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ENSO and interdecadal climate variability over the last century documented by geochemical records of two coral cores from the South West Pacific

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Abstract. The south west Pacific is affected by climatic phenomena such as ENSO (El Niño Southern Oscillation) or the PDO (Pacific Decadal Oscillation). Near-monthly resolution calibrations of Sr/Ca, U/Ca and δ^{18}Oc were made on corals taken from New Caledonia and Wallis Island. These geochemical variations could be linked to SST (sea surface temperature) and SSS (sea surface salinity) variations over the last two decades, itselves dependent on ENSO occurrences. On the other hand, near-half-yearly resolution over the last century smoothes seasonal and interannual climate signals, but emphasizes low frequency climate variability.

1 Introduction

The west Pacific Warm Pool (WPWP), the warmest oceanic waters in the world, plays a crucial role in climate as an intense convective zone, and also in ENSO development (Mc Phaden, 1999). During El Niño, due to the WPWP narrowing toward the equator, the south western Pacific is affected by cooling, contrasting with the well known eastern equatorial Pacific warm anomalies. In the southern part of the western Pacific, temperature and precipitation anomalies present different patterns, depending on the position with respect to a pivotal line along the SPCZ (South Pacific Convergence Zone) (Salinger, 1995). This study aims to calibrate proxies in relation with ENSO in two south west Pacific sites: New Caledonia and Wallis Island (Fig. 1).

Geochemical analyses of corals provide a powerful tool to reconstruct the variations of paleoenvironmental factors. Massive corals can live up to thousands years (Watanabe et al., 2003) and be accurately dated (Bard et al., 1990). During growth, the calcareous skeleton incorporates isotopes and chemical tracers reflecting environmental conditions in ambient sea water. Sr/Ca is linked to SST (Beck et al., 1992). Coral oxygen isotopic ratios (δ^{18}Oc) reflect some thermal imprint, but their variations also give information related to sea water isotopic composition (δ^{18}Osw), itself linked to SSS variations (McCulloch et al., 1994; Gagan et al., 1998). U/Ca has a complex behaviour, and is SST-dependent (Min et al., 1995) but also SSS-dependent (Ourbak et al., 2005). High-resolution measurements of tracers from two coral cores collected from New Caledonia and Wallis allow the calibration of proxies against environmental parameters for the past 20 years. Then, the last century is investigated with half-yearly resolution on the same cores.

2 Study Area

Figure 1 presents the study area. The two sites are situated in the Southwestern tropical Pacific, which is affected by seasonal to interdecadal displacements of the WPWP and the SPCZ. In the SPCZ, for the last 25 years, instrumental records suggest that La Niña impacts for both SST and SSS are slightly stronger in intensity than those of El Niño (Gouriou and Delcroix, 2002). Based on in situ measurements, physicians from the IRD (Institut de Recherche pour le Développement) have shown that SST and ENSO-related precipitation anomalies are of an order of magnitude smaller than seasonal patterns. On the contrary, ENSO-related SSS signal is twice as strong as seasonal signal, with a 2 months-lag signature (Gouriou and Delcroix, 2002). In our two coring sites, more detailed regional studies confirm similar ENSO-related patterns, but with differences in intensity. Thermosalinograph (TSG) data and satellite based SST provide climatic records for the last two decades (Fig. 2).

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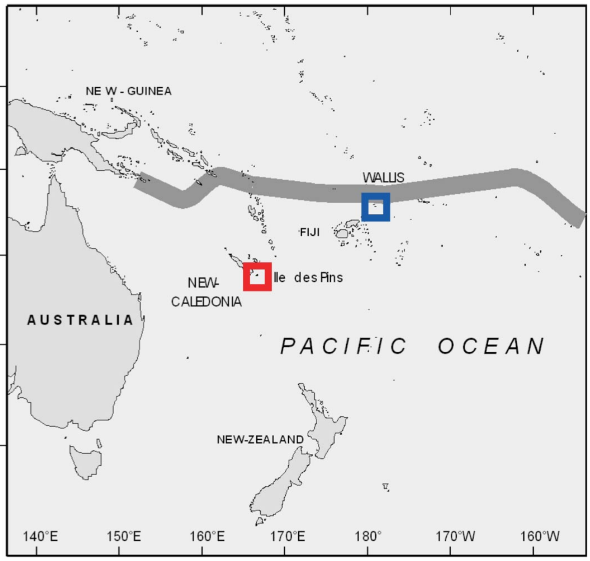

Fig. 1. South Pacific map with the location of Ile des Pins (New Caledonia, red square) and Wallis (Blue square) in relationship with the rainfall maximum axis of the South Pacific Convergence Zone (modified from Folland et al. (2002)).

In New Caledonia, December to February are the warmest months and correspond to the rainy season; July to September are colder and drier. Our coring site, Ile des Pins (22°31 S; 167°25 E, Fig. 1) has a clear seasonal climatic signal (Fig. 2). Nicet and Delcroix (2000) have shown a positive SSS (∼0.2‰) and negative SST (∼0.5°C) anomalies during El Niño events. Although some New Caledonia corals were previously investigated (Quinn et al., 1996; Quinn et al., 1998; Corrège et al., 2000), this is the first one from Ile des Pins.

Wallis Island (13°17 S, 176°08 W, Fig. 1), situated in the heart of the SPCZ, is subjected to small seasonal SST variations, but a large amount of rainfall has a great impact on SSS (Fig. 2). El Niño signature at Wallis generally consists in a stronger SSS anomaly (∼0.4‰), and in a 0.3°C cooling (Alory and Delcroix, 1999). Nevertheless, for the 1973–1995 period, not all El Niño events had a negative impact on precipitation and SSS.

3 Material and methods

In February 2003, we retrieved a continuous 3.4 m long core from a *Porites sp* colony growing on the Northeast side of Ile des Pins (IP thereafter), New Caledonia, at 8 m depth. In August 2000, a 3.65 m coral core was recovered from a *Porites sp* colony growing at 5 m depth inside the Wallis lagoon. Coral slabs (1 cm thick) were cut and cleaned with deionized water in an ultrasonic bath. Dry slabs were X-rayed for chronological purpose, and then sampled with a micro-drill along the main growth axis. Sr/Ca and δ^{18}Oc were measured continuously every 0.08 cm for the calibration period (1989–2003 for IP, 1982–1999 for Wallis). Then, taking a mean extension rate of 1 cm/year (based on X-rays), a 0.5 cm resolution was applied for the whole cores, in order to achieve a near half-yearly resolution. We measured oxygen isotope ratios with an Isotope Ratio Mass Spectrometer (Micromass Optima) at UMR 5805 EPOC, University of Bordeaux, with an individual acid reaction vessel system. Standard deviation on NBS19 international standard was 0.12‰. Sr/Ca at IP were measured with an Inductively Coupled Plasma Atomic Emission Spectrometer (ICP-AES) at the IRD centre in Nouméa (New Caledonia). Wallis Sr/Ca and U/Ca measurements were achieved on an Inductively Coupled Plasma Mass Spectrometer (ICP-MS) at the IRD centre in Bondy (France), following the method of Le Cornec and Corrège (1997). Standard deviation is ±0.05 mmol/mol for Sr/Ca and ±0.03 μmol/mol for U/Ca (ICP-MS). For ICP-AES, standard deviation on Sr/Ca is ±0.05 mmol/mol. Chronology for the calibration period is based on skeletal measurements, Sr/Ca for IP and U/Ca for Wallis. We tied extrema in trace element/Ca ratio to the corresponding SST annual extrema of each annual cycle, using a "peak to peak matching" technique.

4 Results and discussion

4.1 Calibration

For the calibration period, monthly Southern Oscillation Index (SOI), near-monthly Sr/Ca and δ^{18}Oc at IP, Sr/Ca, U/Ca and δ^{18}Oc at Wallis are represented in Fig. 3.

For the IP record, clear seasonal cycles are visible. The strong 1997–1998 Niño is clearly recorded: higher Sr/Ca in addition to heavier δ^{18}Oc values indicate colder and drier conditions compared to the mean climatic signal. As noted for instrumental data (Alory and Delcroix, 1999), the 1990–1994 period, known as a long, weak El Niño, has an atypical signature in corals, reducing the amplitude of δ^{18}Oc cycles. The 1988–1989 and the 1998–2000 La Niña phenomena are recorded in Sr/Ca and δ^{18}Oc. For example, the Sr/Ca peak in 1999 winter (the highest of the period) reflects warm winter anomalies.

Wallis coral exhibits less clear seasonal cycles. This result is in good agreement with instrumental TSG data. The SST cycle is weak and precipitation patterns are not cyclic, despite a strong seasonal variability due to SPCZ shifts. Signature of the strong 1997-98 El Niño is particularly visible on Sr/Ca, giving the highest values of the calibration period (i.e. lowest SST). The 1991–1994 event again has peculiar impacts, smoothing both U/Ca and Sr/Ca variability. In this coral, there is no signature for the strong 1982–1983 El Niño. Our hypothesis is that the 1982–1983 phenomenon (the highest SOI value of the period) has stressed the coral, inhibiting a normal growth without giving any peculiar geochemical signature. The only strong La Niña available on the studied period (1988–1989) is well recorded. It produces the highest δ^{18}Oc and the lowest U/Ca values, as well as low Sr/Ca ratio, indicating wetter and warmer conditions.

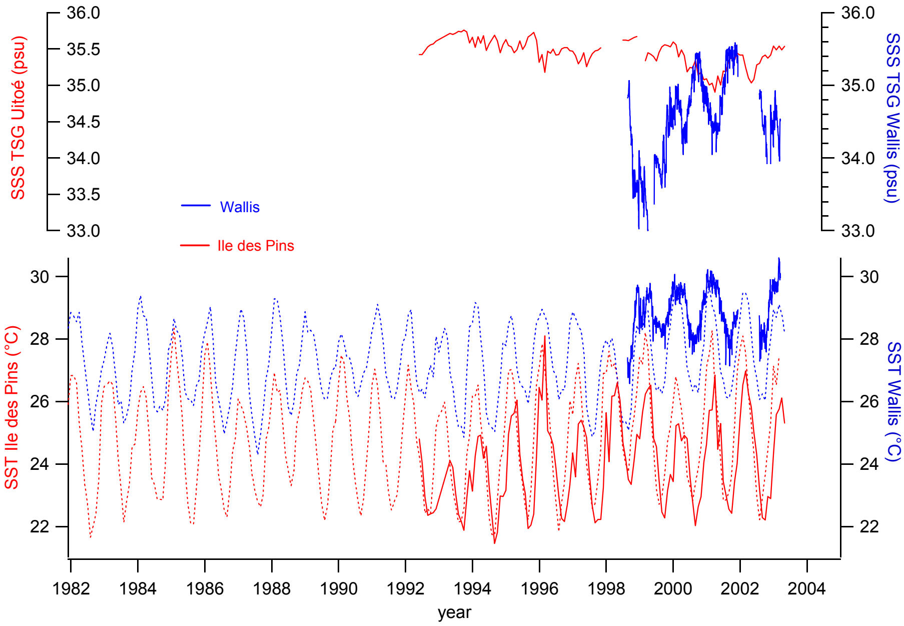

Fig. 2. Instrumental records available for the calibration period. From top (sea surface salinity) to bottom (sea surface temperature): in blue Wallis records, in red: Ile des Pins (New Caledonia). SSS from Institut de Recherche pour le Developpement (IRD) Thermosalinograph (TSG) datasets. SST : OI (Optimum Interpolation) SST (Reynolds and Smith, 1994; dashed lines) from 1982 to present, and TSG data (thick lines). TSG data are from Uitoé site, situated at about one hundred kilometres from Ile des Pins.

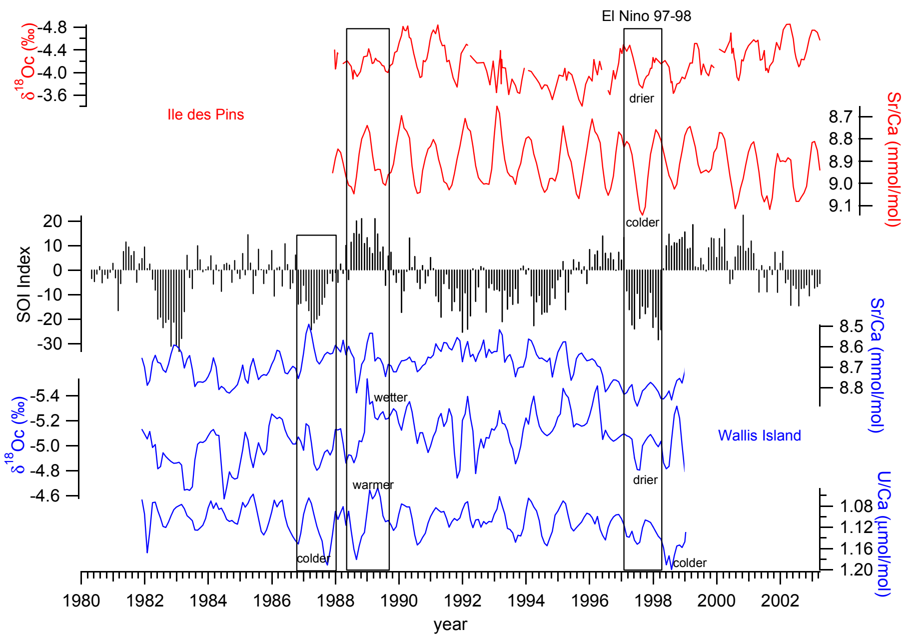

Fig. 3. Calibration of coral proxies at Ile des Pins (top, red) and Wallis Island (bottom, blue). The Southern Oscillation Index (SOI) is also shown. Negative values of the SOI represent El Niño.

This high resolution calibration study confirm previous works (Cole and Fairbanks, 1990; Evans et al., 1998; Cobb et al., 2003, among others). ENSO events can be recorded in corals, providing hope for the reconstruction of past ENSO.

4.2 The last century

On an interdecadal timescale, Mantua et al. (1997) showed the existence of a climatic signal they called the PDO (Pacific Decadal Oscillation). This signal was first described in the North Pacific, but probably has an imprint in the southern

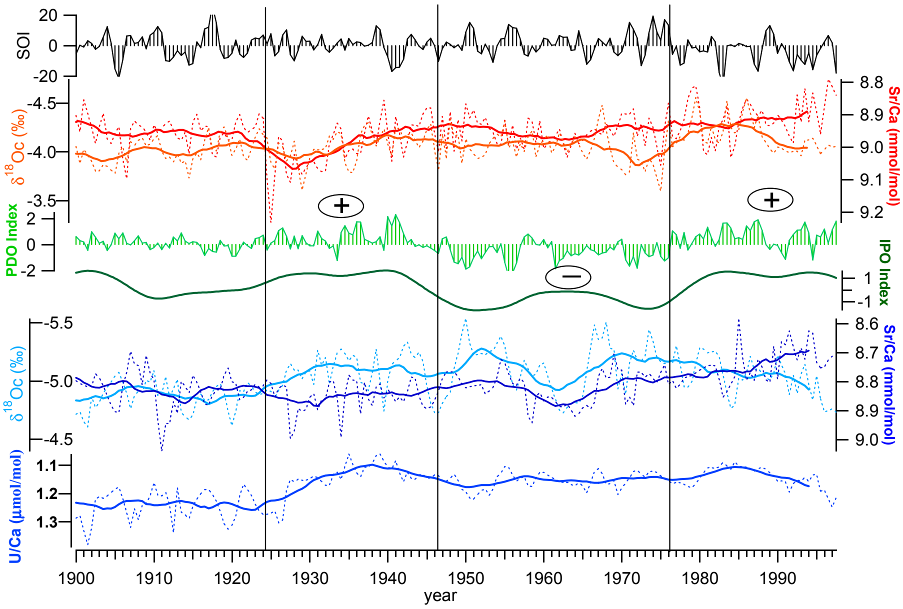

Fig. 4. Comparison of proxy data for IP and Wallis with indices of interdecadal climate variability: SOI (Southern Oscillation Index, black), PDO Index (Pacific Decadal Oscillation, green) (+ and − for positive and negative phases, respectively), IPO (Interdecadal Pacific Oscillation, courtesy of S. Power, dark green). Geochemical measurements: Ile des Pins Sr/Ca (red), δ^{18}Oc (orange). Wallis Sr/Ca (dark blue), δ^{18}Oc (light blue), U/Ca (medium blue). Dashed Lines represent geochemical data, thicker lines are 7 years running means of each series.

hemisphere under the name IPO (Interdecadal Pacific Oscillation, Power et al., 1999). Figure 4 presents coralline tracers (Sr/Ca, δ^{18}Oc at IP; Sr/Ca, δ^{18}Oc and U/Ca at Wallis), as well as the Southern Oscillation Index (SOI), the PDO index and the IPO index. To obtain a near six months resolution, we sampled our corals on a regular basis. However, corals are known to grow irregularly, growing faster in warm months than in cold ones. Thus, one sample could encompass between 3 to 9 months, leading to time scale heterogeneity. As a consequence, the ENSO signal, which has a 2 to 6 months impact, is smoothed and has not a clear signature in our low resolution samples (Fig. 4). However, low frequency climatic regimes of the last century are well recorded in our corals, especially in New Caledonia (Fig. 4). The PDO shift at about 1924–1925 started a positive phase. This shift seems to be recorded in geochemical records. As an example, in comparison with the 1900–1923 period, the 1924–1925 period shows a 0.12 mmol/mol shift in Sr/Ca (IP), reflecting a SST shift. Then, all geochemical signals show a global increase reflecting warmer and wetter conditions. The 1947–1976 period experienced a negative PDO phase. At IP, slight δ^{18}Oc increase, together with quasi constant Sr/Ca, denote precipitation anomalies, toward drier conditions. At Wallis, the signal is more complex. Sr/Ca and δ^{18}Oc show a PDO-like pattern first, then at the beginning of the 1960's, there is an abrupt change contrasting with the PDO pattern. Interestingly, the IPO Index is in antiphase with Sr/Ca and δ^{18}Oc Wallis, as well as, in a minor way, with IP Sr/Ca. After the 1976–1977 shift, PDO returned to a positive phase IP Sr/Ca, as well as Wallis Sr/Ca, followed the same pattern than in 1924. On the contrary, since the mid 1980's, δ^{18}Oc (IP and Wallis) and U/Ca Wallis have increased. This change in behaviour of tracers reveals a possible climatic perturbation, in comparison with the preceding 75 years. When taking into account Sr/Ca ratios, results suggest that this climatic perturbation is most probably linked to a change in hydrological balance, revealing a change in precipitation-evaporation ratios. Due to the position of the core, in the heart of the SPCZ, we believe it is mainly a decrease of rainfall amount.

5 Conclusion

Our results demonstrate that paleoENSO occurrences can potentially be identified with geochemical components of New Caledonia and Wallis corals. Nevertheless, only high resolution study allows the detection of ENSO impacts. In the last century, our pseudo-half yearly resolution smoothes ENSO signatures, but emphasizes interdecadal climatic modulations. The 1924–1947, 1947–1976 and 1976-to present periods are recorded at both sites. This preliminary study will be followed by the extension of both coral series over the last centuries. Another core in the same coral in New Caledonia is more than 500 years old, and will extend the understanding of decadal climate variability in this zone of the Pacific.

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References

Alory, G. and Delcroix, T.: "Climatic variability in the vicinity of Wallis, Futuna, and Samoa islands (13°–15° S, 180°–170° W), Oceanologica Acta, 22 (3), 249–263, 1999.

Bard, E., Hamelin, B., and Fairbanks, R. G.: U-Th ages obtained by mass spectrometry in corals from Barbados: sea level during the past 130 000 years, Nature, 346 (6283), 456–458, 1990.

Beck, J. W., Edwards, R., Ito, E., Taylor, F., Recy, J., Rougerie, F., Joannot, P., and Henin, C.: Sea surface temperature from coral skeletal Strontium/Calcium ratios, Science, 257, 644–647, 1992.

Cobb, K. M., Charles, C. D., Edwards, R. L., Cheng, H., and Kastner, M.: El Niño-Southern Oscillation and Tropical Pacific climate during the last millennium, Nature, 424, 271–276, 2003.

Cole, J. E. and Fairbanks, R. G.: The Southern Oscillation recorded in the oxygen isotopes of corals from Tarawa Atoll, Paleoceanography, 5, 669–683, 1990.

Corrège, T., Delcroix, T., Récy, J., Beck, W. J., Gabioch, G., and Le Cornec, F.: Evidence for stronger El Niño-Southern Oscillation (ENSO) events in a mid-Holocene massive coral, Paleoceanography, 15, 465–470, 2000.

Evans, M., Fairbanks, R. G., and Rubenstone, J. L.: A proxy index of ENSO teleconnections, Nature, 394, 732–733, 1998.

Folland, C. K., Renwick, J., Salinger, M. J., and Mullan, A. B.: Relative influences of the Interdecadal Pacific Oscillation and ENSO on the South Pacific Convergence Zone, Geophys. Res. Lett., 29 (13), 1643, doi:10.1029/2001GL014201, 2002.

Gagan, M. K., Ayliffe, L. K., Hopley, D., Cali, J. A., Mortimer, G. E., Chappell, J., McCulloch, M. T., and Head, M. J.: Temperature and surface-ocean water balance of the mid-Holocene tropical western Pacific, Science, 279, 1014–1018, 1998.

Gouriou, Y. and Delcroix, T.: Seasonal and ENSO variations of sea surface salinity and temperature in the South Pacific Convergence Zone during 1976–2000, J. Geophys. Res., 107 (C12), 8011, doi:10.1029/2001JC000830, 2002.

Le Cornec, F. and Corrège, T.: Determination of Uranium to Calcium ratios in corals by Inductively Coupled Plasma Mass Spectrometry, J. Analyt. Atomic Spectr., 12, 969–973, 1997.

Mantua, N. J., Hare, S. R., Zhang, Y., Wallace, J. M., and Francis, R. C.: A Pacific interdecadal climate oscillation with impacts on salmon production, Bulletin of American Meteorological Society, 78 (6), 1069–1079, 1997.

Mc Phaden, M. J.: Genesis and evolution of the 1997–1998 El Niño, Science, 283, 950–954, 1999.

McCulloch, M. T., Gagan, M. K., Mortimer, G. E., Chivas, A. R., and Isdale, P. J.: A high-resolution Sr/Ca and δ^{18}O coral record from the Great Barrier Reef, Australia, and the 1982–1983 El Niño, Geochimica et Cosmochimica Acta, 58, 2747–2754, 1994.

Min, R. G., Edwards, L. R., Taylor, F. W., Recy, J., Gallup, C. D., and Beck, W. J.: Annual cycles of U/Ca in coral skeletons and U/Ca thermometry, Geochimica et Cosmochimica Acta, 59 (10), 2025–2042, 1995.

Nicet, J. B. and Delcroix, T.: ENSO-related Precipitation changes in New Caledonia, southwestern tropical Pacific 1969–98, Mon. Wea. Rev., 128, 3001–3006, 2000.

Ourbak, T., Corrège, T., Malaizé, B., Le Cornec, F., Charlier, K., and Peypouquet, J.: A High Resolution investigation of temperature, salinity and upwelling activity proxies in corals, Geochemistry, Geophysics, Geosystems, in press, 2005.

Power, S., Casey, T., Folland, C., Colman, A., and Mehta, V.: Interdecadal modulation of the impact of ENSO on Australia, Clim. Dyn., 15 (5), 319–324, 1999.

Quinn, T. M., Crowley, T. J., Taylor, F. W., Joannot, P., and Join, Y.: A multicentury stable isotope record from a New Caledonia coral: Interannual and decadal sea surface temperature variability in the southwest Pacific since 1657 A.D., Paleoceanography, 13 (4), 412–426, 1998.

Quinn, T. M., Taylor, F. W., Crowley, T. J., and Link, S. M.: Evaluation of sampling resolution in coral stable isotope records: a case study using records from New Caledonia and Tarawa, Paleoceanography, 11 (5), 529–542, 1996.

Reynolds, R. W. and Smith, T. M.: Improved global sea surface temperature analyses using optimum interpolation, J. Clim., 7, 929–948, 1994.

Salinger, M. J.: Southwest Pacific temperatures: trends in maximum and minimum temperatures, Atmos. Res., 37 (1–3), 87–99, 1995.

Watanabe, T., Gagan, M. K., Corrège, T., Scott-Gagan, H., Cowley, J., and Hantoro, W. S.: Oxygen isotope systematics in Diploastrea heliopora: new coral archive of tropical paleoclimate, Geochimica et Cosmochimica Acta, 67 (7), 1349–1358, 2003.