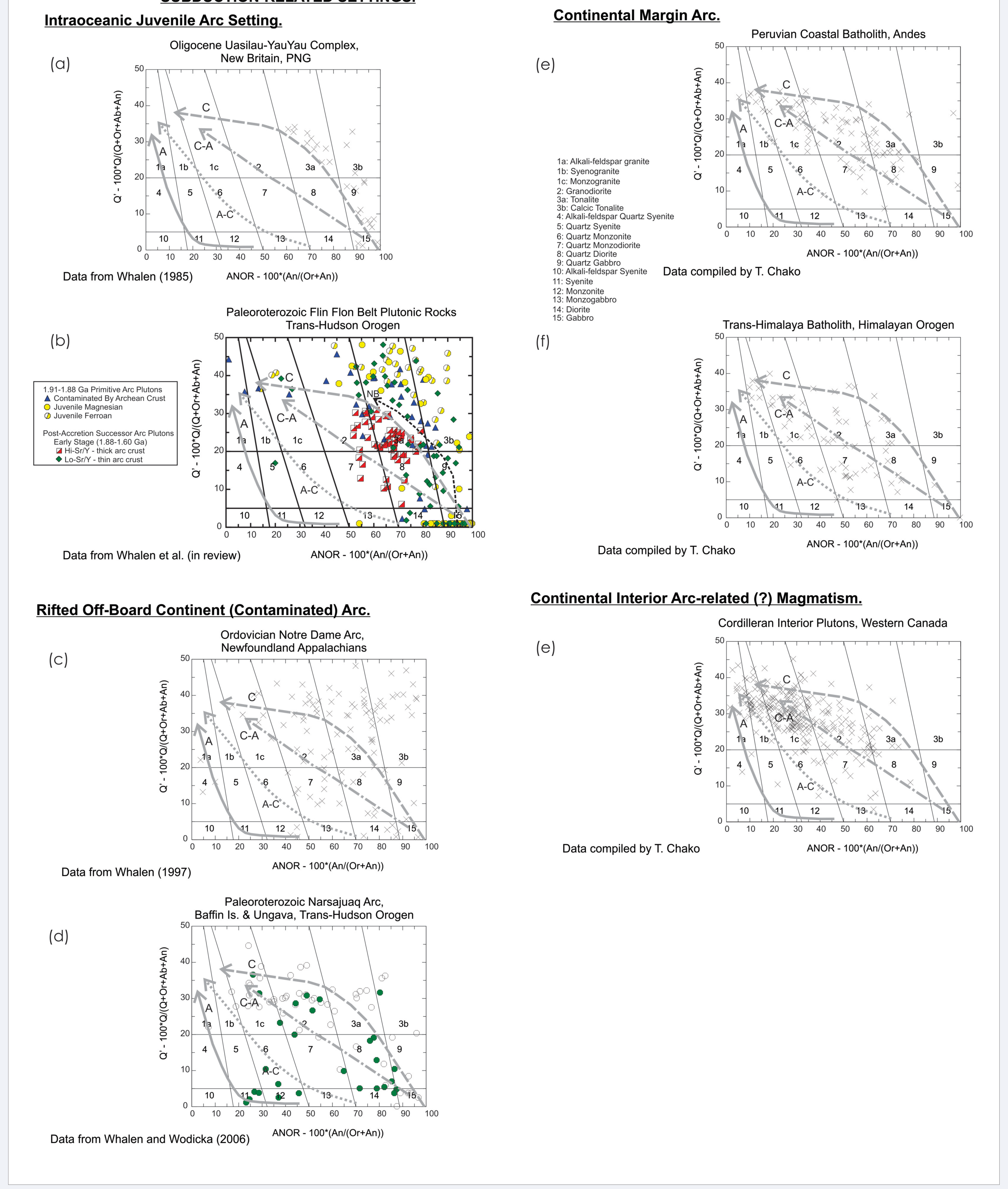


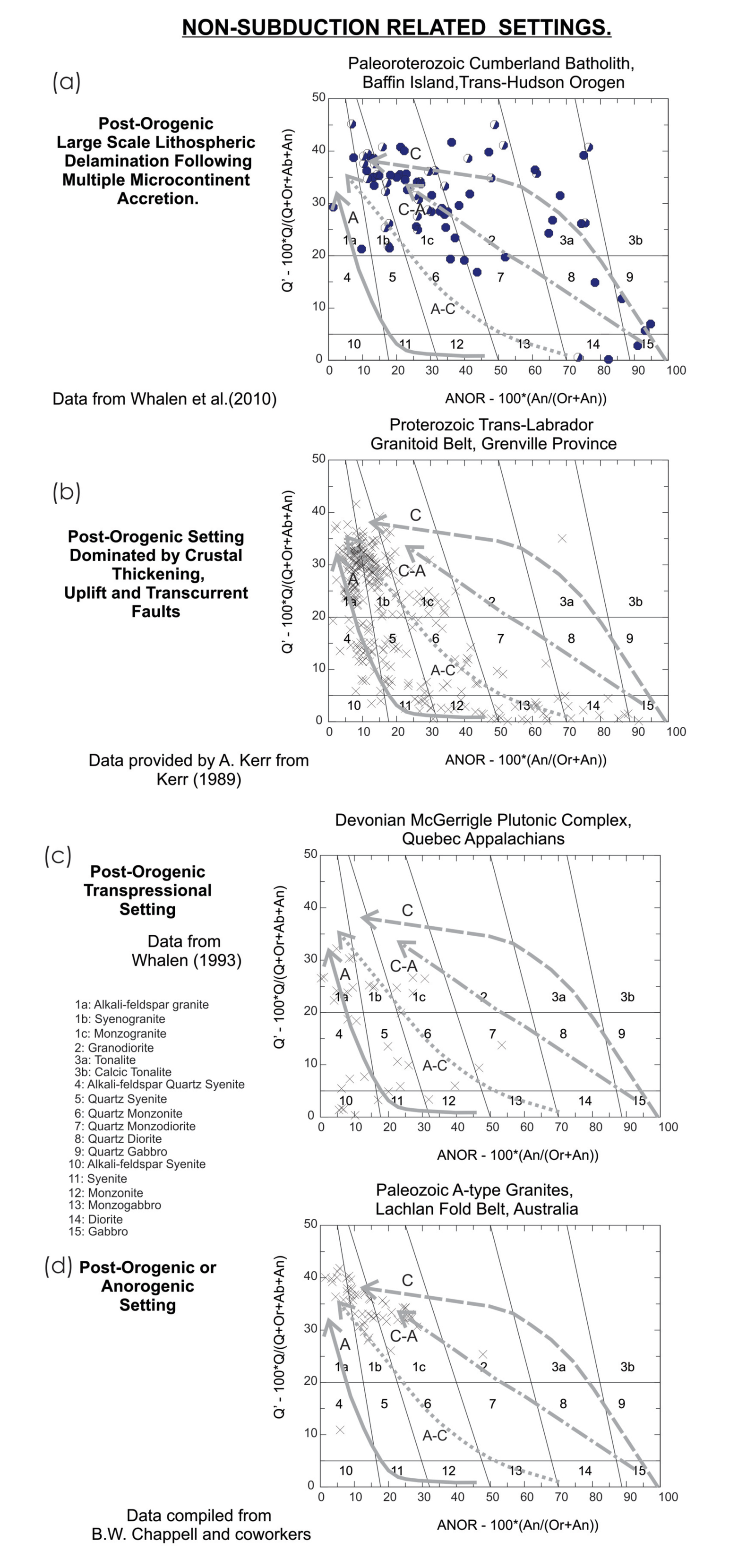
Figure 5



Derivation of a Modified Q-ANOR Diagram

In a plot of the four type plutonic suites utilized by Frost and Frost (2008) on the Q-ANOR diagram (Fig. 2c), the four suites exhibit distinct well separated data clusters and trends. However, a fairly limited number of major element analyses were available for the Lofoten and Ballachulish suites, making their apparent trends less well defined. These suites had been substituted by Frost and Frost (2008) for the alkalic Bjerkeim-Sokndal (Duchesne and Wilmart, 1997) and alkali-calcic Sherman (Frost et al., 1999) suites due to a paucity of modal data for these suites. The Bjerkeim-Sokndal, Sherman, Tuolumne and southern California suites were employed in Frost et al. (2001) to constrain boundary positions on their SiO_2-MALI (Na_2O+K_2O-CaO) diagram. Spreadsheets containing published data from these 'type' plutonic suites were downloaded at http://research.gg.uwyo.edu/granite/. A plot of these four type suites on the Q-ANOR diagram yielded better defined alkali and alkali-calcic data trends than Figure 2c from which visually inferred suite trends were superimposed onto the Q-ANOR diagram (Fig. 3a). The application of this modified Q-ANOR diagram (Fig. 4) to plutonic suites formed within subduction-related and non-subduction-related settings are shown in Figures 5 and 6, respectively.

Figure 5



Applications of the Q-ANOR Diagram

1. Provides an accurate identification of plutonic rock types present and, depending on representative sampling, illustrates composition diversity and dispersion within granitoid suites.
2. Provides an additional method to the SiO_2-MALI (Na_2O+K_2O-CaO) diagram of Frost et al. (2001) for characterizing suites as to their alkali-lime index, an important petrogenetic parameter. The better spatial separation of the type suites of Frost et al. (2001) on the Q-ANOR diagram (Fig. 3a) than on the SiO_2-MALI diagram (Fig. 3b) may enable subtle, but petrogenetically significant, differences to be distinguished between or within suites.
3. Represents an empirical tool for tectonomagmatic characterization of granitoid suites. This has been demonstrated by earlier workers (Kerr, 1989; Chacko et al., 2001), who compared datasets from suites with poorly constrained tectonic settings to suites/batholiths of know tectonic setting. In this regard, rock types present, compositional dispersion and relative abundance of different compositions are key aspects in this empiracal approach.
4. Addition of trends for the four type MALI suites on the Q-ANOR diagram (Fig. 4) can provide addition tectonomagmatic information during empirical comparison to suites with well-constrained tectonic setting. For example, it appears that juvenile oceanic arc plutonic suites (New Britain and Flin Flon Belt)(Fig. 5) are more calcic than the type calcic suite (southern California batholith) of Frost et al. (2001), plotting to the right of that trend, within the gabbro-quartz diorite-tonalite fields. The curvature and continuation of the southern California batholith calcic trend into the monzogranite field as compared to oceanic arc plutonic trends, which evolve only into the high-quartz portion of the tonalite field, may reflect AFC processes within a continental margin arc underlain by a thicker crustal substrate. Another avenue of exploration would be adding fields, based on experimental studies, where partial melts derived from different composition protoliths plot. It is likely that partial melts of mafic arc-type crust would plot in the quartz-rich portion of the tonalite field, whereas partial melts of average intermediate continental crustal sources would mainly fall within the monozogranite field where the four type suite trends converge.
5. A major element based approach to tectonomagmatic characterizing of granitoid suites employing the modified Q-ANOR diagram, in conjunction with the feldspathic igneous rock classification scheme of Frost and Frost (2008), is preferable to an approach based exclusively on trace element tectonomagmatic classification schemes (e.g. Pearce et al., 1984). As regards the dependability of the trace element approach, it must be borne in mind that many trace elements are not incompatible in granitic rocks but reside in minor silicate and oxide phases and that trace element abundances are more strongly affected by crustal assimilation and the crystallization history of the magma. In contrast, major elements more reliably reflect the composition of the parent magma, source(s) or protoliths and processes involved in magma generation.

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