

Chapter 2

Luminescence Dating Protocols and Dating Range

Luminescence dating comprises estimation of paleodose, or rather the equivalent dose (D_e), and annual dose rate (D_T). These are discussed below.

The estimation of D_e can be done using multiple aliquot (MA), single aliquot (SA) or single grain (SG) techniques and in each case additive dose or regenerative dose procedures are used. In the additive dose procedures, several laboratory doses of varying magnitude are given additionally on top of the natural dose of a sample, on several identical subsamples of a natural sample (so called aliquots). The luminescence signal from the natural dose, as well as the natural plus added doses is plotted against the added doses (zero added dose for the natural) and the relation is fitted with a linear or exponential curve, which describes the growth of the luminescence signal with increasing dose (growth curve). The additive growth curve is extrapolated to the dose axis to provide an estimate of the equivalent dose. In the regeneration method, the natural signal is bleached first and then doses are added to construct a luminescence vs. dose growth curve. The natural signal is then interpolated on to this regenerated growth curve to estimate the equivalent dose.

The techniques are further discussed below.

2.1 Multiple Aliquots Additive Dose

In this method the additive technique is applied to multiple aliquots. This means that each dose point of an additive growth curve is represented by the (mean) luminescence from several aliquots. For reliable results, it is important to ensure that all aliquots are identical and that the extrapolation is both realistic in terms of the underlying physical mechanisms and accurate. Jain et al. (2003) review all the normalization procedures to normalize aliquots and evaluate their efficacy to produce identical subsamples. Felix and Singhvi (1997) review the extrapolation procedures and optimization of the measurement protocols in terms of errors. The advantage of multiple aliquot additive dose (MAAD) is that it averages the luminescence signal over several thousand grains and hence provides a mean age

for an ensemble of grains. MAAD is suitable for samples for which heterogeneity in zeroing may be excluded (e.g. heating or daylight bleaching at grain level) (Fig. 2.1a, b). For heterogeneously zeroed samples, however, non judicious use of MAAD methods can lead to erroneous results.

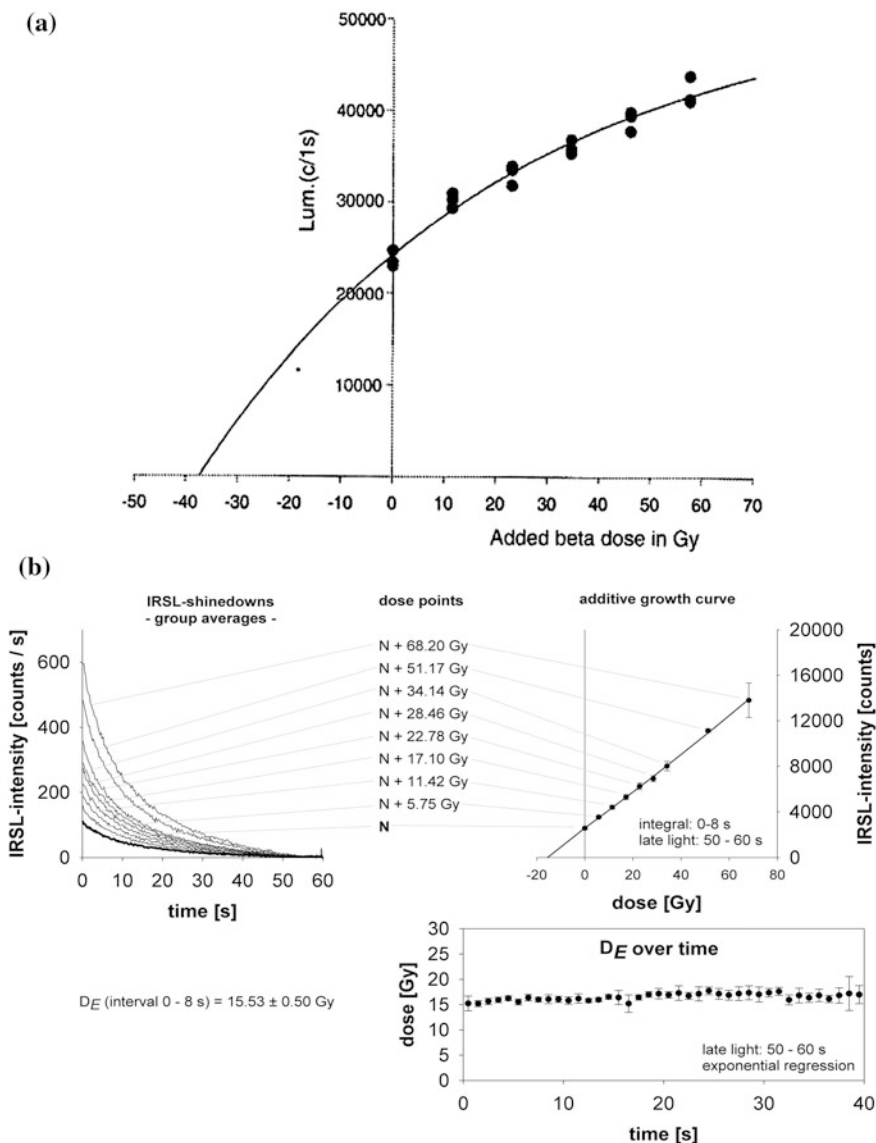


Fig. 2.1 Illustration of MAAD-protocol for (a) growth curve of ceramic quartz (3 aliquots per dose) fitted with a single exponential function (Liritzis et al. 2002), (b) IRSL fine-grains with shine-down curves (*upper left*), additive growth-curve (*upper right*) and DE-plateau test (*lower right*) (Kadereit et al. 2007)

2.2 Single Aliquot and Single Grain Techniques

In introducing OSL dating, Huntley et al. (1985) suggested that it should be possible to make sufficient measurements on a single aliquot to allow a D_e determination. Duller (1991) developed a single aliquot method for D_e -determination by administering additive doses to potassium feldspar extracts. This single aliquot additive dose (SAAD) technique requires correction for sensitivity change during read outs, (Liritzis et al. 1997, 2001, 2002). In SAAD a single aliquot (disc) is measured with consecutively administering beta doses and reading the OSL by short shining from diodes at certain wavelength. The signal growth is fitted by appropriate functions. A single aliquot regeneration (SAR) method developed for quartz is now widely used for the dating of sediments (Murray and Wintle 2000). The SAR protocol—given dose D_i , preheat, OSL reading (L_i), test dose D_t , preheat, measured OSL (T_i), repeated steps—takes into account possible sensitivity changes during the construction of the regeneration growth curve. Sensitivity may change from repeated irradiation, preheating and OSL stimulation of an aliquot. The development of automated luminescence readers with capabilities of carrying out complete measurement sequences including stimulation and read out of the luminescence signal as well as irradiation and preheat of aliquots without the need to physically move the samples, has made it possible to undertake all the measurements necessary for D_e determination in a sequential way. Given that a large number of independent measurements can be made on many single aliquots in principle it is possible to improve the precision of the paleodose measurement to any desired level, by simply increasing the number of measurements (Fig. 2.2a, b).

When using the SAR protocol, several tests and checks are required to ensure reliable D_e values (Wintle and Murray 2006; Singhvi et al. 2010, 2011). These checks include: (a) making sure the sensitivity correction is consistent for identical doses (recycling test), (b) testing for any build up of dose from preheating (recuperation test), (c) testing quartz separates for feldspar contamination, (d) optimizing the preheat (by plateau tests), (e) dose recovery of a known dose, (f) plotting D_e against the stimulating time to test for partial bleaching, and (g) crystal sensitivity change. If the sample fails any of the test/checks, the data are discarded. A logical extension of single aliquot methods is the use of single grains. This permits age determination on individual grains and hence provides the best resolution for understanding the bleaching history of the samples. On the flip side is the fact that radiation dose at single-grain scale can be heterogeneous, requiring precautionary measures (Mayya et al. 2006; Chauhan et al. 2011). In the SAR protocol for quartz grains, it is an underlying assumption that the measured OSL signal is dominated by a signal that is most easily bleached, called the fast component. Isolation of the fast component can be done either mathematically by curve fitting (Murari 2007) or experimentally by using linearly modulated OSL (LM-OSL) where the stimulation power is increased linearly and the OSL is measured (Singarayer and Bailey 2004). The LM-OSL components can also be separated by curve fitting (Kitis et al. 2002; Li and Li 2006a). We refer to

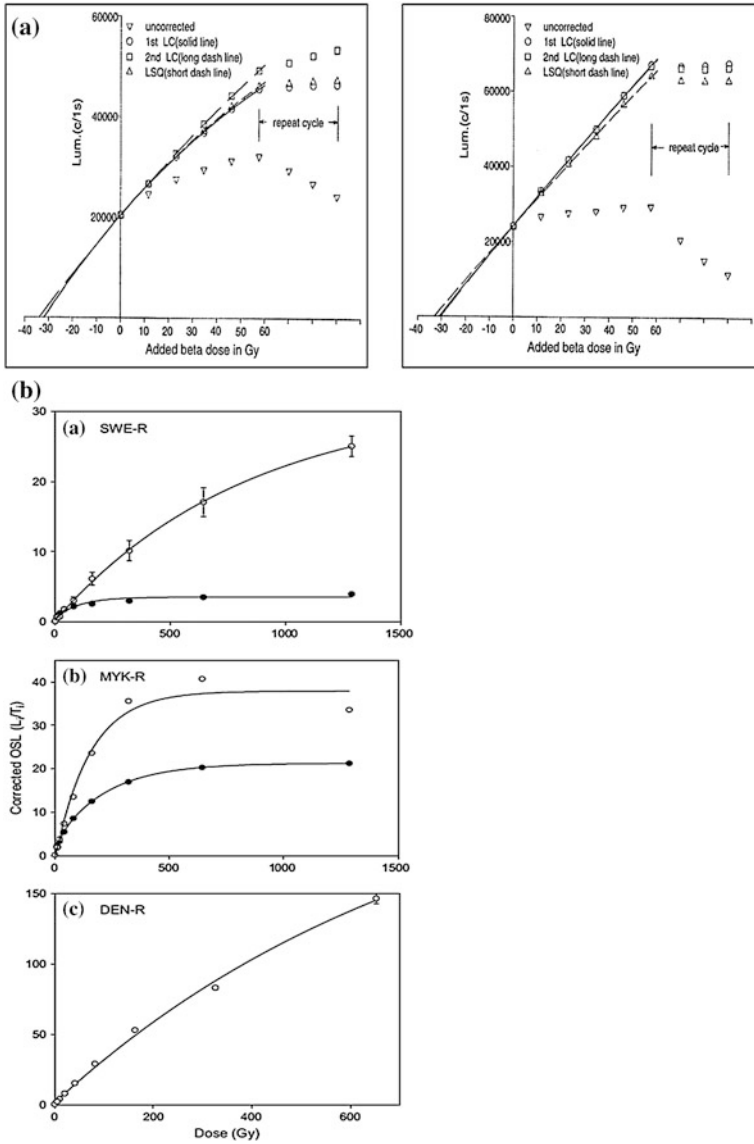


Fig. 2.2 Plots illustrate **a** the single aliquot additive dose (SAAD) on ceramic following Duller (1991) shining and preheating crystal sensitivity correction labelled “1st LC”, the Duller (1994) correction labelled “2nd LC”, and the iterative least squares method of Galloway (1996) and Liritzis et al. (1997) labelled “LSQ”. The points from each correction procedure are fitted by a saturating exponential curve, which is extrapolated to the equivalent dose value. Preheating was for *a* 1 min at 220 °C and for *b* 5 min at 220 °C (Liritzis et al. 2002), **b** single aliquot regenerated (SAR) technique, curves for single slices of rock samples *a* Swedish ultramafic, *b* Mykonos granite and *c* Danish quartz metamorphic. The *filled circles* represent the sensitivity corrected blue OSL response and the *open circles* the IR response. The growth curves have been fitted with an expression of the form $y = \alpha (1 - e^{-bx})$, Li/Ti is defined the ratio of IR readings during OSL SAR protocol, where Li and Ti are natural and regenerated points as a function of laboratory dose Di (Vafiadou et al. 2007)

interesting papers by Choi et al. (2003) and Li and Li (2006b) for other methodological possibilities using LM-OSL, such as the detection of an ultrafast component and influence of medium bleaching components. It is important to notice that isolation of components is desirable as different components may have different dose response curves.

An important aspect is the calibration of beta dose rate in the laboratory. The net dose absorbed depends on the type of radiation and stopping power of the irradiated material and the backscattering from the mounting disc on which the grains are kept. Thus, the dose rate delivered by the same source to fine grain quartz mounted on aluminium disc is different from fine grain feldspar on steel discs. Similarly the dose rate to quartz and feldspar grains of identical size are different by $\sim 7\%$ on account of differences in the stopping power. Also different sizes of quartz grains also absorb different amounts of doses. Thus, for example, the dose to fine grained (4–11 μm) quartz mounted on aluminium disc could be lower by $\sim 25\text{--}30\%$ compared to 100 μm quartz grains mounted on stainless steel (SS) discs. Therefore, beta dose calibration needs to be established for each mineral type and grain size and measurement condition (e.g. material of the disc on which the grains are mounted). The Risø National Laboratory/DTU in Denmark now provides standard quartz for calibration purposes with nominal charges (Kadereit and Kreutzer 2013).

Table 2.1 gives the protocols used for D_e determination. The single aliquot regeneration (SAR) protocol (2000) is now the most widely applied technique worldwide and the recent revision of this protocol (Singhvi et al. 2011) provides a robust way to estimate ages. A variety of further modifications exist, e.g. pulsed optical stimulation which allows the quasi-simultaneous detection of several OSL/IRSL-emissions; thermally transferred OSL for very old and pre-dose OSL for very young samples, respectively (for further details see text). As ‘old fashioned’ multiple aliquot protocols often deliver reliable results they are still widely applied when material availability is not a problem and however small aliquots to check heterogeneous bleaching cannot be prepared routinely (e.g. from fine-grained loess). Also, TL-dating might be more appropriate for heated objects than OSL (e.g. flint) though a concordance between TL and OSL results has been established over and over again. Furthermore, novel TL-techniques have been developed even for sediments with the aim to extend the upper dating limit for older samples for which an unbleachable luminescence residuum does not lead to significant age-overestimation (Vandenbergh et al. 2009).

2.3 New Developments

Luminescence dating based on measurement of the fast component of the OSL quartz signal plays a major role for dating late Quaternary sediments though limited to ca 100–200 ka because of saturation. A thermally-transferred OSL (TT-OSL) signal is observed when quartz is heated to $\sim 200\text{--}300^\circ\text{C}$ after an

Table 2.1 Schematic overview of the basic stimulation, detection and protocol types of luminescence dating

Aliquot type	Protocol	Stimulation/detection			
		TL/UV to red ¹⁶	OSL-blue/UV	OSL-green/ blue to UV	IRSL/UV ⁹ , blue, yellow
Multiple aliquots	Additive dose	Ceramic (q, f, pfg) R-B ¹ : sediments (q, f, pfg) Calc. stone surface (c) [520 nm] ¹⁵		Sediments (q, f) ⁴	Ceramics (f) Sediments (f)
		Ceramic (pfg) ²⁰ Heated flint (q) Sediments (q) Burned stone (q, f) ^{2a} Ceramic and brick (q) ^{2a}			
	Regeneration (slide) ²¹				
	SARA ²			Ceramics (q) ^{2a} , 2b Brick (q) ^{2a} Burned stone (q) ^{2b} Sediment (f) ^{2b}	
Single-aliquot	SA additive ³ SAR ¹¹	Heated flint (q) [620 nm] ¹⁰ Slag (q) [620 nm] ⁹	Ceramics (q) Sediments (q) Calc. stone surface (q) ¹⁴		Sediment (f)
	IRSL (and post-IR/ IRSL)-SAR				Sediments > 20 ka (f)

(continued)

Table 2.1 (continued)

Aliquot type	Protocol	Stimulation/detection		
		TL/UV to red ¹⁶	OSL-blue/UV	IRSL/UV ⁷ , blue, yellow
Single-grain	SG-SAR (includes OSL, post IR-OSL, and IRSL)		OSL-green/blue to UV	IR-RF/IR [865 nm] ¹⁹
ROI ⁸	HR-OSL SAR		Sediments (q) ¹² Mortar (q) ¹³ Granitic and limestone (with quartz) stone surface (f) ⁵	Sediment (f) Granitic and limestone (with quartz) stone surface (f) ⁵

Generally, the development was from TL (1950s) to OSL (1985) and to IRSL (1988) and to RF (1999); from the dating of ceramics to sun bleached sediments (1978); from multiple-aliquot to single-aliquot (1990s) and to single-grain dating (1999) and to the dating of small parts (ROIs) of intact stone surfaces (2002). These include limestone and sandstone rocks from masonry that include quartz
f = feldspar
q = quartz
pfg = polymineral fine-grain
1 A special technique to subtract the unbleachable background of a TL-signal (Wintle and Huntley 1980; Berger et al. 1987), necessary for sediment dating
2 A regenerative protocol with few additively dosed aliquots introduced by Mejdahl and Botter-Jensen (1994^{2a}, 1997^{2b}), but hardly or not in use any longer
3 Developed by Duller (1991^{3a}, 1994^{3b}) for coarse-grain potassium feldspars from sediments, using additional monitor aliquots to record changes of an aliquot during a dating procedure; on loose grains extracted from masonries (see Liritzis et al. 2010b)
4 Huntley et al. (1985) using an argon laser on aeolian quartz
5 Greilich et al. (2002, 2005) analyzing feldspar from granitic stone surfaces from Peruvian geoglyphes and a castle in S-Germany (slice technique for sample preparation)
6 Banerjee et al. (2001)
7 The UV-emission is often regarded as especially unstable, showing unwanted a thermal signal loss (fading) (Lang 1996)
8 Range of interest: an area within a stone surface with a bright luminescence signal and good dating properties, usually corresponding to a 'single grain', yet still preserved in its original position of the mineral assemblage and dose field
9 Haustein and Krbetschek (2002)
10 Richter and Krbetschek (2006)
11 Murray and Wintle (2000) introducing the basic version of the SAR protocol most luminescence laboratories in the world refer to nowadays
12 Olley et al. (1999)
13 Jain et al. (2004)
14 Liritzis et al. (2010) dating quartz from surfaces of calcareous schist blocs (powder technique for sample preparation)
15 Liritzis (1994), Liritzis et al. (1997) dating calcite from the surface of marble blocs by the use of a partially bleached TL MAAD technique (powder technique)
16 Detected range of emission given in square brackets
17 For heterogeneously bleached samples, so called 'small aliquots' (Olley et al. 1998) are used for coarse grains, with only few hundreds to few tens of grains, instead of thousands of grains per aliquot
18 Trautmann et al. (1999a, b) introducing the new technique under the name radioluminescence (RL)
19 Emission from luminescence traps of feldspar due to radiative electron capture, not from luminescence centres
20 Feathers (2009)
21 Prescott et al. (1993)

optical bleach. As the comparatively small OSL signal saturates at far higher radiation doses it offers the potential to date sediments back to, and even more, than, 1 million years (1 Ma). The optical and thermal behaviour of the TT-OSL signal has been characterised by Wang et al. (2006a, b) who showed that it consists of two signals: a recuperated OSL (ReOSL) signal and a basic-transferred OSL (BT-OSL) signal. A SAR protocol had been developed (Wang et al. 2007) with loess deposits dated successfully back to the Brunhes-Matuyama time-marker horizon at 780 ka (see, also, Porat et al. 2009). Though under continuous testing, the method has up to now provided sensible luminescence ages from several case studies and a good basis for understanding the applicability and limitations of the method is now available. Athanassas and Zacharias (2010) carried out a preliminary study on raised beaches in southern Greece; their bleaching experiments showed that exposure to daylight in Athens for half an hour reduced their TT-OSL signal to less than 15 % of its initial signal but the low TT-OSL signal obtained was a major impediment and currently restricts application to samples with very bright luminescence emission. Jacobs et al. (2011) produced ages for raised marine sediments from Quaternary landforms along the Cape coast of South Africa that are consistent with an interglacial high sea level (MIS 11) around 400 ka. One major research outcome from that study is that both TT-OSL signals are much less sensitive to light than previously thought, thus only well-bleached samples should be considered for TT-OSL dating, which restricts the range of possible applications of this method. Furthermore, the reliability of TT-OSL and the age range over which it can be applied still needs more work via the analysis of samples with good independent age control.

The SAR protocol has been used for both quartz and feldspar minerals. But often quartz samples possess low sensitivity and low saturation dose that limits the dating range to about 200 ka. On the other hand, feldspar despite their ten fold higher luminescence sensitivity and higher saturation dose, may suffer from athermal loss of luminescence signal (called anomalous fading) and hence may provide underestimated ages. This undesirable feature may be minimized by selecting more stable luminescence emissions and appropriate storage and preheat procedures, as e.g. shown for loess samples from southern Germany by Lang et al. (2003). Several other methods have now been developed to enable correction/circumvention of the fading component in feldspar luminescence (Huntley and Lamothe 2001). Three recent developments merit a mention.

The first is the use of the IRSL signal from K-feldspars using an isochron for different grain sizes as proposed by Li et al. (2007, 2008a, b). This requires the sample to contain a wide range of grain sizes typically in the range from 90 to 250 μm from which K feldspar is extracted using density separation with heavy liquids. Under the assumption that the grains were well-bleached, such grains receive variable amounts of internal doses based on their sizes (Li et al. 2008a) bearing in mind that this is independent of whether they were sufficiently bleached or not. The D_e values increase with grain size, due to an increased component of internal dose. A plot of D_e values as a function of the internal dose rate (contributed from the potassium and rubidium content of the K-feldspar grains) enables

creation of an isochron plot. An effective external dose contribution is then calculated for each grain size after consideration of the attenuation of the radiation by the grain size. The *isochron IRSL* (*iIRSL*) age is then obtained as the difference between the slopes of plots of D_e and external dose attenuation against the internal dose rate, calculated for the grain sizes. The *iIRSL* method may overcome age underestimation due to anomalous fading. Also, since the isochron method (*iIRSL*) is reliant on only the internal dose rate, it overcomes problems related to: (1) changes in past dose rate due to post-depositional migration of radionuclides, (2) changes in water content as waterlain sediments dry out, (3) spatial heterogeneity in the gamma dose rate, (4) uncertainties in the cosmic ray dose rate during the period of sample burial.

A second more recent effort uses IRSL measurements at elevated temperatures, e.g. 290 °C, after the IR signal is read out at 50 °C (Ankjaergaard et al. 2010; Buylaert et al. 2009; Jain et al. 2011). The post-IR luminescence signal measured at elevated temperature has a smaller fading rate than the signal measured at 50 °C. Recently, it was proposed that a non fading signal can be achieved by using several elevated temperatures and looking for a plateau of D_e values in terms of stimulation temperature (Li and Li 2011). The plateau region is considered stable. Though physically sound, the efficacy of this proposal needs testing and several studies are in progress and some have shown good results (Biswas et al. 2013).

In a third approach, presence of a signal with a stability of only 50 ka is considered and based on this it is surmised that the signal is lost due to loss of charge luminescent centres. A sensitivity based correction for a sample as received (with decayed centres) and the sensitivity of the same sample rejuvenated via a large dose (to mimic geological dose) and day light exposure is compared. The ratio provides a correction factor for the paleodose. The use of such sensitivity ratio has yielded sensible results (Biswas et al. pers. comm.).

Another novel technique, though sparingly used by researchers, is the *infrared radiofluorescence* (*IR-RF*) [(Trautmann et al. 1999a, b, 2000; Schilles and Habermann 2000); earlier terminology: radioluminescence (RL)]. Although related to other trapped-charge techniques, it does not use the signal resulting from recombination of charge after trap eviction. Rather it monitors an IR-signal around 865 nm that is emitted by electron capture at luminescence traps during ionizing laboratory irradiation. This way, radiofluorescence is not influenced by the possible problems related to lifetimes (fading), electron competition and other features concerning luminescence recombination centres, but refers only to the luminescence traps. For dating applications, a single-aliquot regenerative procedure (IR-SAR) is used (Krbetschek and Erfurt 2003a). As for the classical SAR-protocol, first the natural signal is measured, with RF intensity denoting the ‘filling level’ of the luminescence traps; thereafter the RF-signal accompanying the filling of the traps up to saturation is monitored during laboratory irradiation. Finally, the sample is bleached and an RF-curve of a regenerating sample is recorded. Correction of the additive and the regenerative curve is at times necessary due to possible sensitivity changes. So far, studies of IR-RF have concentrated on feldspar from sediments (e.g. Erfurt and Krbetschek 2003b; Krbetschek et al. 2008).

The RF-signal bleaches faster than a TL-signal but less rapidly than an OSL-signal. The dating range is from ca. 20 ka to several hundred ka, depending on the natural dose rate. Apart from the fact that SA-protocols on coarse-grains allow thorough scrutinizing of insufficient bleaching, an unbleachable residual RF signal is less problematic for older samples. The method therefore enables a significant extension of the upper age limit in luminescence dating. In one example, IR-RF dating was applied to coarse-grain potassium feldspar extracts from sediment archives containing Palaeolithic Neanderthal hunting sites on lake-shore environments at Neumark-Nord 2 in E-Germany. These were dated to an interstadial at around 90 ka (layer Neumark-Nord 2.0) and to the last interglacial at around 120–130 ka (layer Neumark-Nord 2.2), respectively (Strahl et al. 2010).

Recently, IR-RF-dating of potassium feldspar grains from sediment layers at the type-site of *Homo heidelbergensis* at Mauer in southern Germany (where a lower jaw with teeth of the oldest central European considered as the ancestor of Neanderthals in Europe was found) helped to constrain the age of the hominin to the marine isotope stage (MIS) 15 (Wagner et al. 2010). Mean IR-RF ages from small aliquots from two samples of fluvial sand from immediately below and above the gravelly find layer were 607 ± 55 and 603 ± 56 ka, respectively. Successful numeric dating of Pleistocene hominins is important in view of the numerous theories about their migration history out of Africa and from southern Europe northward, and the possible replacement of earlier population groups by later ones.

2.4 Instrumentation

Conceptually, the measurement of TL and OSL is simple. It needs: (1) a stimulation source that provides heat or light to the sample at a known intensity and rate and does so with high reproducibility (to better than 0.1 %); (2) a light detection source, normally a photomultiplier (PM) tube with appropriate filters to discriminate against the stimulation light (in the case of OSL and IRSL) and black body radiation (in case of TL) and to optimize the colour of the signal and thus extract a specific luminescence emission for dating. These parameters have been standardized by the two automated systems now available, from Risø National Laboratory, Denmark and Daybreak Nuclear and Medical Systems, USA. The most recent development, is Freiberg Instruments, Germany, however its instruments are not yet to be used routinely. These systems are also equipped with a beta irradiation source for onplate irradiation and thereby enable measurements of several aliquots in a programmed manner. These systems have custom made software for a speedy reduction of data for data analysis and age calculation.

Most commonly, the excitation light intensity is kept constant i.e. to within a fraction of percent or less, and the stimulated luminescence is measured under various constant stimulation termed as continuous wave (CW OSL). Under this mode, read out can be only at wavelengths other than the stimulating wavelength,

i.e. usually at shorter wavelength to avoid unwanted noise. It produces a decay curve (cf. Fig. 2.1b, upper left), which is usually a composite of several decay curves, each attributable to different traps.

Mathematical deconvolution enables isolation of these curves so that the best suited component can be used (Murari 2007). Typically quartz OSL decay is described by 3 and sometimes up to 7 components. Feldspar IRSL decay may also comprise one or several components but this is still a matter of discussion. For CW OSL rigorous optical filtering is needed to ensure that stimulation light does not enter the detection system, given that the stimulation intensity is typically 10^{16} times stronger compared to the stimulated luminescence from the sample. Some typical filter combinations are given in Table 2.2. The use of filters in the detection channel also results in loss of light due to reflection at each of the filter surfaces and the larger distance between the sample and the photomultiplier. Separating stimulation and emission light is not necessary with pulsed OSL (POSL) for which short pulses of sub millisecond duration are given and the light is measured in between the pulses. The photomultiplier is gated and hence during the stimulation it remains inactive and is not damaged by stimulation light. This approach is very useful for samples with low photon yield. An advantage of pulsed technique is that a short illumination can be used for OSL read out without depleting the signal much ($<1\%$). A further advantage is the ability to measure luminescence lifetimes, the time between excitation and emission. It has been found that quartz lifetimes are much longer than feldspar lifetimes, so that selection of a proper pulse width can isolate quartz from feldspar (Ankjaergaard et al. 2010). Longer lifetime components in feldspars also appear to suffer less from anomalous fading (Jain and Ankjaergaard 2011). A third measurement mode is linear modulation OSL (LM OSL) for which the intensity of light is increased in a linear manner. This permits a better segregation of the

Table 2.2 Typical conditions used for measurements by Boetter-Jensen (2000), Yukihiro and McKeever (2011)

Stimulations	Filters	Transmission window
TL-heating	UV Schott BG9 + Hoya 340/BG 39 + Schott UG 11	270–380
TL-heating	Blue Schott BG39 + Corning 7–58 or 7–59	340–480 nm
TL-heating	Red Komar IU	
OSL-Blue Light 470 nm LED	UV Schott BG39 + Hoya 340 nm	280–340 nm
OSL-Green Light 532 nm laser of Green diode		
IRSL LED 880 nm 940 nm	Blue Schott BG39 + Corning 7–59	340–480 nm
	Red Komar IU (will fill these later)	650–750 nm

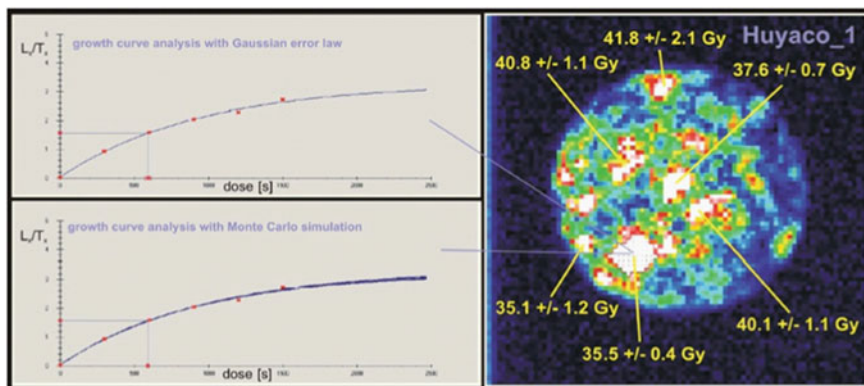


Fig. 2.3 Illustration of SAR-protocol for HR-OSL-dating on feldspar minerals within a granitic surface of a cobble. De determination for one aliquot (82×82 areas, each area $100 \mu\text{m}$ side length) of the sampled boulder. Luminescence intensities are presented in *false colours*. Low intensities are represented by *dark colours* (black and dark blue denoting background noise), and the brightest luminescence signal have a *white filling* (Kadereit et al. 2009)

components, allowing, in particular, the isolation of faster components for dating applications.

In TL the heating is generally done using resistive heating and is achieved by passing a large current through a kanthal or nichrome heater strip with feedback control to ensure faithful reproduction of the linear heating rate. Normally the heating is done with flowing inert gas, nitrogen or argon, to eliminate spurious luminescence due to reactions with oxygen or water vapour, and also to serve as an efficient mechanism for heat conduction from the heater plate to the sample, ensuring that the sample faithfully follows the temperature of the heater plate for the entire duration (Table 2.2).

Another innovation has been the use of CCD chips and variants for imaging the sample surface and providing spatially resolved luminescence. These detectors provide high detection efficiency close to that of a PM tube. The basic philosophy is to stimulate a rock slice ($\sim 2 \text{ mm}$ or less thick, $\sim 10 \text{ mm}$ in diameter) and measure luminescence of rocks as received as well as after laboratory irradiations and to then use from the images selected pixels for the analysis. Key issues in these applications are optical depth and material density of the sample. Optical depth determines the depth in the sample from which the luminescence reaches the detection system and the density determines the depth to which electrons penetrate the sample. The new spatially resolved dating technique (high resolution OSL resp. HR-OSL) was successfully applied to the dating of stone surfaces from a stone wall of the medieval castle of Lindenfels (Odenwald, 12th century AD), Germany, and from the pre-Columbian Nasca lines (geoglyphs) around Palpa, in southern Peru (200 BC–600 AD) (Greilich et al. 2002, 2005, 2007; Greilich and Wagner 2009) as well as, a stone from a fluvial deposit from that area (Fig. 2.3).

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Kadereit, A.; Zacharias, N.; Li, S.-H.

2013, VII, 70 p. 10 illus., 5 illus. in color., Softcover

ISBN: 978-3-319-00169-2